A modelling study of the economic and environmental impacts of integrating forage and cash crops into a Canterbury dairy farm (LUDF)

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Simon David James

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The New Zealand dairy industry has experienced rapid intensification during recent decades in response to increasing land values. Incorporating forage crops on the milking platform is a potential strategy to increase dry matter production and milk production for greater profitability. However, in previous studies, intensification has increased the cost of milk production. This has diminished the low-cost competitive advantage that New Zealand dairy producers have had in international markets. Feeding low crude protein forage crops has also been shown to reduce the nitrogen (N) concentration in cow urine, which may help reduce N leaching.

This study used farm system modelling to determine the profitability and N leaching on the 160.1 ha (effective) Lincoln University Dairy Farm (LUDF) when fodder beet, wheat for feed and sales, and a double crop rotation of maize and oats silage was grown. The cash operating profit was calculated using FARMAX® Professional Dairy, assuming $6.00/kg MS. The projected N leaching was calculated using Overseer ™ (version 6.2.0), which is now compulsory for all farms in Canterbury under the Environment Canterbury Land and Water Regional Plan. The only crop scenario that increased profitability was fodder beet. Incorporating 10 ha each of spring and autumn grazed fodder beet increased operating profit by 20.0% to $4,782/ha compared to the existing 100% pastoral system ($3,984/ha). The other cropping scenarios had significant decreases in profitability. Incorporating 20 ha of maize and oats silage reduced operating profit by 10.6%, despite increased overall dry matter production. This was due to poor feed conversion efficiency (FCE) and increased feed crop expenses. Operating profit reduced by 3.2% and 13.1% when wheat was grown for feed and sales respectively. The wheat (fed) scenario had similar milk production to the existing scenario, however greater crop expenditure. The wheat (sold) scenario had significantly reduced overall revenue which impacted on profitability. A second simulation with fodder beet was done so than daily intakes were increased to the recommended maximum 6.0 kg DM/cow/day. Harvested fodder beet was included in the rotation and fed at 4.0 kg DM/cow/day during mid-lactation when there was no grazed fodder beet available. The total fodder beet area was increased to 33.9 ha, which increased the operating profit by 34.8% to $5,368/ha.

The projected nitrate leaching for the all proposed scenarios increased due to significant nutrient loss from the cropping blocks. The overall N leaching increased from 34 kg N/ha for the existing system to 41 kg N/ha for both the fodder beet (20 ha) and maize/oats silage scenarios. Leaching was 39 and 37 kg N/ha for the wheat (fed) and wheat (sold) scenarios respectively. Leaching increased to 44 kg N/ha when the fodder beet area was increased to 33.9 ha.

It was concluded that fodder beet was the only suitable crop to increase profitability, however the projected increase in N leaching will likely prevent the strategy from being implemented.

Keywords: Dairy farming, Canterbury, profitability, nitrogen leaching, forage crops, fodder beet, maize silage, cereal silage, wheat, FARMAX®, Overseer ™

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Chapter 1:
Introduction

1.1 Overview

New Zealand dairy farms have traditionally used a low cost, low input pasture-based system. The low cost of production has been the industry's competitive advantage against other dairy exporting countries that operate more intensive systems (Shadbolt, 2012). However, in recent years, farmers have intensified their systems to increase milk production and profitability. An increasingly popular strategy is to increase dry matter (DM) production through integrating high yielding forage crops on the milking platform.

Maize silage is commonly used as supplementary feed on North Island dairy farms to fill the feed deficit during early and late lactation (Densley, Miller & Kolver, 2001; Minneé, Fletcher, De Ruiter & Clark, 2009; Densley, Austin, Williams, Tsimba & Edmeades, 2006). It is a summer crop and is commonly followed by a winter crop, such as whole-crop oats silage, producing two crops in one year. Fodder beet is a high yielding forage crop that is mainly used for winter grazing of non-lactating dairy cows and finishing beef cows (Gibbs, 2014; Chakwizira et al., 2013). The superior yields and metabolisable energy (ME) content compared to pasture and other forage crops make it a promising crop for cows during lactation. Canterbury is the main arable region of New Zealand; achieving high grain yields due to its ideal climate. Grain is commonly used throughout the season on New Zealand dairy farms, predominantly through in-shed feeding. It is a high energy feed, however DM yields are significantly lower compared with most forage crops.

Future growth of the New Zealand dairy industry will be constrained due to restrictions on N leaching. The main source of leaching on dairy farms is urine deposition, as a result of excess crude protein (CP) content in pasture relative to cow demand. CP is made up of 16% N and the surplus CP consumed is mainly excreted as urinary N, resulting in significant leaching losses in grazing systems (Bryant, Dalley, Gibbs & Edwards, 2014). The low CP content of maize/oats silage, fodder beet and wheat may be an effective strategy to rebalance the ME and CP ratio of the diet and reduce N leaching (Edwards et al., 2014; Williams, Ledgard, Edmeades & Densley, 2007; Gibbs, 2014). However, there has shown to be significant leaching losses on the land used for crop production as a result of cultivation (Ledgard et al., 2006). This research will determine the effect of the proposed strategy on N leaching and profitability for the Lincoln University Dairy Farm (LUDF).

1.2 Research objective and relevance for the dairy industry

The main research objectives of this research are to investigate the suitability of a maize and oats silage rotation, fodder beet and wheat on the LUDF for maximising profitability and reducing N leaching. There has been extensive research into the DM production of both maize silage and fodder beet, however there is a lack of understanding of how they can be integrated into a dairy farm system. The aim for greater profitability to increase the return on farm assets has encouraged farmers to intensify their systems. Forage crops have higher input costs than pasture which often results in greater costs of milk production. Milk payouts have been historically very volatile and the system needs to be financially sustainable at low milk prices.

Driving this research is significant public concern regarding the environmental impact of dairy farming and its potential effect on human health and the international perception of New Zealand. Environment Canterbury has imposed restrictions on N leaching which will require the LUDF to significantly reduce leaching in the near future (SIDDC, 2014a). This research will determine whether integrating crops will comply with these regulations.

1.3 Research questions

1. What are the potential changes in milk solids (MS) production through incorporating maize/oats silage, fodder beet and wheat for feed or sales on the LUDF?
2. What is the change in the cost of milk production ($/kg MS) when incorporating maize/oats silage, fodder beet and wheat?
3. What is the optimum area of pasture, maize/oats silage, fodder beet and wheat for maximum profitability at various milk prices?
4. Will the proposed integration of crops increase or decrease nitrogen leaching per hectare compared to the current pastoral system?

1.4 Research approach

Computer modelling will be undertaken using a whole farm systems approach. This will take into account the practical implications of incorporating fodder crops on other parts of the farm system, such as pasture management and stocking rate. FARMAX® Professional Dairy will be used as a farm systems simulator to model the production and cash operating profit of the existing and proposed systems. Linear programming will be used as a systems optimiser which will determine the optimum areas of pasture and each crop at various milk prices, using certain constraints ensuring suitable diet composition. Overseer™ (6.2.0) will be used to model N leaching. The purpose of using whole farm systems modelling is to demonstrate how the integration of forage crops affects the farm as a whole, which may encourage uptake of the strategy by farmers.

Chapter 2:

Literature Review

2.1 Introduction

The purpose of this literature review is to discuss the previous studies on incorporating crops into dairy farm systems. The factors determining the profitability of fodder crops on a dairy system are the DM yield per hectare, cost of DM production and the milk production response, which is a function of nutritional value. Research into the N leaching when crops are integrated on dairy farms has also been reviewed. Both field trials and modelling studies have been analysed.

2.2 Whole farm systems theory

Whole farm systems theory is a holistic study of the various elements contributing to the farm as a whole (Kelly & Bywater, 2005). This is in contrast to a reductionist approach where the individual elements are studied separately. The elements include the productive capacity of land and the availability of labour and financial resources. Whole farm systems theory emphasises the complex interactions between each factor. An adjustment to one factor may change overall performance in more ways than first thought.

Each element can be categorised into inputs, outputs and the environment (Kelly & Bywater, 2005). One of the main purposes of the system is to generate a profit that is both economically and environmentally sustainable for the future. The environmental factors affecting the system include the regulatory, economic and physical environment. The adverse effects on the physical environment are increasingly of concern for dairy farm systems, especially the issue of N leaching. The regulatory environment governs areas such as labour laws and resource use. The economic environment of the agricultural industry is volatile and farmers have minimal control over adverse input and output price movements. This warrants the need for financially resilient farm systems.

2.2.3 Production economics

A major part of farm systems theory is production economics. The law of diminishing returns states that the production response of each additional unit of input is less than from the previous unit of input (Spedding, 1988). In biological systems, the ratio of outputs to inputs decreases as input level increases. Figure 1 shows how wheat yield initially increases rapidly as N fertiliser is applied, then subsequent responses are smaller per additional unit of N. In a dairy farm system, this is demonstrated by the response of pasture production at various levels of N fertiliser.

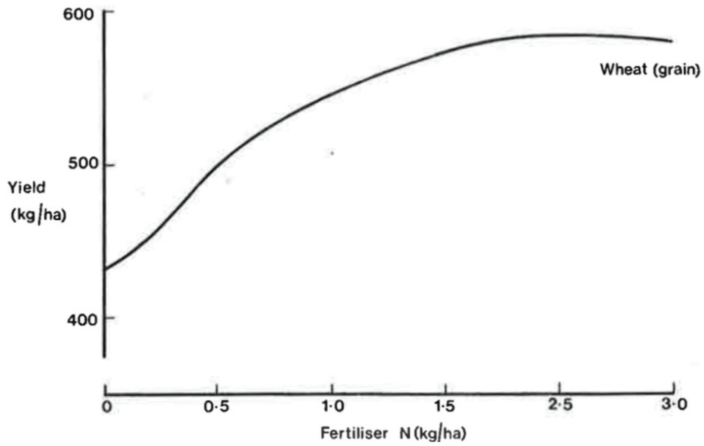


Figure 1: Diminishing returns of wheat using in response to N fertiliser (Spedding, 1988).

The consequence of this law for farm systems is that maximising production almost always does not maximise profitability. The optimum level of production will change based on input and product price. A major challenge for farm systems is their inability to respond quickly to price volatility. The competitive advantage of the New Zealand dairy industry has traditionally been its low input, pasture-based systems which can operate profitably at low milk prices (Shadbolt, 2012). High input systems typically have high costs of production which are difficult to adjust to unfavourable market conditions. For this reason, low cost systems may be more economically sustainable.

2.3 Profitability

2.3.1 Dry matter production

The rationale behind integrating forage crops into dairy systems is primarily to increase DM production for greater milk production. Genetic gains of perennial ryegrass in New Zealand through plant breeding have been minimal, estimated at 0.25 to 0.73% increase in DM production annually during recent decades (Lee, Matthew, Thom & Chapman, 2012). There is limited research on the rate of genetic gain of forage crops. Productivity increases, resulting from both genetic gain and improved crop husbandry practices, have been significantly greater for forage crops during the same period. Figure 2 shows the productivity gains from 1961 to 1997 in New Zealand have been significant for maize silage and negligible for the typical perennial ryegrass/white clover pastures used on dairy farms. Reasons cited for the rapid improvements of maize silage is the financial incentive for seed companies to invest in genetic improvements. Maize silage is an annual crop and must be sown each year, resulting in large seed sales (Densely et al., 2001).

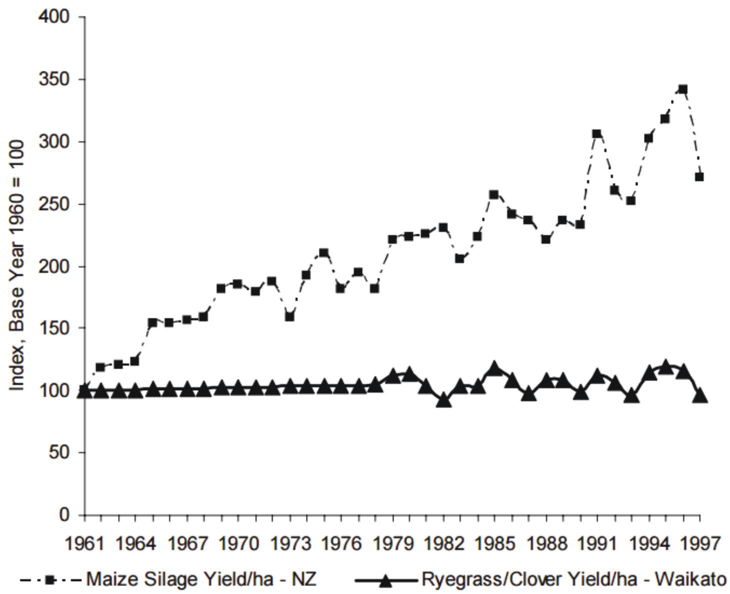


Figure 2: Productivity gains in New Zealand maize silage and Waikato pasture from 1961 to 1997 (Deane, 1999, as cited in Densley et al., 2001, p. 290).

Densely et al. (2001) modelled that if 15.0% of farm area was used for maize silage (assuming 25 t DM/ha) as part of pasture renewal programme, overall DM production would increase by 10.6%. Table 1 shows the annual DM yields observed in various field trials in Waikato and Canterbury. The winter crops used were all whole-crop silage unless otherwise stated. Maize silage is more productive in the North Island due to higher temperatures (Densely et al., 2001). It is a tropical plant that uses the C4 photosynthetic pathway, which is most productive in warmer climates. There have been fewer field trials of maize silage in Canterbury due to its lower popularity in the region.

Table 1: Annual dry matter production of maize silage followed by a winter crop in Waikato and Canterbury

Summer crop	Winter crop	Yield (t DM/ha)	Publication
Waikato			
Maize	Oats	48.9	Minneé et al. (2009)
Maize	Oats	48.8	FAR (2010)
Maize	Triticale	41.7	FAR (2010)
Maize	Italian ryegrass	39.2	FAR (2010)
Maize	Triticale	37.6	Densley et al. (2006)
Maize	Oats (grazed)	32.8	Densley et al. (2006)
Maize	Italian ryegrass	31.6	Densley et al. (2006)
Canterbury			
Maize	Oats	31.7	FAR (2010)
Maize/maize	Wheat/triticale	30.1[1]	De Ruiter, Maley, Chakwizira, Fletcher & George (2010a)
Maize/kale	Wheat/triticale	29.1[2]	De Ruiter et al. (2010a)
Maize	Triticale	27.9	FAR (2010)
Maize	Italian ryegrass	27.4	FAR (2010)

[1]Annualised yield of a two year rotation of maize, wheat, maize, triticale.

[2]Annualised yield of a two year rotation of maize, wheat, kale, triticale.

The increase in popularity of fodder beet in New Zealand has been relatively recent. Gibbs (2014) estimated that the area of fodder beet in New Zealand has increased from approximately 100 ha in 2006 to 15,000 ha in 2014. Fodder beet yields typically range from 20 to 35 t DM/ha (Table 2), however yields greater than 40 t DM/ha have been observed (Milne et al., 2014). Both maize/oats silage and fodder beet have potential to increase DM production on Canterbury dairy farms. Annual productivity of irrigated dairy pastures on light Canterbury soils has been measured at 17.6 t DM/ha (DairyNZ, n.d.) which is significantly less than these forage crops. The four year average from 2009 to 2013 of autumn-sown feed wheat in Canterbury was 11.0 wet tonnes per hectare (FAR, 2014). At 87% DM, this equates to 9.57 t DM/ha, which is significantly less than maize/oats silage and fodder beet.

Table 2: Dry matter production of fodder beet in New Zealand.

Yield (t DM/ha)	Region	Publication
19-35	Hawkes Bay	Matthew, Nelson, Ferguson & Xie (2011)
36.5	Manawatu	Priest (2014)
21-32	Canterbury	Chakwizira et al. (2013)
27.2	Canterbury	Chakwizira, De Ruiter & Maley (2014)
19.9-26.1	Canterbury	DLF Seeds Ltd (2014)

2.3.2 Cost of pasture and crop production

Although pasture may be less productive than maize/oats silage and fodder beet, it has significantly less costs of production. Table 3 shows the cost of production of pasture and the various feed crops based on the total direct expenses (excluding irrigation). The cost of pasture was calculated at 3.9 cents/kg DM which is significantly less than both fodder beet and maize silage/grazed oats at 8.2 and 11.9 cents/kg DM respectively. Wheat had the highest cost of production at 12.4 cents/kg DM due to its low DM yield.

Table 3: Cost of production of pasture, maize silage/oats and fodder beet

Land use	**Annual yield (t DM/ha)**	**Direct expenses ($/ha)**	**Cost of production (cents/kg DM)**
Pasture	17.6[1]	689[5]	3.9
Maize silage/grazed oats	32.8[2]	3,909[2]	11.9
Fodder beet	27.2[3]	2,225[6]	8.2
Wheat	9.57[4]	1,183[7]	12.4

[1] DairyNZ. (n.d.).

[2] Densely et al. (2006)

[3] Chakwizira et al. (2014)

[4] FAR. (2014)

[5] SIDDC. (2015a)

[6] Matthew et al. (2011)

[7] Askin and Askin. (2012)

Fodder beet is an expensive crop to grow, however can have a lower cost of production than other feed crops. It can also be harvested at approximately 5 cents/kg DM and stored without cover for up to six months (Gibbs, Saldias & Trotter, 2015). Only cultivars with DM content greater than 20%, such as sugar beet, should be stored for this long to avoid decomposition. Lower DM cultivars can still be stored, however should be used within three to four months of harvesting. Priest (2014) found the cost of production of growing and harvesting fodder beet in Manawatu was 11.3 cents/kg DM. Very high yields of 36.5 t DM/ha were achieved due to the increased thermal time in the North Island.

The published research does not analyse the effect of the cost of debt servicing or opportunity cost of farm assets. Even if pasture has the lowest cost of production, higher yielding forage crops may generate greater financial returns. Based on a typical farm asset value for Canterbury dairy farms of $59,000/ha (MPI, 2012), an average annual cost of capital of 7.0% and pasture production of 17.6 t DM/ha/year (DairyNZ, n.d.), the cost of capital for pasture is 23.4 cents/kg DM ($4,130/ha). The rational for using forage crops is to spread these fixed costs over greater DM production.

2.3.3 Milk production response to forage crops

The additional milk production achieved through integrating forage crops into pastoral dairy systems is possible because pasture contains surplus CP than required by lactating dairy cows. Cow CP demand is approximately 18% of DM during early lactation, decreasing to 14% during late lactation (DairyNZ, 2010). Table 4 shows the ME and CP content of pasture, maize and oats silage, fodder beet and wheat. Well managed pasture on irrigated South Island has relatively high ME and CP content. Forage crops are typically lower in both ME and CP. Fodder beet is an exception which has similar energy content to high quality pasture. An advantage with fodder beet is there is only a very minimal decrease in nutritive value as the plant matures (J. Gibbs, personal communication, September 3, 2014). Pasture quality fluctuates significantly due to periods of stem and seed-head production. Wheat has the highest ME value at 13.0 to 13.5 MJ ME/kg DM.

Table 4: Metabolisable energy and crude protein content of pasture and forage crops (DairyNZ, 2010).

Land use	ME (MJ/kg DM)	CP (% of DM)
Pasture	11.0-12.5	18-30
Maize silage	10.0-11.0	8
Oat silage	10.0-10.5	8-9
Fodder beet	12.0-12.5	9-14
Wheat	13.0-13.5	13

Dalley, Collis and Clough (2005) observed a milk production response of 80 g MS/kg DM for maize silage. The average milk production per hectare over four years of the trial was 34% greater when 1.5 t DM/cow/year was fed, compared with no maize supplementation. However, the maize silage was imported so does not account for the lost pasture production that results when removing paddocks to be sown into crop. Despite the additional milk production, the economic farm surplus (EFS) was 8.4% lower on the maize supplemented trial, using an average milk payout of $4.52/kg MS (average milk payout from 2000/01 to 2003/04). It was concluded that maize silage made the farm system more susceptible to low milk payouts due to the additional feed costs.

Densley et al. (2006) modelled potential MS production to be 3,160 kg MS/ha from an entirely maize silage and grazed oats farm system, assuming 96 g MS/kg DM. This is significantly greater than the 2014/2015 budgeted production of 1,750 kg MS/ha for the LUDF (SIDDC, 2015a). In reality, this system is not possible without CP supplementation. Kolver, Roche, Miller and Densley (2001) modelled that production could increase to 4,135 kg MS/ha using a maize/oats silage rotation, supplemented with imported soybean meal (47-53% CP (DairyNZ, 2010)) at 20% of the daily DM intake to avoid CP deficiency. Significant investment would be required in cow housing or feed pads due to the loss of grazing land, however it shows that significant productivity gains could be achieved through intensive crop production.

However, there have been few field trials measuring actual milk production when growing maize on-farm. De Ruiter, Clough, Macdonald and Glassey (2010b) found MS production per hectare was statistically similar when 10% of farm area was planted with forage crops including maize silage, compared with a completely pastoral system. Operating profit significantly decreased due to the additional feed crop costs. There have been no scientific field trials done in New Zealand measuring milk production when using fodder beet. The Manawatu farm case study by Priest (2014) used harvested fodder beet at 6 kg DM/cow/day during early lactation, however the overall change in milk production was not stated. Fodder beet is more common overseas, particularly in Europe as part of a total mixed ration (TMR) diet. Phipps, Sutton and Jones (1995) found milk yield per cow increased by 12.6% when fodder beet was 33% of the diet for lactating dairy cows, compared with a solely grass silage diet. This was due to a 23.7% increase in total daily DM intake when fodder beet was included, indicating that it is a highly palatable feed for dairy cows.

While there has been significant research into the MS response to maize grain, there is minimal research into the response to wheat. Penno, McGrath, Macdonald, Coulter, and Lancaster (1999) found the MS response to supplementation was 98 g/kg DM when 1.2 t DM/cow of maize grain was fed. Maize grain has similar ME content to wheat at 13.5 MJ ME/kg DM (DairyNZ, 2010), so a similar MS response could be expected.

2.4 Nitrogen leaching

2.4.1 The cause and effect of nitrogen leaching

The rapid expansion of the New Zealand dairy industry has significantly increased the amount of nitrogen leached into surface and groundwater sources. Soil N is present as organic N, nitrate (NO_3^-) and ammonium (NH_4^+). Both the NO_3^- ion and soil particles are negatively charged which results in nitrate being repelled into the soil water and subsequently leached during periods of drainage (Di & Cameron, 2002). Pasture almost always contains excess CP (16% N) than required by lactating cows and the excess N is excreted in urine. Cow urine patches have been observed to deposit approximately 1,000 kg N/ha which far exceeds pasture uptake. Silva, Cameron, Di, and Hendry (1999) found that 12% of the nitrogen in urine was leached from the soil and that approximately 25% of pastoral area received urine patches every year. The leachate obtained was found to have nitrate-N concentrations exceeding the drinking water standards set by the Ministry of Health (2008) of 11.3 mg N/L. During recent years, there have been many drinking wells in Canterbury that have breached this health standard (Environment Canterbury, 2010). A major health concern with nitrate in drinking water is methemoglobinemia, which can cause infant deaths through loss of haemoglobin function (Di & Cameron, 2002). Nitrate run-off into surface water also has major implications on the ecosystem. The main effect is increased algae growth, leading to reduced oxygen concentration in the water which is harmful to aquatic life.

The LUDF is located in the Selwyn–Waihora catchment which is part of the 'red' zone established by Environment Canterbury (2014a), meaning N leaching per hectare must not exceed the 'nitrogen baseline.' The baseline is the average annual leaching for the farm calculated by Overseer™ (Section 3.4.3) from 1 July 2009 to 30 June 2013. Because N leaching on the farm is greater than 15 kg N/ha, from 2022 the LUDF will have to reduce N leaching by up to 30% (Environment Canterbury, 2014b). The LUDF has a relatively high nitrogen baseline of 52 kg N/ha (SIDDC, 2014a) and is currently investigating methods to reduce N leaching to comply with these regulations.

2.4.2 Effect of forage cropping on nitrogen leaching

Low protein crops such as maize and oats silage, fodder beet and wheat may be effective feed sources to rebalance the ME and CP content in the diet. Edwards et al. (2014) found that the N concentration in urine was 2.1 g N/L in non-lactating dairy cows fed fodder beet (10.9% CP) and pasture baleage at 8 and 6 kg DM/cow/day respectively. In contrast, Bryant et al. (2014) found urinary N concentration was 4.54 g N/L in pasture-fed dairy cows during mid-lactation. This is despite CP demand being greater during mid-lactation (16% of DM) than during the non-lactating period (12% of DM, (DairyNZ, 2010)). The lower urinary N concentration should decrease leaching losses from urine patches.

Maize silage is also low in CP (8.0% of DM) and has been shown to decrease the total amount of N excreted per cow and reduce the proportion of N excreted in relation to total N consumed (Table 5). Ledgard (2006) found that cows fed maize and cereal silage had significantly reduced total urinary N excretion compared with cows fed pasture and lucerne silage. The N use efficiency dramatically increased, with greater proportions of N consumed converted into milk at the expense of urinary N.

Table 5: Effect of feed type on N output per cow (Ledgard, 2006, as cited in Williams et al., 2007, p. 138).

Type of silage	**N intake[1] (kg N/cow)**	**N output (kg N/cow)** ***(% of intake)***	
		Milk	Urine
Lucerne	37	6 *(16)*	23 *(62)*
Pasture	24	6 *(25)*	11 *(46)*
Cereal	16	6 *(38)*	5 *(31)*
Maize	12	6 *(50)*	3 *(25)*

[1]Based on 1 t DM/cow supplementation

Maize has a very deep rooting system that can access nitrogen that has leached below the root zone of pasture. An annual winter crop, such as whole-crop oats, has greater growth rates and N uptake during winter compared with a perennial ryegrass pasture (Malcolm, Cameron, Di, Edwards & Moir 2014). Greater N uptake reduces the surplus N in the soil that can be leached. However, a study by Ledgard et al. (2006) found the additional cultivation for a double-cropping rotation of maize silage and annual ryegrass resulted in significant leaching losses on the land used for cropping. Cultivation for crops increases soil aeration, resulting in mineralisation of organic N to NH_4^+. The NH_4^+ ion is rapidly convertible to NO_3^-, which is easily leached (Di & Cameron, 2002).

Ledgard et al. (2006) found that feeding maize silage at a rate of 5.5 t DM/ha enabled the stocking rate to increase from 3.0 cows/ha to 3.8 cows/ha; increasing milk production per hectare by 30%. Despite the increased stocking rate, there was no measured increase in N leached per hectare at 42 kg N/ha. This was due to an 18% decrease in N leached per tonne of milk solids on the dairy farm (Figure 3) as a result of a reduced CP surplus in the diet. However, when the whole farm system was accounted for (including area for cropping and rearing cow replacements), N leaching significantly increased per t MS and per hectare. This was due to high N leaching maize silage land (70 kg N/ha) as a result of mineralisation.

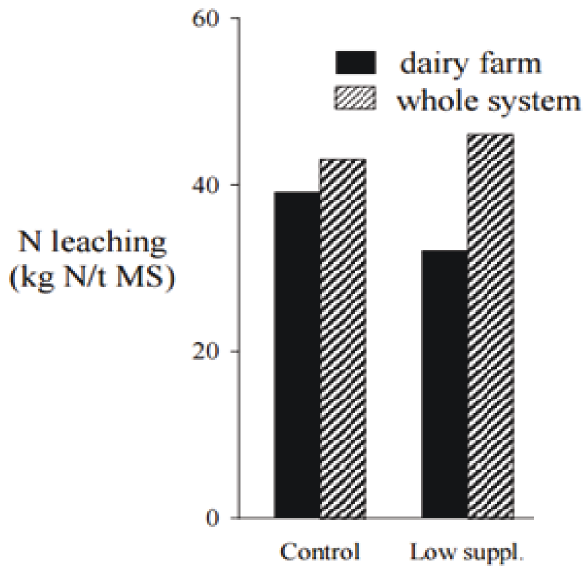


Figure 3: Dairy farm N leaching per t MS when incorporating maize silage (low suppl.) or solely pasture fed (control), (Ledgard et al., 2006).

Beare et al. (2010) measured N leaching of 72 kg N/ha for a maize silage/wheat (green-chop) rotation on a silt loam soil near Lincoln. This is very similar to that measured by Ledgard et al. (2006) and indicates that growing forage crops may not be an effective strategy to reduce N leaching.

There is no published data on the N leaching of fodder beet fed to lactating dairy cows (K. Cameron & R. Bryant, personal communication, May 11, 2015). Leaching of a fodder beet and kale winter grazing block on the Ashely Dene farm was measured with lysimeters at 64 kg N/ha (SIDDC, 2015b). However, it was not possible to determine the leaching of only the fodder beet area. Brown (2014) modelled a fodder beet wintering system on the Ashely Dene farm on Overseer ™ (6.1.3) and found that the projected N leaching was similar at 65 kg N/ha. This was assuming daily intakes of 8 and 6 kg DM/cow/day of fodder beet and pasture silage respectively. The leaching on the cropping area when fed to lactating cows during autumn or spring will likely be less than in winter (K. Cameron, personal communication, May 11, 2015). Winter grazing of fodder crops typically results in very high leaching due to high winter rainfall. Stocking rates are much higher than during lactation due to reduced daily DM intake per cow, resulting in large amounts of urine deposition over a short period of time. However, as fodder beet also requires cultivation, there may still be greater N leaching losses when used for lactation compared with pasture.

A modelling study done by Lilburne and Webb (2002) found the N leaching of autumn cultivated, spring sown wheat ranged from 5.6 kg N/ha to 28 kg N/ha, with freely drained soils resulting in higher leaching. This study used the Groundwater Loading Effects of Agricultural Management Systems model (GLEAMS). It would be expected that this crop rotation would have much greater leaching than that predicted by the model. Cultivation in early autumn can result in large leaching losses as soil temperature is relatively high, which increases microbial activity in the soil which increases mineralisation of organic N (Di & Cameron, 2002). Having several months of fallow during winter would be expected to result in high leaching losses. Francis, Haynes and Williams (1995) measured N leaching of 102 kg N/ha for winter wheat on a Templeton silt loam soil in Canterbury. Autumn sown wheat will utilise mineralised N during winter, although there will still be a large excess of mineral N following cultivation.

There is currently inconclusive research into whether direct drilling is able to reduce N leaching through reduced disturbance of the soil. Figure 4 shows the average nitrate leaching of several spring sown crops (barley, wheat and peas) sown in Lincoln, Canterbury as measured by Fraser et al. (2013). The trial also measured the N loss with and without a winter cover crop of forage rape. The trial found there were clear benefits of using a winter cover crop to reduce leaching. However, there were surprisingly no significant differences in the N leaching when reducing the intensity of cultivation. Similarly, Constantin et al. (2010) observed only a small 6 kg N/ha decrease in N leaching of an arable system using direct drilling compared with conventional cultivation. Proposed explanations for these findings are that conventional cultivation disrupts the continuity of macropores in the soil (Fraser et al. 2013). This may reduce drainage and counteract the effect of increased mineralisation. However, this theory appears to contradict other research that cultivation from pasture increases leaching through increased mineralisation (Ledgard et al., 2006; Beare et al., 2010).

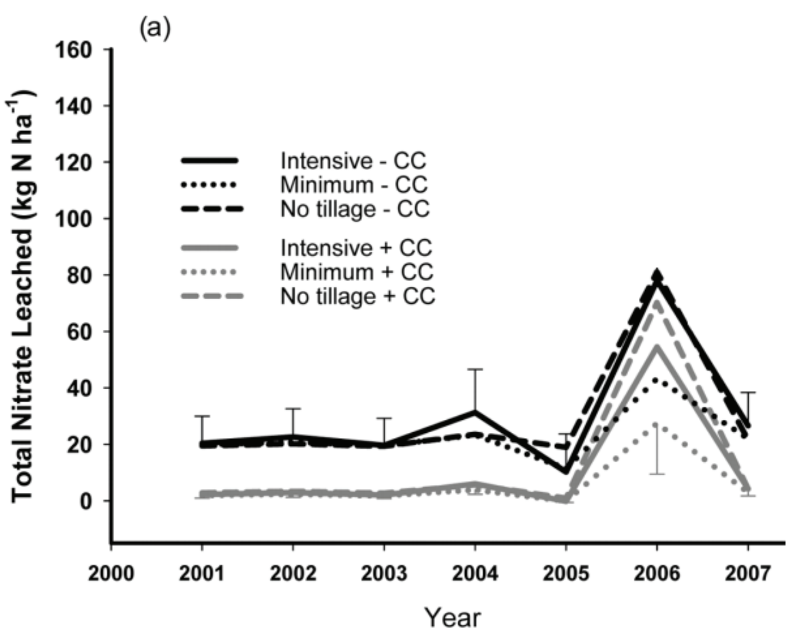


Figure 4: Effect of cultivation type and use of cover crop on nitrate leaching (Fraser et al., 2013)

The rationale of selling wheat to reduce N leaching is to export N off the farm. Assuming wheat yield of 11.0 t/ha (87% DM, 13% CP), there would be 199 kg N/ha exported as product. However, the literature suggests that N losses remain high, even when the wheat is sold. There is limited research of the N losses of dairy farms with grain crops grown on-farm. It is expected that feeding wheat on farm will reduce the N concentration in urine as demonstrated by using other low CP feeds. However, wheat is higher in CP than maize and oats silage and fodder beet so the benefits may be reduced.

2.5 Literature review conclusion

There have been many trials indicating that forage crops such as maize and oats silage and fodder beet can increase DM production on New Zealand dairy farms. This enables stocking rate to be increased for greater overall milk production. Whether this strategy results in increased overall profitability is less certain. Maize silage followed by a winter crop has particularly high cost of production compared with pasture. The reduced energy content also will likely reduce the FCE compared with pasture and fodder beet. Fodder beet is a promising crop that has high yields, high ME content and lower cost of production than maize silage.

The use of low CP forage crops has been shown to be an effective strategy to reduce the urinary N concentration in lactating dairy cows. The decreased N content in the diet reduces the N deposited in urine, which is the main source of leaching on pastoral dairy farms. However, significant leaching occurs on the cropping land as a result of cultivation, which has been shown to outweigh this benefit. Further research is needed to investigate the change in N leaching when crops are incorporated into a dairy system.

Chapter 3:
Research Methodology

3.1 Introduction

A farm systems modelling approach was used to determine the economic and environmental performance of the existing system on the LUDF and the proposed integration of fodder beet, maize/oats silage and wheat for feed and sales. The farm is located near Lincoln, Canterbury and operated by South Island Dairying Development Centre. The farm was established to demonstrate profitable and environmentally sustainable dairy farm management practises in the South Island (SIDDC, 2014b). The effective dairy platform is 160.1 ha of perennial ryegrass/white clover pasture. The actual milk production for the 2014/2015 season was 269,999 kg MS (482kg MS/cow and 1,686 kg MS/ha) with a stocking rate of 3.50 cows/ha (SIDDC, 2014c).

Quantitative research was the appropriate type of research as the analysed statistical data was used to confirm or reject a hypothesis (Muijs, 2010). FARMAX® Professional Dairy was used to simulate the profitability of the different systems. This software is commonly used by farm consultants to identify strategies to increase profitability. Linear programming was used as a farm systems optimiser to determine the most profitable land use at various milk prices. Nutrient budgeting with Overseer ™ (6.2.0) is compulsory for dairy farms in Canterbury and is the most suitable model to predict N leaching losses of the various systems.

3.2 Hypothesis

The hypothesis for this research was the following:

"Incorporating crops on the LUDF as supplementary feed during lactation will increase milk production and operating profit per hectare, however overall N leaching per hectare will increase also. Fodder beet will be the most profitable cropping option"

3.3 Theoretical model

The theoretical model for this research was based on profit maximisation. Maximum profit is achieved by increasing the level of input until the cost of an additional unit of input equals the additional income that would be generated (Martin & Woodford, 2005). This is represented by the following formula:

$$MR = MIC$$

where MR is the marginal revenue, or additional revenue generated and MIC is the marginal input cost, or the cost required to obtain this additional revenue. It has been established that fodder crops have greater costs of production than pasture. However, using forage crops should increase overall profitability if the additional milk revenue per kg DM is greater than the cost of production (cents/kg DM). The formula for operating profit for a dairy farm system is the following:

Operating profit = Y x MR x MP - E

where Y is DM yield (kg DM/ha), MR is milk solids response (kg MS/kg DM), MP is milk payout ($/kg MS) and E is expenses.

3.4 Current and proposed systems

The current system on the LUDF will be the control farm system. The milking platform is entirely pasture-based, with pasture silage made during periods of feed surplus. Approximately 300 kg DM/cow of pasture silage is imported per season as baleage (SIDDC, 2014a). All cows are wintered off-farm during the non-lactating period (SIDDC, 2014c). Replacement livestock are grazed off-farm all year round.

The proposed systems incorporating feed crops continued the current strategy of importing pasture silage and grazing replacements and wintering cows off-farm. An initial analysis compared the productivity and profitability of 20 ha of each crop, creating five different scenarios in total. The 20 ha of fodder beet scenario consisted of 10 ha of spring grazed fodder beet and 10 ha of autumn grazed fodder beet. The maize/oats silage scenario included 20 ha of spring sown maize silage, followed by a winter crop of whole-crop oats silage. Two scenarios incorporating 20 ha of autumn feed wheat were modelled. The wheat (fed) scenario included 20 ha of grain to be fed during lactation. The wheat (sold) scenario exported all the wheat off-farm at $400/tonne (Askin & Askin, 2012).

The results of this initial analysis found that fodder beet was by far the most suitable alternative for increased profitability on the LUDF. An additional scenario was modelled that increased the daily intake of spring and autumn grazed fodder beet to 6.0 kg DM/cow/day. This is based on the maximum recommended intake of 5-7 kg DM/cow/day for lactating dairy cows according to Gibbs et al. (2015). Harvested fodder beet was also included in this rotation and was fed during mid-lactation, after the spring grazed beet had been consumed and was finished by the time the autumn-grazed fodder beet was ready to be grazed (see section 3.5.1.1). A maximum daily intake of harvested fodder beet (without leaf) was assumed to be 4.0 kg DM/cow/day (Gibbs et al., 2015). This is lower than for grazed fodder beet as the crop has less CP, calcium and phosphorous without the leaf. This scenario with maximised fodder beet areas was called the optimised scenario. The crop rotations and feeding regime are described in greater detail in section 3.5.1. It was assumed that all crops would be re-sown into pasture following harvest or final grazing.

3.4.1 Feed supply assumptions

The assumed productivity of pasture and each crop was based on expected performance on an irrigated Canterbury dairy farm. The total potential pasture production was assumed to be 18.9 t DM/ha. Figure 5 shows the daily growth rates by month, which were based on the default values assumed by FARMAX® Professional Dairy for a Lincoln silt loam soil and historical growth rates measured on the LUDF. Growth rates peaked during November at 177 kg DM/ha/day, which then decreased to a minimum of 10 kg DM/ha/day during June.

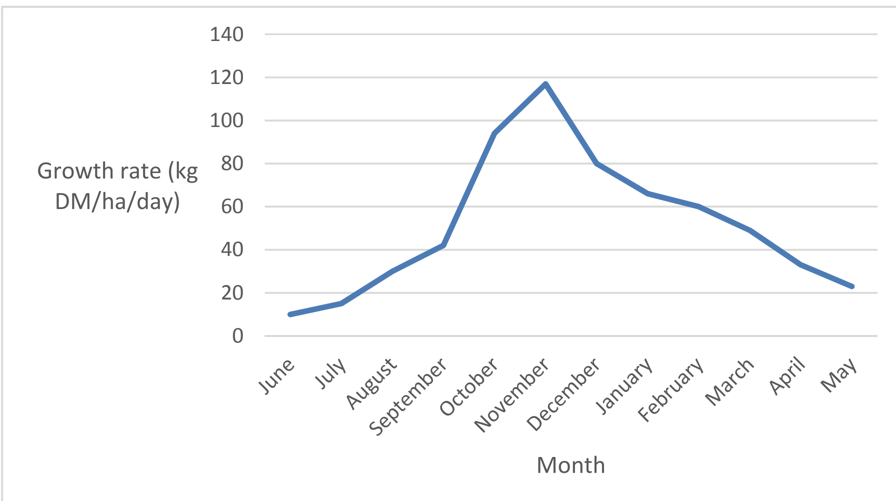


Figure 5: Daily pasture growth rates by month

The default values for the utilisation and feed quality of pasture on an irrigated dairy farm provided by FARMAX® were used for the modelling and are shown in Table 6. The cows are wintered off-farm for majority of time when utilisation is low at 80%. From October to April, the default utilisation rate used by the software is 100%. Irrigated pasture has relatively high feed quality, with a non-weighted monthly average of 12.3 MJ ME/kg DM.

Table 6: Utilisation rate and feed quality of pasture

Month	Utilisation	Feed quality
	(%)	(MJ ME/kg DM)
June	80	12.5
July	80	12.9
August	80	12.6
September	90	12.7
October	100	12.5
November	100	12.2
December	100	12.1
January	100	11.8
February	100	11.6
March	100	11.7
April	100	12.2
May	90	12.3

The productivity of the feed crop options were based on the findings from the literature review.

Table 7 details the assumptions regarding feed supply for each crop. Spring grazed fodder beet was assumed to have the highest DM production of 30.0 t DM/ha. Autumn grazed fodder beet was assumed to be less productive, at 23.0 t DM/ha, due to the shorter growing period. This is based on the assumption that the yield may increase by 5 t DM/ha during the four months from May to September (J. Gibbs, personal communication, September 3, 2014). For this trial the average yield difference between the autumn and spring grazed crop was assumed to be 7.0 t DM/ha as there is a greater period of time between the grazing of each crop. It was assumed harvested fodder beet would yield 25.2 t DM/ha. This was based on the finding by Jenkinson, Edwards and Bryant (2014) that the leaf contributed 16% of total DM yield. From a pre-harvest yield of 30.0 t DM/ha, this represents 4.8 t DM/ha forfeited. The utilisation rate of both grazed and harvested fodder beet was assumed to be very high at 95% (Milne et al., 2014; Gibbs, 2014). The feed quality was assumed to be 12.5 MJ ME/kg DM.

The cumulative yield of maize and oats silage was 32.0 t DM/ha. The utilisation rate of maize and oats silage was assumed to be 75% (DairyNZ, 2012). The feed quality of maize and oats silage was 10.8 and 10.0 MJ ME/kg DM respectively, based on the figures published by DairyNZ (2010). The utilisation rate of pasture silage was also assumed to be 75% and had 11.0 MJ ME/kg DM.

Wheat was the highest quality feed at 13.0 MJ ME/kg DM (DairyNZ, 2010). The utilisation rate was assumed to be 100% as it would be allocated through in-shed feeding. The assumed yield for both wheat (fed) and wheat (sold) scenario was 11.0 t/ha (87% DM) (FAR, 2014).

A budget of expenditure for each crop was done is detailed in Appendix 1 to 4. The cost of harvested fodder beet includes the growing costs and an additional $1,260/ha (5.0 cents/kg DM (Gibbs et al., 2015)) for harvesting.

Table 7: Yield, utilisation, feed quality and direct costs of feed crops

	Yield	**Utilisation**	**Feed quality**	**Direct costs**
	(t DM/ha)	(%)	(MJ ME/kg DM)	($/ha)
Fodder beet (spring grazed)	30.0	95	12.5	2,007
Fodder beet (autumn grazed)	23.0	95	12.5	2,007
Fodder beet (harvested)	25.2	95	12.5	3,267
Maize silage	22.0	75	10.8	2,864
Oats silage	10.0	75	10.0	1,141
Wheat	9.6[1]	100	13.0	1,470

[1]Based on 87% DM and 11.0 t/ha fresh weight

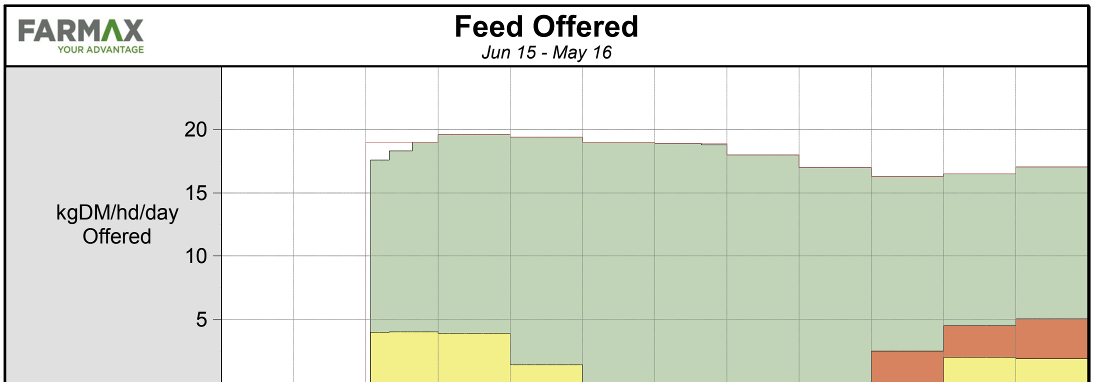
3.5 Quantitative research methods

3.5.1 FARMAX® Professional Dairy

FARMAX® Professional Dairy is a powerful decision support software designed for New Zealand dairy farm systems. It is commonly used by farm consultants to simulate the whole-farm system to predict milk production and profitability. It is a very useful software to model various options for development and compare the expected profitability with an existing system. A study by Bryant et al. (2010) found that the milk solids production per cow and per hectare of two farms in Hamilton and Palmerston North was similar to that predicted by FARMAX® Professional Dairy. In this study, the software was used to compare the profitability and cost of milk production ($/kg MS) of each system. The effects on grazing management due to reduced pastoral area were analysed. The model calculated the average monthly pasture cover (APC) and optimised the stocking rate so that the APC did not go below the minimum required for maximum pasture production (in most situations being 1,700 kg DM/ha). Bryant et al. (2010) found that predicted monthly APC by the software was also similar to that measured on the two farms.

3.5.1.1 Feeding regime

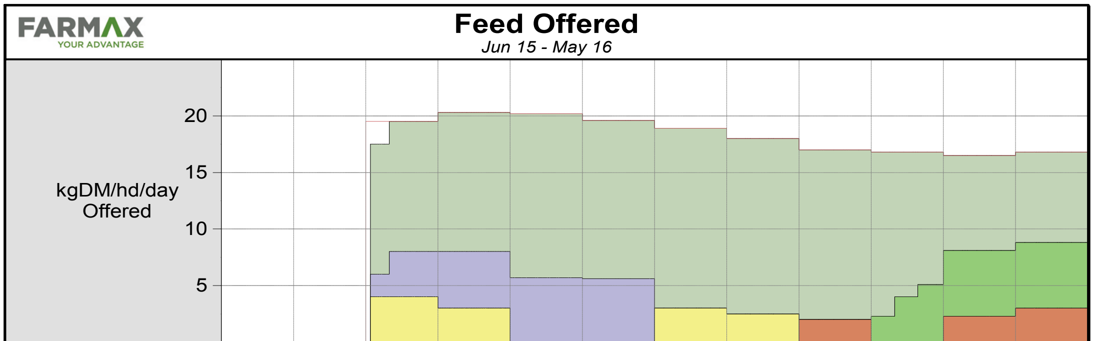
This section describes the feeding regime that was used for each system. Figure 6 shows the daily pasture and pasture silage offered to lactating cows and the total amount utilised for the existing system. Pasture silage was fed at up to 4.0 and 5.0 kg DM/cow/day during early and late lactation respectively. Total feed utilised peaked at 19.0 kg DM/cow/day during October and November and reduced to 14.6 kg DM/cow/day by the end of the season.



Select a Feed	J	J	A	S	O	N	D	J	F	M	A	M
Pasture			14.3	15.7	18.0	19.0	18.9	18.0	17.0	13.8	12.0	12.0
Pasture Silage										2.5	2.5	3.1
Pasture silage imported			4.0	3.9	1.4						2.0	1.9
Total (Utilised)			14.5	17.1	19.0	19.0	18.9	18.0	17.0	15.7	15.4	14.6

Figure 6: Feed offered by month and total feed utilised by lactating cows for existing system

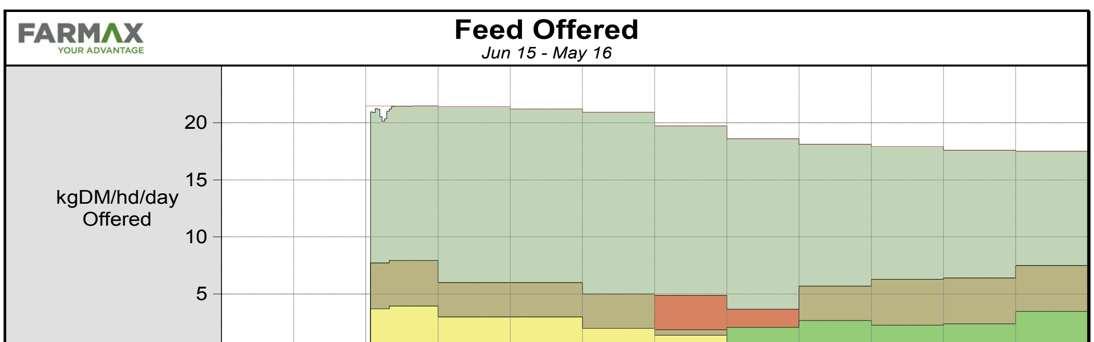
Incorporating 10 ha each of spring and autumn grazed fodder beet provided high daily allocations during early and late lactation. Spring grazed fodder beet was grazed from August until November and autumn grazed beet was grazed from March to May. It was assumed that the cows were not on fodder beet during winter grazing, so daily allocations for the first week were low to allow for adequate transitioning. Gibbs et al. (2015) recommend that allocations begin at 1 kg DM/cow/day and increase by a maximum of 1 kg DM every second day. In this model, the intake averaged at 2.0 kg DM/cow/day for the first week of lactation, increasing to 4.0 kg DM by the end of the month. Transitioning on the autumn grazed crop used similar initial allocations. Pasture silage was used during most of the season to supplement early and late lactation feed deficits and to replace the spring fodder beet during mid-lactation until the autumn crop is grazed in March. Total feed utilised peaked in October at 19.9 kg DM/cow/day and decreased to 15.0 kg DM in May.



Select a Feed	J	J	A	S	O	N	D	J	F	M	A	M
Pasture			11.5	12.3	14.5	14.0	15.9	15.5	15.0	13.0	8.4	8.0
Fodder Beet (spring grazed)			3.4	5.0	5.7	5.6						
Fodder beet (autumn grazed)										3.8	5.8	5.8
Pasture silage imported			4.0	3.0			3.0	2.5	0.0			
Pasture Silage									2.0		2.3	3.0
Total (Utilised)			15.4	18.1	19.9	19.3	18.2	17.4	16.5	16.6	15.6	15.0

Figure 7: Feed offered by month and total feed utilised by lactating cows for fodder beet scenario

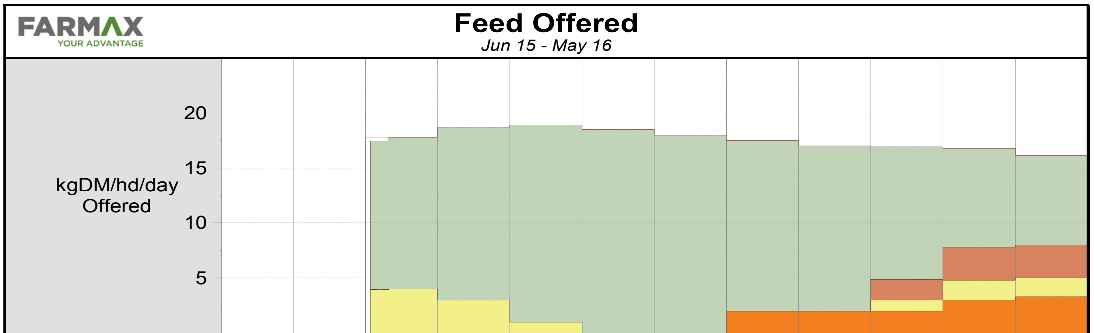
The daily allocations for the maize/oat silage scenario are shown by Figure 8. Maize silage was fed throughout the season except for January. Daily allocations were predominantly 3.0 to 4.0 kg DM/cow/day. Pasture silage was fed from August to January at approximately 3.0 kg DM/cow/day. Oats silage was fed from January to May at 2.1 to 3.5 kg DM/cow/day. Daily intake also peaked in October at 19.7 kg DM/cow/day and decreased to 14.6 kg DM by May.



Select a Feed	J	J	A	S	O	N	D	J	F	M	A	M
Pasture			13.5	15.4	15.2	15.9	14.8	14.9	12.4	11.6	11.2	10.0
Pasture Silage							3.0	1.6				
Maize Silage			4.0	3.0	3.0	3.0	0.5		3.0	4.0	4.0	4.0
Oats silage								2.1	2.7	2.3	2.4	3.5
Pasture silage (imported)			3.9	3.0	3.0	2.0	1.4					
Total (Utilised)			16.7	18.4	19.7	19.6	18.5	17.7	16.7	16.3	16.0	14.6

Figure 8: Feed offered by month and total feed utilised by lactating cows for maize/oats silage scenario

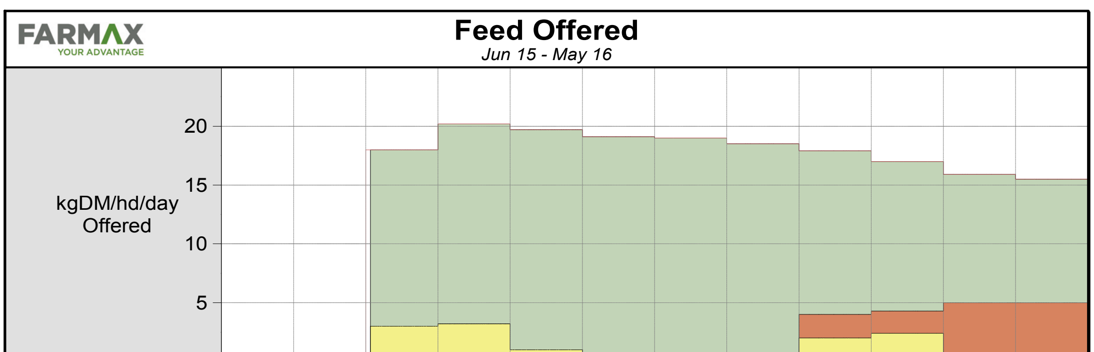
The feeding regime for the wheat (fed) scenario included pasture silage fed from August to October and March to May at 1.0 to 4.8 kg DM/cow/day as shown by Figure 9. Wheat grain was used to fill the late lactation feed deficit. It was fed at 2.0 to 3.3 kg DM/cow/day from January to May, with intakes increasing toward the end of the season. Feed intake peaked at 18.7 kg DM/cow/day during October and decreased to 14.1 kg DM during May.



Select a Feed	J	J	A	S	O	N	D	J	F	M	A	M
Pasture			13.7	15.7	17.9	18.5	18.0	15.5	15.0	12.0	9.0	8.1
Pasture Silage										1.9	3.0	3.0
Pasture silage imported			4.0	3.0	1.0					1.0	1.8	1.7
Wheat								2.0	2.0	2.0	3.0	3.3
Total (Utilised)			14.0	16.4	18.7	18.5	18.0	17.5	17.0	16.2	15.6	14.1

Figure 9: Feed offered by month and total feed utilised by lactating cows for wheat (fed) scenario

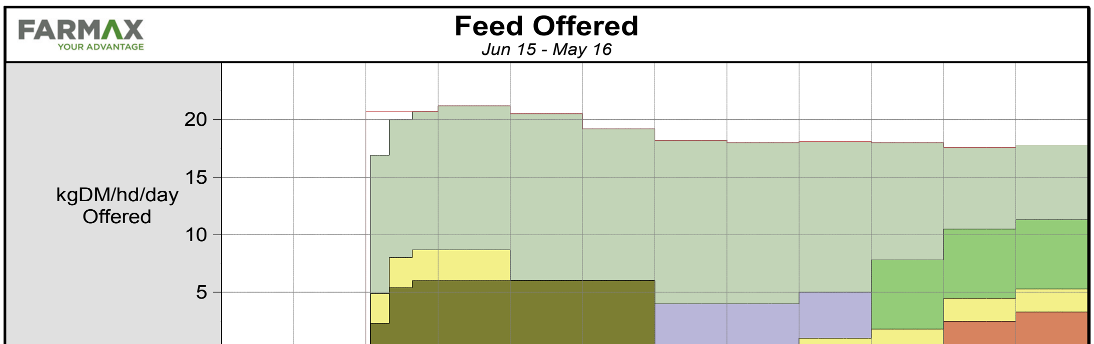
The feeding regime for the wheat (sold) scenario (Figure 10) was very similar to the existing scenario. The only supplementation used was pasture silage during early and late lactation. Pasture silage allocations ranged from 1.0 to 5.0 kg DM/cow/day. Total feed intake peaked in October at 19.5 kg DM/cow/day and decreased to 13.2 kg DM during May.



Select a Feed	J	J	A	S	O	N	D	J	F	M	A	M
Pasture			15.0	17.0	18.7	19.1	19.0	18.5	13.9	12.7	10.9	10.5
Pasture Silage									2.0	1.9	5.0	5.0
Pasture silage imported			3.0	3.2	1.0				2.0	2.4		
Total (Utilised)			14.3	17.7	19.5	19.1	19.0	18.5	16.9	15.9	14.7	13.2

Figure 10: Feed offered by month and total feed utilised by lactating cows for wheat (sold) scenario

The feeding regime for the optimised scenario is shown by Figure 11. Fodder beet is supplemented throughout the entire lactation period. The average daily intake of fodder beet during the first week of lactation was 2.3 kg DM/cow/day to allow for transition onto the crop. This was increased to 6.0 kg DM/cow/day by the end of August and this intake was maintained until the end of November. Harvested fodder beet was fed at 4.0 kg DM/cow/day from December to February. Autumn grazed fodder beet was grazed from March until the end of the May at 6.0 kg DM/cow/day. It was assumed after the initial transition in August, that no further transition was necessary when switching from grazed beet to harvested, then back to grazed beet in March. Pasture silage was fed during August and September at 2.6 to 2.7 kg DM/cow/day. Most silage was fed during late lactation, with allocations increasing to 5.3 kg DM/cow/day in order to maintain the APC above the minimum level of 1,700 kg DM/ha.



Select a Feed	J	J	A	S	O	N	D	J	F	M	A	M
Pasture			12.0	12.5	14.5	13.2	14.2	14.0	13.1	10.2	7.1	6.5
Fodder Beet (harvested)							4.0	4.0	4.0			
Fodder beet (autumn grazed)										6.0	6.0	6.0
Pasture silage imported			2.6	2.7					1.0	1.8	2.0	2.0
Pasture Silage											2.5	3.3
Fodder beet (spring grazed)			4.6	6.0	6.0	6.0						
Total (Utilised)			16.0	19.0	20.2	18.9	18.0	17.8	17.7	17.3	16.2	15.5

Figure 11: Feed offered by month and total feed utilised by lactating cows for the optimised scenario

3.5.1.2 Crop and pasture rotations

This section depicts the crop and pasture rotations for each scenario. Figure 12 shows the areas of new pasture and silage made on-farm that were used for the existing system. It was assumed that 10% of the farm was regrassed annually (16.0 ha). Old pasture was sprayed out mid-August and sown on the 1st of September. It was assumed that there would be two months from sowing until the first grazing of the re-sown pasture (Pasture Renewal Charitable Trust, 2013). Figure 12 shows there were two harvests of pasture silage on-farm of 30 ha each (2.0 t DM/ha) during October and November. The width horizontally of each silage block indicates how long that area is out of the grazing rotation.

It was assumed it would take 18 to 20 days until this area could be grazed again based on expected growth rates.

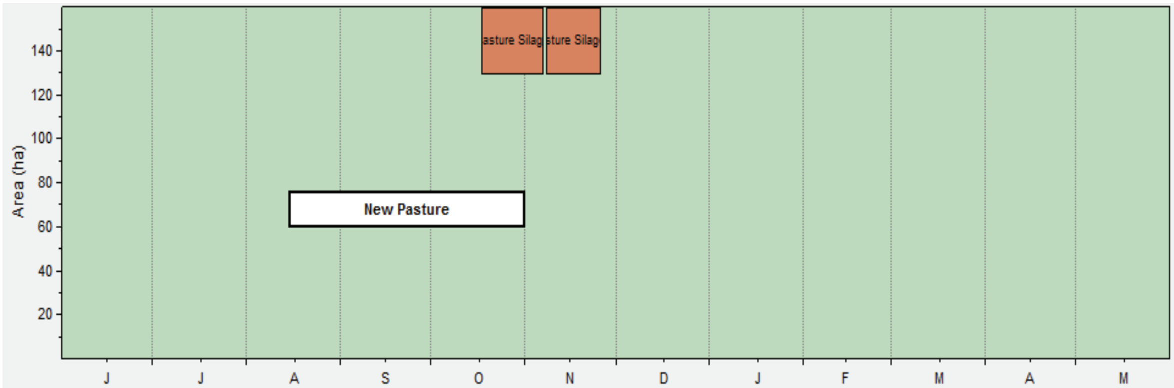


Figure 12: Land use for existing system

The sowing and harvesting dates of the feed crops shown in Table 8 were used to model the proposed systems on FARMAX®. As with regrassing the existing system, it was assumed there would be two weeks from spraying out old pasture until the sowing date. After harvest or final grazing, it was also assumed there would be two months until the first grazing of the re-sown pasture. An exception to this is for the autumn grazed fodder beet. It was assumed the final grazing at the end of May would be too late in the season to regrass before winter. The area was left fallow and regrassed in mid-August and grazed from mid-October.

Table 8: Timing of crop rotations

Crop	Spray out	Sowing date	Harvest date	Date of first pasture grazing
Fodder beet (spring grazed)	1 Dec	15 Dec	Aug-Nov	31 Jan
Fodder beet (autumn grazed)	1 Oct	15 Oct	Mar-May	15 Oct
Fodder beet (harvested)	1 Nov	15 Nov	31 Sep	31 Nov
Maize silage	15 Sep	1 Oct	30 Apr	-
Oats silage	-	15 May	31 Oct	31 Dec
Wheat (grain)	1 Apr	15 Apr	15 Mar	15 May

Fodder beet in Canterbury is typically sown in November (DLF Seeds Ltd, 2014). The spring grazed fodder beet was later-sown in mid-December so that feed quality would be maintained until the final grazing in November. The autumn grazed fodder beet was sown two months earlier in mid-October to maximise the growing period before the start of grazing in March. Figure 13 shows how this was modelled on FARMAX®. The spring grazed fodder beet effectively takes pasture out of the feed supply at the beginning of December. At the end of the following January (first grazing), this area begins to contribute to pasture supply. The diagram shows that the autumn grazed crop was sown two months earlier. Two pasture silage harvests of 30 ha each were made in October and November.

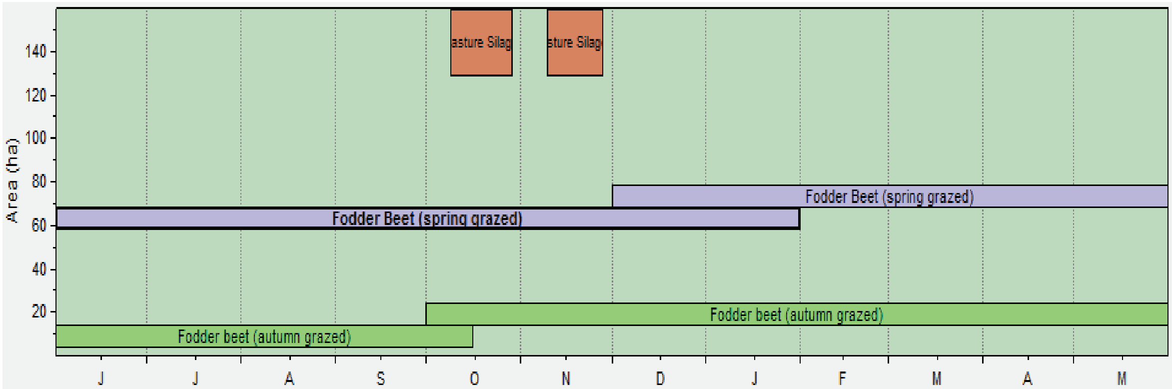


Figure 13: Land use for fodder beet scenario

The rotation for the maize/oat silage scenario was 13 months. Pasture was sprayed out in mid-September for sowing at the beginning of October (Figure 14). The maize was harvested at the end of April and was followed by whole crop oats. The harvest date of the oats was the end of October and the first grazing at the end of December following regrassing. The area of pasture silage harvested was reduced to two harvests of 20 ha. This was because of the greater length of time the cropping area remains out of pasture. From mid-September to December, there is effectively 40 ha out of the grazing rotation. The silage area was reduced to avoid the pasture cover from decreasing excessively during these months.

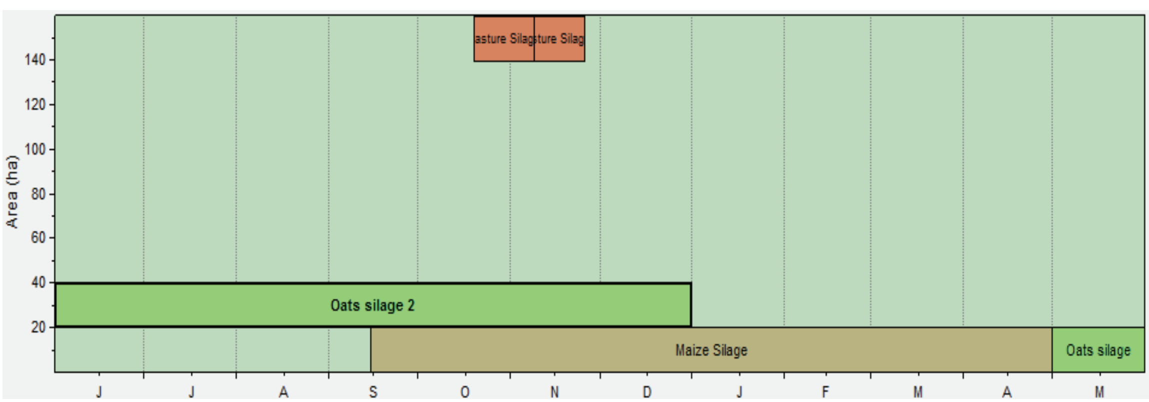


Figure 14: Land use for maize/oats silage scenario

Figure 15 and Figure 16 show the crop rotation for the wheat (fed) and wheat (sold) scenarios respectively. Pasture was initially sprayed out at the beginning of April and sown mid-April. The harvest date was mid-March; resulting in a mid-May return to pasture grazing. Both the wheat (fed) and wheat (sold) scenarios have the same land use, except the wheat (sold) scenario has one additional pasture silage harvest on 30 ha in December. This was in response to the low APC during

April and May as a result of 40 ha being out of the grazing rotation during April until mid-May. The additional silage was used to supplement the significant feed deficit during this time. In contrast, the wheat (fed) scenario had grain supplementation that supported the APC.

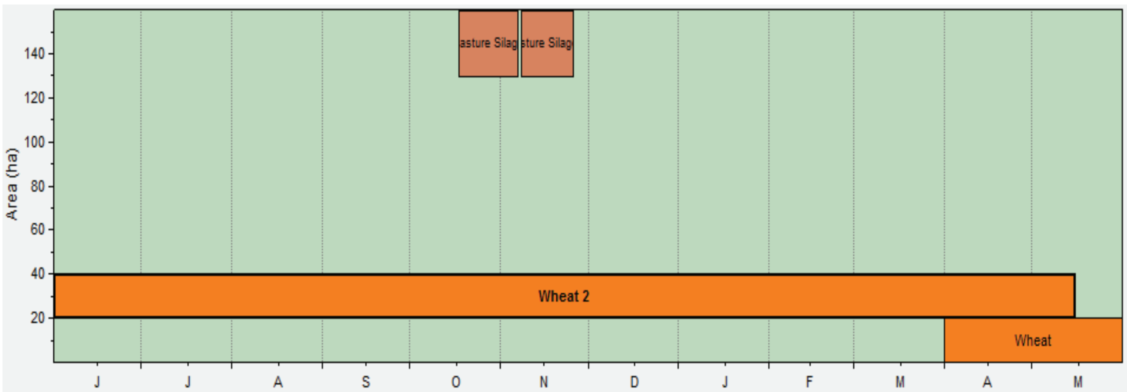


Figure 15: Land use for wheat (fed) scenario

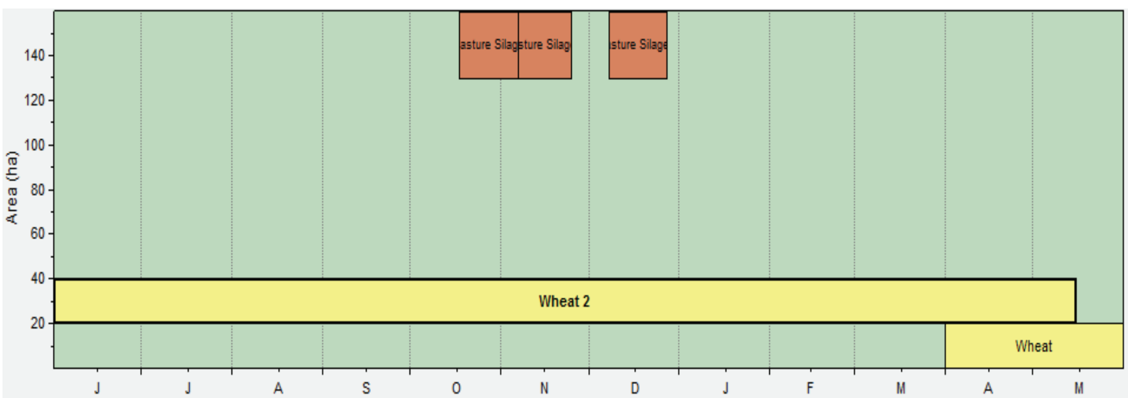


Figure 16: Land use for wheat (sold) scenario

The optimised scenario incorporated expanded areas of spring and autumn grazed fodder beet (11.7 and 13.3 ha respectively) as shown in Figure 17. Harvested fodder beet was grown on 8.9 ha. The harvested crop had a sowing date of mid-November and was harvested at the end of September the following year. The spring and autumn grazed fodder beet had the same sowing and grazing dates as the initial fodder beet scenario of 20 ha. The area pasture silage made on-farm was slightly reduced to two harvests of 25 ha during October and November.

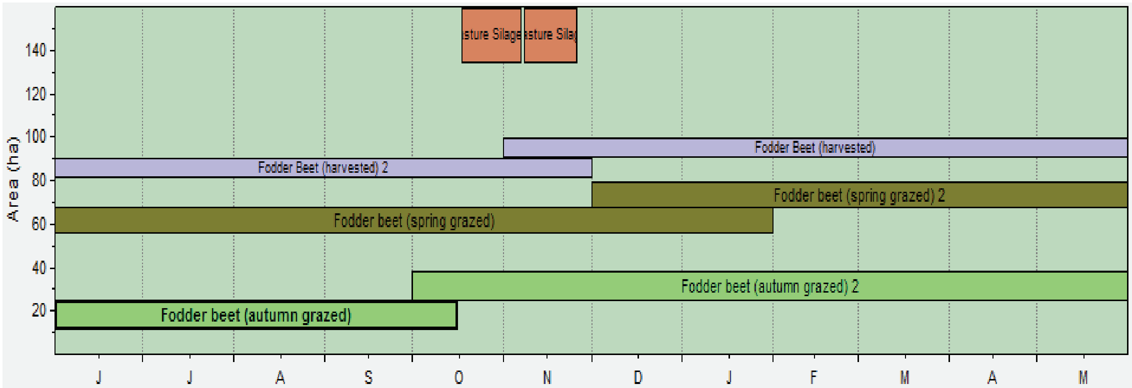


Figure 17: Land use for the optimised scenario

3.5.1.2 Financial assumptions

Milk solids income for the initial financial projections was based on a milk payout of $6.00/kg MS. The budgeted expenditure on the LUDF for the 2014/2015 season (SIDDC, 2015d) was used to calculate the variable expenses dependent on cow numbers (such as animal health and breeding). The cost of regrassing was calculated at $489/ha for the existing system (Appendix 5). For the cropping scenarios where regrassing occurs post-harvest or grazing, the cost of spraying out pasture was not included ($424/ha in total). All fixed costs such as administration, rates and insurance were based on the 2014/2015 LUDF budget. The cost of N fertiliser was based on the current price of urea and $12/ha for cartage and spreading (Askin & Askin, 2012). The cost of non-N fertiliser was based on the budgeted figure for the LUDF, with an adjustment made for the proposed scenarios based on the remaining area of pasture. The cost of non-N fertiliser for the crops was included in the budgeted crop expenditure (Appendix 1 to 4). Adjustments were made for the increase in machinery costs for the feeding out of maize and oats silage and harvested fodder beet. The cost of grazing included the heifer calves, rising one-year-old heifers and winter grazing of rising two-year-old and mixed-aged cows. It was assumed wages would not increase or decrease for any of the scenarios. Pasture silage was imported at 42 cents/kg DM and was made on-farm for $340/ha.

3.5.2 Linear programming

Linear programming is a method used to optimise farm systems to maximise operating profit (Rendel, Mackay, Manderson & O'Neill, 2013). A model was created on Microsoft® Office Excel™ that determined the optimum area of pasture, maize/oats silage, autumn and spring grazed fodder beet, harvested fodder beet and wheat for feed or sales. The model was based on the gross margins per hectare of each land use based on their DM yield, ME content and utilisation rate. The monthly ME requirements per cow were calculated for maintenance, pregnancy, walking and lactation as specified by Nicol and Brookes (2007). The ME required for milk synthesis was assumed to be 76 MJ ME/kg MS

(Holmes & Roche, 2007). This data was used to calculate the average FCR on an MJ ME basis for the herd as a whole, assuming average production per cow of 500 kg MS/cow. This equated to 125.8 MJ ME/kg MS. Assuming 12.3 MJ ME/kg DM, this results in a FCR of 10.2 kg DM/kg MS on a feed utilised basis.

The ME supply from feed crops was based on their expected DM yields, ME content and utilisation rate, as specified in Table 7. The ME supply from pasture was based on the quantity of pasture utilised for the existing system as calculated by FARMAX® shown in Table 14 (14.8 t DM/ha). This figure does not include the 120 t DM of pasture silage made on-farm, therefore an additional 0.7495 t DM/ha was included in the total pastoral yield (15.55 t DM/ha in total). A non-weighted average of the monthly pasture quality used by FARMAX® (Table 6) was calculated at 12.3 MJ ME/kg DM for the linear programme.

The model calculated the expected gross margin for each land use option. Gross income was calculated using the expected milk production less the direct, variable costs of feed production. The variable costs of pasture and crop production include establishment costs, fertiliser, weed and pest control, pasture renewal and irrigation. The cost assumptions were the same used for the FARMAX® simulations. Fixed costs, such as administration, were not included as they do not directly influence DM or milk production (Rendel et al., 2013).

A sensitivity analysis identified the optimal land use under different milk payouts. The milk price paid to farmers has been very volatile during recent years. Fonterra suppliers received a record payout of $8.65/kg MS during the 2013/2014 season, compared with $4.25 to $4.35/kg MS forecasted for the 2015/2016 season as at August 7, 2015 (Fonterra, 2015). Low milk payouts ranging from $2.50/kg MS to $5.00/kg MS were used for the analysis.

A major assumption was that ME is the limiting nutrient to milk production throughout the year. The model may have overestimated milk production if CP in the diet was limiting during periods where fodder crops are a large proportion of the diet. Microsoft® Office Excel ™ allowed for constraints to be placed on the total area of crops which were necessary to reduce the likelihood of CP deficiency. Constraints were placed on the area of crop based on maximum area that could be grown so that daily intake did not exceed recommended levels.

3.5.3 Overseer ™ (6.2.0)

3.5.3.1 Introduction

Overseer ™ (version 6.2.0) was used to compare the N leaching of the proposed systems with the current system. It is a nutrient budgeting software that calculates farm outputs of nitrogen, phosphorous and other macronutrients. The software is a simulation based on inputted milk production, livestock, fertiliser regime and soil type data. It is commonly used on New Zealand dairy farms to create fertiliser recommendations and has recently been made mandatory for all farms in the Canterbury region to model N leaching (Environment Canterbury, 2014a). The N leaching will be modelled for the cropping area, the remaining pastoral area and the entire farm as a whole.

The accuracy of the model is uncertain, however an older version in 2001 was found to have accuracy within +/- 30% (AgResearch, 2013). The software has been updated many times since then and likely has greater accuracy. Ledgard et al. (2006) found that the N leaching per hectare predicted by Overseer ™ for four different systems was very similar to that measured on-farm by collecting leachate 90cm below the soil surface (Figure 18). Despite continued concerns about the accuracy of the model, it is considered to be the best nutrient management tool available for New Zealand conditions and will continue to be mandatory for Canterbury farms.

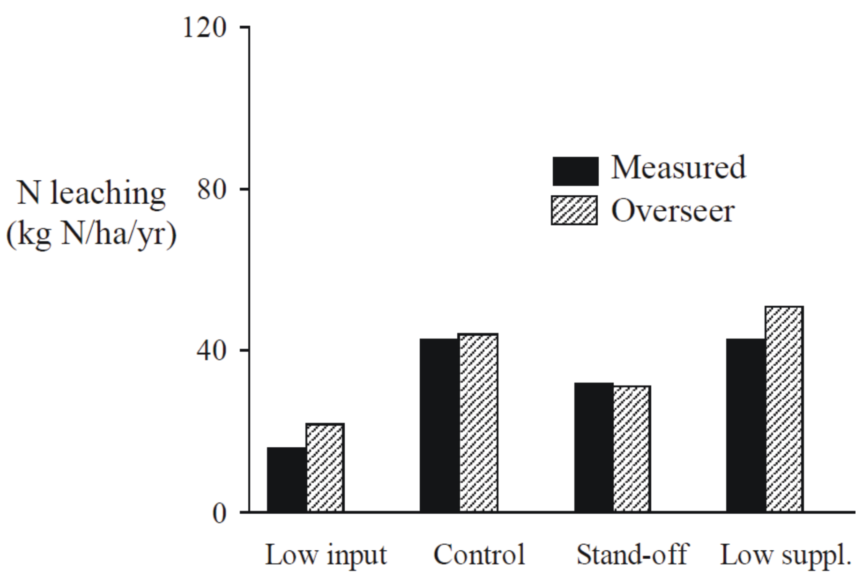


Figure 18: Nitrogen leaching measured on-farm and as modelled by Overseer ™ (Ledgard et al., 2006).

While this study will focus on N leaching, there are other environmental concerns such as methane and nitrous oxide. These gases contribute 54.8% of New Zealand's annual greenhouse gas (GHG) emissions (Saggar, Tate, Giltrap & Singh, 2008). Livestock are the main emitters of methane in New

Zealand, while urine patches are a major source of nitrous oxide. Further research needs to be done to determine whether integrating forage crops will increase or decrease the GHG emissions of the system.

3.5.3.2 Current and proposed systems

The LUDF has a range of soil types with varied susceptibility to N leaching. Table 9 shows the areas and drainage class of each soil type that were used to model each system on Overseer ™. The main soil type is Templeton silt loam (72.0 ha) which is moderately well drained. Wakanui silt loam (48.1 ha) is imperfectly drained. The Temuka silty clay (32.0 ha) is a poorly drained soil and less prone to leaching than the other soils. There is a small area (8.0 ha) of Eyre sandy loam on the north side of the farm which is well drained and more prone to leaching. This soil class also has a stony matrix in the subsoil which increases the leaching potential.

Table 9: Soil type on the LUDF

Soil type	**Area (ha)**	**Drainage class**
Templeton silt loam	72.0	Moderately well
Wakanui silt loam	48.1	Imperfect
Temuka silty clay	32.0	Poor
Eyre sandy loam	8.0	Well
Total	**160.1**	

For the 2014/2015 season, effluent was applied on 34.0 ha. Table 10 shows the individual farm blocks for the existing system based on soil type and whether effluent was applied. All blocks are irrigated by centre-pivot, except for 24.6 ha irrigated by long laterals and 10.0 ha of K-line irrigation. Native trees have been planted on 1.0 ha of Templeton silt loam and 1.0 ha of Wakanui silt loam. Total block area for the model was 162.1 ha, of which 160.1 ha was effective. Total farm area, including 4.7 ha non-productive area (including lanes and yards), was 166.8 ha.

Table 10: Farm blocks for existing system

Block name	**Area (ha)**
Wakanui - effluent	4.3
Eyre - effluent	3.0
Templeton - effluent	26.7
Temuka - non effluent	17.4
Wakanui - non effluent	30.3
Eyre - non effluent	5.0
Templeton - non effluent	38.8
Trees - Templeton	1.0
Trees - Wakanui	1.0
Templeton - Nth Long laterals	2.9
Temuka - long laterals	4.6
Temuka - K lines	10.0
Wakanui - long laterals	13.5
Templeton - Sth long laterals	3.6
Total declared as blocks	**162.1**
Non-productive area	4.7
Total farm area	**166.8**

The 38.8 ha Templeton (non-effluent) block was used modelling the cropping blocks. Fodder beet in particular performs better in light, well-drained soil (Specialty Seeds Ltd, n.d.; DLF Seeds Ltd, 2014). Templeton silt loams are moderately well drained and were deemed most suitable for the cropping blocks. For proposed scenarios using 20 ha of crop, the Templeton (non-effluent) block was reduced to 18.8 ha and additional cropping blocks added into the system. For the optimised scenario, this block was reduced to 4.9 ha and the three additional fodder beet blocks were created. For consistency between scenarios, it was assumed that all silage made on-farm was made on the Wakanui (non-effluent) block and spread evenly across all pastoral blocks. Milk production data and monthly stock numbers were derived from the outputs calculated by FARMAX®.

Chapter 4:
Economic Analysis

4.1 Introduction

This chapter reviews the results of the economic analysis of this study. The operating profit of the existing farm system, the four proposed farm scenarios and the optimised scenario was modelled on FARMAX® Professional Dairy. The physical and financial performance of the existing and four proposed systems are detailed in section 4.2 and 4.3. The performance of the optimised system has been detailed separately in section 4.4. The financial budget for each system was assuming a milk payout of $6.00/kg MS. A sensitivity analysis has also compared the effect of milk payout on the suitability of each scenario. Section 4.6 details the optimum land use calculated by the linear programme.

4.2 Physical performance

4.2.1 Milk production and stocking rate

Table 11 shows the results modelled by FARMAX®. The milk production of the existing system was 1,779 kg MS/ha, which is similar to the budgeted production for the 2014/2015 season on the LUDF of 1,750 kg MS (SIDDC, 2015d). Among the proposed systems, the fodder beet scenario had significantly greater MS production at 1,989 kg MS/ha; 210 kg MS/ha greater than the existing system. The maize/oats silage and wheat (fed) scenarios had similar production to the existing, at 1,795 and 1,785 kg MS/ha respectively. At 1,566 kg MS/ha, the wheat (sold) scenario had significantly lower MS production than the other scenarios. The fodder beet scenario also had the greatest production per cow at 524 compared with 511 kg MS for the existing. Production per cow was lowest for the wheat (fed) scenario at 505 kg MS/cow, however this was offset by a small increase in stocking rate compared with the existing (3.54 and 3.49 cows/ha respectively), resulting in similar production per hectare. The stocking rate was greatest for the fodder beet scenario at 3.80 cows/ha, contributing to the large increase in MS/ha. Stocking rate was lowest in the wheat (sold) scenario at 3.05 cows/ha.

Table 11: Physical performance

	Existing	Fodder beet	Maize/oats silage	Wheat (fed)	Wheat (sold)
Peak Cows Milked	558	608	567	566	489
Stocking Rate	3.49	3.80	3.54	3.54	3.05
Milk Solids total (kg)	284,886	318,478	287,432	285,848	250,792
Milk Solids per ha (kg)	1,779	1,989	1,795	1,785	1,566
Milk Solids per cow (kg)	511	524	507	505	513

Figure 19 shows the daily milk production per cow during the season for each scenario. The maximum daily production was achieved on the fodder beet scenario at 2.74 kg MS/cow/day. The graph shows that production is greater during the last three months of lactation.

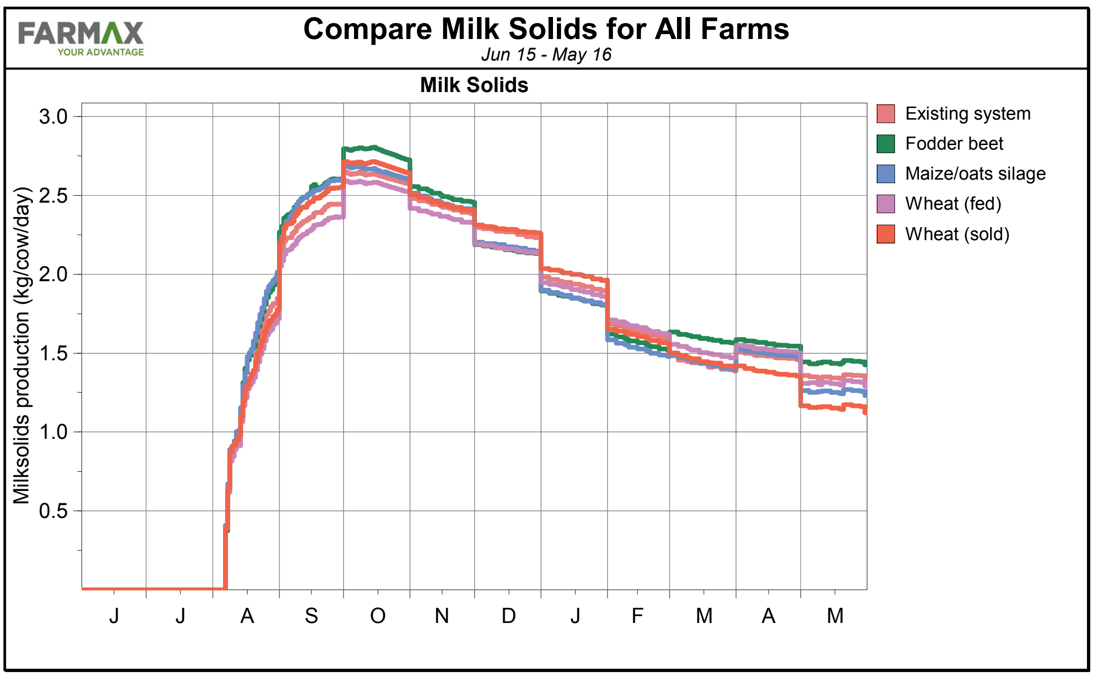


Figure 19: Daily milk production per cow by month

4.2.2 Feed intake and feed conversion ratio

4.2.2.1 Feed offered

The milk production from each system is influenced by the total feed consumed and the feed conversion ratio (FCR). Table 12 and Table 14 show the total feed offered and eaten respectively for each system. This includes pasture, supplements (feed crops and pasture silage made on-farm and imported) and off-farm grazing. The off-farm grazing only included the feed offered to cows greater than 20 months old, excluding young stock. All figures are based on an effective farm area of 160.1

ha, unless otherwise stated. Potential pasture growth was 18.9 t DM/ha for all systems. As expected, the existing system had the greatest pasture offered per effective hectare at 15.2 t DM/ha. The pasture offered is the total amount of pasture actually allocated during the season and was always less than the potential production. The feed crop scenarios had reduced pasture offered per effective hectare as a result of reduced pastoral area. However, when only the pastoral area is considered, the pasture offered was greater for the fodder beet and wheat (fed) scenarios at 15.4 and 16.0 t DM/ha respectively. The maize/oats silage and wheat (sold) scenarios had less pasture offered than the existing system at 14.7 and 14.9 t DM/ha respectively.

Table 12: Feed offered

Description	**Existing**	**Fodder beet**	**Maize/oats silage**	**Wheat (fed)**	**Wheat (sold)**
Pasture Offered per effective ha (t DM/ha)	15.2	13.5	12.9	14.0	13.1
Pasture offered per pastoral ha (t DM/ha)	15.2	15.4	14.7	16.0	14.9
Supplements Offered per ha (t DM/ha)	1.8	5.4	5.6	3.0	2.1
Off-farm Grazing Offered per ha (t DM/ha)	5.0	5.5	5.4	5.2	4.4
Total feed offered (t DM/ha)	22.0	24.4	23.9	22.2	19.6
Supplements and Grazing / Feed Offered (%)	30.9	44.7	46.0	36.9	33.2

Supplements offered per hectare was the greatest for the maize/oats silage scenario at 5.6 t DM/ha (Table 12), reflecting the superior yield of the double cropping rotation of 32.0 t DM/ha. The fodder beet scenario had 5.4 t DM/ha of supplements offered, which was substantially greater than the existing and wheat scenarios. This reflects the high yields of fodder beet (average of 26.5 t DM/ha) compared with wheat (11.0 t DM/ha) and also the additional silage imported due to a higher stocking rate than the other scenarios (Table 13). The wheat (sold) scenario had 2.1 t DM/ha of supplements offered per hectare which is slightly greater than the existing system due to an additional 60 t DM/ha of silage made on-farm. Total feed offered was greatest on the fodder beet system at 24.4 t DM/ha. The feed from supplements and grazing compared as a proportion of total feed offered was 44.7% for the fodder beet scenario compared with 30.9% for the existing system. The maize/oats silage scenario had the highest proportion of 46.0%. However, the low pasture offered per hectare for the maize/oats system resulted in a lower total quantity feed offered (23.9 t DM/ha) compared with the fodder beet scenario (24.4 t DM/ha). Table 13 shows the total quantity of pasture silage imported for each system. Imported silage was 300 kg DM/cow for all scenarios, so the total amount imported reflects the stocking rate for each scenario.

Table 13: Pasture silage imported

Scenario	Silage imports
	(t DM)
Existing system	167
Fodder beet	182
Maize/oats silage	170
Wheat (fed)	170
Wheat (sold)	147

4.2.2.2 Feed eaten

Table 14 shows the quantity of feed eaten for each scenario and takes into account the utilisation rate of the pasture and supplements offered. The total pasture eaten on the existing system was 14.8 t DM/ha, which is very similar to the estimated pasture consumed on the LUDF for the 2013/2014 season of 14.9 t DM/ha (SIDDC, 2015d). The amount pasture eaten per pastoral hectare was greater on the fodder beet and wheat (fed) scenarios (15.1 and 15.5 t DM/ha respectively). The effect of utilisation rate is shown by the amount of feed eaten from supplements and grazing as a proportion of total feed eaten. The amount of supplements and grazing (including feed crops) as a proportion of total feed consumed was the greatest for the fodder beet scenario (42.0%) compared with 41.1% for the maize/oats silage system. Although fodder beet has lower DM yields, the utilisation rate is significantly greater (95%) than maize/oats silage (75%).

The total feed eaten as a proportion of total feed offered metric is essentially a weighted average utilisation rate for all of the sources of feed offered. The maize/oats silage system had the lowest overall utilisation rate of 89.5%, as a result of the high wastage rate of maize and oats silage. The highest utilisation rate was the existing and wheat (fed) scenarios; with 93.2% of feed consumed.

Table 14: Feed eaten

Description	Existing	Fodder beet	Maize/oats silage	Wheat (fed)	Wheat (sold)
Pasture Eaten per effective ha (t DM/ha)	14.8	13.2	12.6	13.6	12.7
Pasture eaten per pastoral ha (t DM/ha)	14.8	15.1	14.4	15.5	14.5
Supplements Eaten per ha (t DM/ha)	1.4	4.7	4.2	2.6	1.6
Off-farm Grazing Eaten per ha (t DM/ha)	4.3	4.8	4.6	4.5	3.8
Total Feed Eaten per ha (t DM/ha)	20.5	22.6	21.4	20.7	18.1
Supplements and Grazing / Feed Eaten (%)	27.8	42.0	41.1	34.3	29.8
Total Feed Eaten/Total Feed Offered (%)	93.2	92.6	89.5	93.2	92.3

4.2.2.3 Feed conversion ratio

The FCR for each scenario is shown in Table 15 on the basis of total feed offered and total feed eaten. The FCR on a feed eaten basis is based on the MJ ME content of the feed. On a feed offered basis, the utilisation rate is also taken in account. The fodder beet scenario had the lowest FCR, or greatest feed conversion efficiency, on both a feed offered and eaten basis (11.2 and 10.4 kg DM/kg MS respectively). In contrast, the maize/oats silage scenario had the highest FCR at 12.2 and 10.9 kg DM/kg MS on a feed offered and feed eaten basis respectively. The wheat (fed) scenario had the same FCR to the existing scenario at 11.3 and 10.5 kg DM/kg MS on a feed offered and feed eaten basis respectively.

Table 15: Feed conversion ratio

Feed conversion ratio	Existing	Fodder beet	Maize/oats silage	Wheat (fed)	Wheat (sold)
Feed offered (kg DM/kg MS)	11.3	11.2	12.2	11.3	11.4
Feed eaten (kg DM/kg MS)	10.5	10.4	10.9	10.5	10.5

4.3 Financial performance

FARMAX® was used to create a financial budget for each scenario (Table 16), assuming a milk solids payout of $6.00/kg MS.

4.3.1 Net cash income and operating profit

The operating profit was greatest for the fodder beet scenario at $4,782/ha compared with the existing system at $3,984/ha. All the other proposed scenarios were less profitable than the existing at $3,563, $3,856 and $3,461/ha for the maize/oats silage, wheat (fed) and wheat (sold) scenarios respectively. Net cash income (NCI) per hectare was greatest for the fodder beet scenario at $12,228/ha compared with $10,936/ha for the existing. NCI for the maize/oats silage and wheat (fed) scenarios was $11,047 and $10,996/ha respectively; slightly greater than the existing. The wheat (sold) scenario had total income of $10,184/ha; substantially less than the other scenarios.

4.3.2 Expenses

The range of farm working expenses (FWE) between each scenario was narrower than the range of NCI. The maize/oats silage scenario had the greatest FWE at $7,484/ha, followed closely by the fodder beet scenario at $7,446/ha and then wheat (fed) at $7,140/ha. The wheat (sold) scenario was the only system that had lower FWE than the existing system ($6,723/ha and $6,953/ha respectively). A major cost for the maize/oats silage scenario was feed crop costs of $80,090. The cost of feed crops were significantly less for the fodder beet and wheat scenarios at $40,137 and $29,407 respectively. The cost of non-N fertiliser was the greatest for the existing system at $47,507 compared with $41,572 for the proposed scenarios. This is because all fertiliser expenditure on crops was included in crop expenses. Grazing was largest expense for all scenarios and was greatest for the fodder beet scenario at $346,368, as result increased stocking rate. Other variable expenses were also greatest for this scenario, such as animal health, breeding and electricity.

Table 16: Financial budget

	Existing ($)	**Fodder beet ($)**	**Maize/oats silage ($)**	**Wheat (fed) ($)**	**Wheat (sold) ($)**
Income					
Milk solids income	1,699,633	1,900,037	1,714,821	1,705,369	1,496,233
Net Livestock Sales	51,279	57,700	53,868	55,076	46,211
Surplus Feed	0	0	0	0	88,000
Net cash income	1,750,912	1,957,737	1,768,689	1,760,445	1,630,444
Net cash income/ha	10,936	12,228	11,047	10,996	10,184
Farm working expenses					
Wages	259,884	259,884	259,884	259,884	259,884
Animal Health	53,955	58,806	54,747	54,945	47,619
Breeding	41,965	45,738	42,581	42,735	37,037
Farm Dairy	9,810	10,692	9,954	9,990	8,658
Electricity	37,060	40,392	37,604	37,740	32,708
Pasture Conserved	20,400	20,400	13,600	20,400	30,600
Feed Crop	0	40,137	80,090	29,407	29,407
Bought Feed	70,131	76,440	71,442	71,391	61,732
Calf Feed	5,450	5,940	5,530	5,550	4,810
Grazing	316,888	346,368	323,963	323,754	276,491
Fertiliser (Excl. N)	47,507	41,572	41,572	41,572	41,572
Nitrogen	39,607	34,659	33,310	34,659	34,648
Irrigation	70,600	70,600	70,600	70,600	70,600
Regrassing	7,825	8,480	8,480	8,480	8,480
Weed & Pest Control	500	500	500	500	500
Vehicle Expenses	31,336	31,336	44,146	31,336	31,336
R&M Land/Buildings	13,625	13,625	13,625	13,625	13,625
R&M Plant/Equipment	40,875	40,875	40,875	40,875	40,875
Administration Expenses	24,700	24,700	24,700	24,700	24,700
Rates and Insurance	21,020	21,020	21,020	21,020	21,020
Total farm working expenses	1,113,138	1,192,164	1,198,223	1,143,163	1,076,302
Farm working expenses/ha	6,953	7,446	7,484	7,140	6,723
Operating profit	637,774	765,573	570,466	617,282	554,142
Operating profit/ha	3,984	4,782	3,563	3,856	3,461

4.4 Optimised system

The analysis showed that incorporating 10 ha each spring and autumn grazed fodder beet on the LUDF increased operating profit by 20.0%. The other cropping alternatives resulted in reduced profitability. As discussed in section 3.4, an additional simulation was created on FARMAX® to model the maximum area of fodder beet that could be grown when daily intakes were maximised. Table 17 shows the maximum areas of fodder beet that could be grown on the LUDF were 13.3, 11.7 and 8.9 ha of autumn grazed, spring grazed and harvested fodder beet respectively. This equates to 33.9 ha of fodder beet, or 21.2% of effective farm area.

Table 17: Optimised land use

Land use	**Area (ha)**
Pasture	126.2
Fodder beet (autumn grazed)	13.3
Fodder beet (spring grazed)	11.7
Fodder beet (harvested)	8.9
Total	**160.1**

4.4.1 Physical performance

The additional dry matter produced allowed for a significant increase in stocking rate to 3.96 cows/ha as shown in Table 18. Production per cow was increased to 543 kg MS/cow and production per hectare increased significantly to 2,149 kg MS/ha. Figure 20 shows the daily milk production during early and late lactation was greater than all the other scenarios. Daily milk production peaked at 2.78 kg MS/cow/day during October.

Table 18: Physical performance of optimised system

Peak Cows Milked	634
Stocking Rate	3.96
Milk Solids total (kg)	344,117
Milk Solids per ha (kg)	2,149
Milk Solids per cow (kg)	543

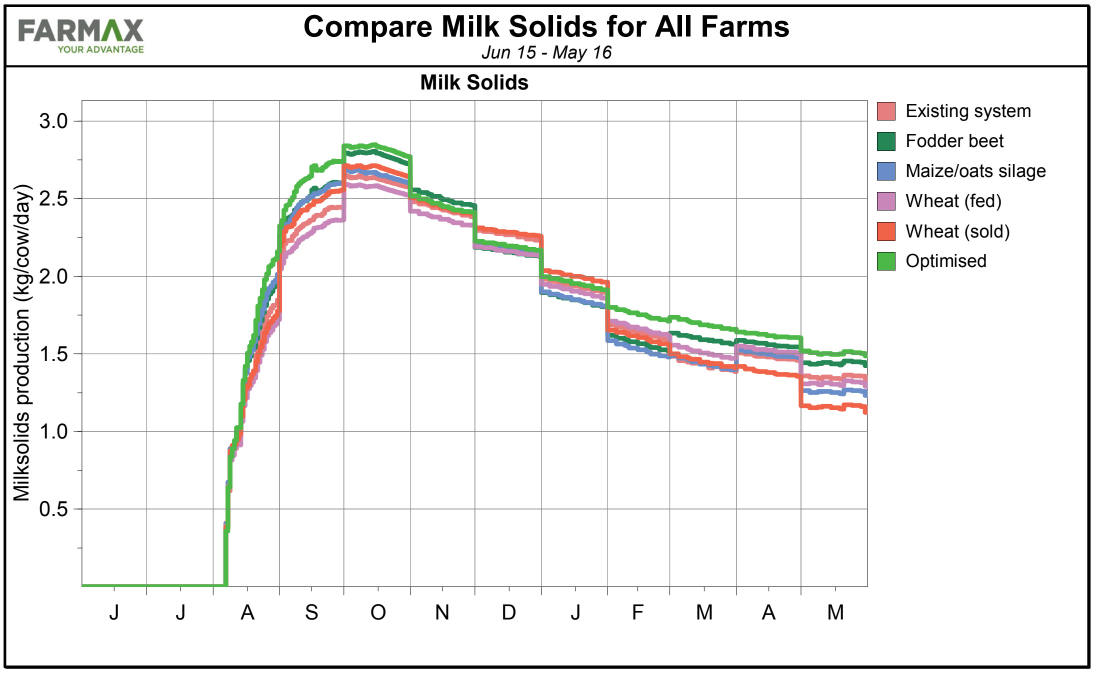


Figure 20: Daily milk production per cow by month

The total pasture offered per effective hectare was 12.8 t DM/ha, as shown in Table 19. This was the lowest compared with the other scenarios, because of the increased crop area. However, on a pastoral hectare basis, the total pasture offered was the greatest at 16.2 t DM/ha. Supplements offered per hectare were also the greatest for this scenario at 7.4 t DM/ha due to increased use of fodder beet. Increased stocking rate lead to additional imported pasture silage, totalling 190 t DM. Feed offered during winter grazing was the greatest at 5.8 t DM/ha due to having the highest stocking rate. Total feed offered was 25.9 t DM/ha, which was 1.5 and 3.9 t DM/ha greater than the fodder beet (20 ha) and existing scenarios respectively. The feed offered as supplements and grazing as a proportion of total feed offered was 51.0%; the only scenario with less than half of the total feed offered being pasture.

On a feed eaten basis, the results have a similar trend as on a feed offered basis. Pasture eaten per pastoral hectare was the greatest at 15.7 t DM/ha. Intakes of supplements and from winter grazing were also the highest for this scenario at 6.6 and 5.0 t DM/ha respectively. The proportion of feed eaten to total feed offered was almost as high as the existing and wheat (fed) scenarios at 93.1%. The FCR was superior for this system both on a feed offered and eaten basis at 11.0 and 10.2 kg DM/kg MS respectively.

Table 19: Feed offered, feed eaten and feed conversion ratio for optimised scenario

Feed offered	
Pasture Offered per ha (t DM/ha)	12.8
Pasture Offered per pastoral ha (t DM/ha)	16.2
Supplements Offered per ha (t DM/ha)	7.4
Off-farm Grazing Offered per ha (t DM/ha)	5.8
Total Feed Offered per ha (t DM/ha)	25.9
Supplements and Grazing / Feed Offered (%)	51.0
Feed eaten	
Pasture Eaten per ha (t DM/ha)	12.4
Pasture eaten per pastoral ha (t DM/ha)	15.7
Supplements Eaten per ha (t DM/ha)	6.6
Off-farm Grazing Eaten per ha (t DM/ha)	5.0
Total Feed Eaten per ha (t DM/ha)	24.1
Supplements and Grazing eaten / Feed Eaten (%)	48.1
Total Feed Eaten / Total Feed Offered (%)	93.1
Feed conversion ratio	
Feed Offered (kg DM/kg MS)	11.0
Feed Eaten (kg DM/kg MS)	10.2

4.4.2 Financial performance

The increased production increased NCI to $13,210/ha as shown (Table 20); 20.8% greater than the existing system. FWE increased by 12.8% to $7,842/ha. The operating profit significantly increased to $5,368/ha; a 34.8% increase compared with the existing.

The fodder beet costs, including harvesting on 8.9 ha, amounted to $79,246. This is similar to the maize/oats silage scenario at $80,090. The second largest increase in expenditure was grazing, which increased by $44,739. Expenses that are affected by cow numbers, such as animal health, breeding, farm dairy and electricity increased by 13.4%, due to the increased stocking rate. Imported pasture silage costs increased by $9,669 to maintain allocations at 300 kg DM/cow. Regrassing costs increased by $6,549 as an additional 17.9 ha was regrassed. Vehicle expenses increased by $3,864 as a result of feeding out the harvested fodder beet.

Table 20: Financial budget for optimised system

	Optimised system ($)
Income	
Milk solids income	2,053,000
Net Livestock Sales	61,852
Surplus Feed	0
Total net cash income	2,114,852
Net cash income/ha	13,210
Farm working expenses	
Wages	259,884
Animal Health	61,182
Breeding	47,586
Farm Dairy	11,124
Electricity	42,024
Pasture Conserved	17,000
Feed Crop	79,246
Bought Feed	79,800
Calf Feed	6,180
Grazing	361,627
Fertiliser (Excl. N)	37,448
Nitrogen	31,439
Irrigation	70,600
Regrassing	14,374
Weed & Pest Control	500
Vehicle Expenses	35,200
R&M Land/Buildings	13,625
R&M Plant/Equipment	40,875
Administration Expenses	24,700
Rates and Insurance	21,020
Total farm working expenses	1,255,434
Farm working expenses/ha	7,842
Operating profit	859,418
Operating profit/ha	5,368

4.5 Susceptibility to risk

4.5.1 Cost of production

The cost of production ranged considerably between each scenario. Table 21 shows the cost of production of the existing system, the four proposed cropping scenarios and the optimised system.

The lowest cost of production of $3.65/kg MS was achieved with the optimised system. This was followed by the fodder beet (20ha) and existing system at $3.74 and $3.91/kg MS respectively. The other feed crop scenarios had significantly greater cost of production. The maize/oats silage and wheat (fed) scenarios were $4.17 and $4.00/kg MS respectively. The highest cost of production was calculated on the wheat (sold) scenario at $4.29/kg MS. However, this does not account for the fact the wheat was sold, rather than used for milk production.

The proportion of FWE to NCI followed a similar pattern to the cost of production. The optimised system had the lowest ratio of 59.4%, followed closely by the fodder beet (20 ha) at 60.9%. The existing system had a ratio of 63.6%, while the maize/oats silage scenario had the highest at 67.7%. The wheat (fed) and wheat (sold) scenario had a ratio of 64.9 and 66.0% respectively. The wheat (sold) had a lower ratio than the maize/oats silage scenario, as this metric accounted for the wheat sales in the NCI.

Table 21: Cost of production and FWE/NCI

System	**Cost of production**	**FWE/NCI**
	($/kg MS)	(%)
Existing	3.91	63.6
Fodder beet	3.74	60.9
Maize/oats silage	4.17	67.7
Wheat (fed)	4.00	64.9
Wheat (sold)	4.29	66.0
Optimised	3.65	59.4

4.5.2 Sensitivity analysis

The suitability of the proposed strategies compared with the existing system at different milk payouts is shown in Table 22. At $6.00 to $8.00/kg MS, the ranking of scenario profitability from highest to lowest was the same: optimised, fodder beet (20 ha), existing, wheat (fed), maize/oats silage, and wheat (sold). At $8.00/kg MS, the optimised scenario had an operating profit of $9,667/ha compared with $7,542/ha for the existing.

At a lower milk payout of $5.00/kg MS, the most profitable system was still the optimised system at $3,219/ha, followed in descending order by the fodder beet scenario, existing and wheat (fed) scenario. However, at this milk price, the wheat (sold) was more profitable than the maize/oats silage scenario, at $1,895/ha and $1,768/ha respectively.

At $4.00/kg MS, the optimised scenario still had a considerable profit advantage over the existing system. The operating profit was $1,069/ha; significantly greater than the existing scenario at $425/ha. The second and third most profitable systems were the fodder beet ($803/ha) and existing scenario respectively. The wheat (sold) system was the fourth most profitable system at $328/ha. The wheat (fed) system generated a profit of $285/ha, while the maize/oats silage scenario made a small operating loss of $27/ha.

Table 22: Sensitivity analysis (operating profit per hectare)

Scenario	**Milk price ($/kg MS)**				
	4.00	**5.00**	**6.00**	**7.00**	**8.00**
Existing	425	2,204	3,984	5,763	7,542
Fodder beet	803	2,793	4,782	6,771	8,760
Maize/oats silage	-27	1,768	3,563	5,359	7,154
Wheat (fed)	285	2,070	3,859	5,641	7,426
Wheat (sold)	328	1,895	3,461	5,028	6,594
Optimised	1,069	3,219	5,368	7,517	9,667

4.6 Linear programming

Linear programming was used to optimise the areas of the various crops at milk payouts ranging from $2.00 to $5.00/kg MS. Appendix 6 shows the gross margin for each land use option at $4.00/kg MS and the optimal land use for maximum overall gross margin. The gross margin of pasture was $5,024/ha, which was less than grazed and harvested fodder beet, although more than the other crops. From this, the model maximised the area of fodder beet to the areas used in the FARMAX® optimised scenario. Table 23 shows the optimised scenario had the greatest total gross margin at a milk payout of $4.00/kg MS or greater. At $3.00 to $3.50/kg MS, it was more profitable to replace the 8.9 ha of harvested fodder beet with pasture. At $2.50/kg MS, the gross margin was maximised by only growing spring grazed fodder beet.

Based on average production per cow of 500 kg MS and a replacement rate of 19.7%, the ME requirements for milk production for the herd as a whole was calculated at 125.80 MJ ME/kg MS. Assuming average feed quality of 12.3 MJ ME/kg DM, the FCR equates to 10.2 kg DM/kg MS on a feed eaten basis. This is the same FCR as calculated by FARMAX® for the optimised scenario.

The milk production calculated by the model was significantly less than when modelled by FARMAX®. With maximised fodder beet areas, production was 1,714 kg MS/ha. This decreased to 1,666 kg MS/ha when harvested beet was excluded and 1,611 kg MS/ha when only spring grazed fodder beet was grown.

Table 23: Optimum land use at various milk prices

	Milk price ($/kg MS)					
Land use area (ha)	**2.50**	**3.00**	**3.50**	**4.00**	**4.50**	**5.00**
Pasture	148.4	148.4	135.1	126.2	126.2	126.2
Maize/oats						
FB (spring grazed)	11.7	11.7	11.7	11.7	11.7	11.7
FB (autumn grazed)		13.3	13.3	13.3	13.3	13.3
FB (harvested)				8.9	8.9	8.9
Wheat (fed)						
Wheat (sold)						
Total	**160.1**	**160.1**	**160.1**	**160.1**	**160.1**	**160.1**
Milk production (kg MS/ha)	1,611	1,666	1,666	1,714	1,714	1,714
Gross margin ($/ha)	2,857	3,674	4,507	5,360	6,217	7,074

Chapter 5:
Environmental Analysis

5.1 Introduction

Overseer ™ (version 6.2.0) was used to calculate the N leaching of each system and identify the key sources of leaching. The farm inputs and outputs used for the nutrient budget were derived from the FARMAX® simulations.

5.2 Nitrogen losses by system

The N loss to water (leaching) for the existing system was calculated at 34 kg N/ha/year (Table 24). SIDDC modelled the farm using actual farm figures for the 2014/2015 season and the calculated leaching was found to be 35 kg N/ha, which was very similar to the results of this study. The highest leaching was projected for the optimised system at 44 kg N/ha. Among the 20 ha crop scenarios, the fodder beet and maize/oats silage scenario had the highest leaching, both at 41 kg N/ha. The wheat (fed) and wheat (sold) had leaching of 39 and 37 kg N/ha respectively.

Table 24: Nitrogen budget for whole farm

Nitrogen	**Existing**	**Fodder beet**	**Maize/ oats silage**	**Wheat (fed)**	**Wheat (sold)**	**Optimised**
(kg/ha/yr)						
Nutrients added						
Fertiliser, lime & other	137	134	137	135	135	133
Rain/clover N fixation	205	211	135	200	192	169
Irrigation	7	7	7	7	7	7
Supplements	29	32	30	50	26	33
Nutrients removed						
As products	125	140	126	151	135	150
Exported effluent	0	0	0	0	0	0
As supplements and crop residues	0	0	0	6	6	0
To atmosphere	140	147	118	142	134	144
To water	34	41	41	39	37	44
Change in plant pools						
Plant material	0	-4	7	-27	-27	-18
Organic pool	79	39	7	46	39	-11
Inorganic mineral	0	0	0	0	0	0
Inorganic soil pool	0	23	9	36	36	32

5.3 Nitrogen losses for cropping land

All forage crops were grown on the non-effluent Templeton soil block. Table 25 and Table 26 show the nitrogen budget for this block for the existing system and individual cropping blocks. For the existing system, this block had N loss to water of 34 kg N/ha; the same as for the farm as a whole. The maize/oats silage block had the highest leaching at 96 kg N/ha. The nitrogen budget for the wheat block for the wheat (fed) and wheat (sold) scenarios were the same, with leaching calculated at 36 kg N/ha. Table 26 shows the leaching for each fodder beet block for both the 20 ha and the optimised scenarios. The leaching of autumn grazed fodder beet block was 77 and 72 kg N/ha for the 20 ha and optimised scenario respectively. In comparison, the leaching of spring grazed fodder beet was significantly lower at 25 and 23 kg N/ha for the 20 ha and optimised scenario respectively. The N loss of the harvested fodder beet block was higher at 42 kg N/ha.

Table 25: Nitrogen budget for Templeton (non-effluent) block for existing scenario and cropping blocks for maize/oats silage and wheat scenarios

Nitrogen	**Existing**	**Maize/ oats silage**	**Wheat**
(kg/ha/yr)			
Nutrients added			
Fertiliser, lime & other	173	175	159
Rain/clover N fixation	189	2	2
Irrigation	6	4	3
Supplements fed on block	51	-	-
Nutrients removed			
As products	135	0	206
As supplements/crop residues	0	449	49
Net transfer by animals	80	-	-
To atmosphere	119	59	42
To water	34	96	36
Change in plant pools			
Standing plant material	-	9	-
Root and stover residuals	-	53	-
Organic pool	52	-564	-251
Inorganic mineral	0	0	0
Inorganic soil pool	0	79	303

Table 26: Nitrogen budget for cropping blocks for fodder beet scenarios

Description	Fodder beet (autumn grazed, 20 ha)	Fodder beet (autumn grazed, optimised)	Fodder beet (spring grazed, 20 ha)	Fodder beet (spring grazed, optimised)	Fodder beet (harvested)
(kg/ha/yr)					
Nutrients added					
Fertiliser, lime & other	151	151	151	151	151
Rain/clover N fixation	2	2	2	2	16
Irrigation	5	5	5	5	5
Supplements fed on block	-	-	-	-	-
Nutrients removed					
As products	109	62	123	70	6
As supplements/crop residues	0	0	0	0	650
Net transfer by animals	54	30	65	36	3
To atmosphere	35	31	24	20	26
To water	77	72	25	23	42
Change in plant pools					
Standing plant material	-132	-132	-258	-258	-264
Root and stover residuals	113	113	205	205	27
Organic pool	-243	-162	-257	-168	-406
Inorganic mineral	0	0	0	0	0
Inorganic soil pool	146	145	231	231	88

A major difference between blocks is the net gain or decrease in the organic N soil pool. The existing scenario is the only block that has a net increase in soil organic N (+52 kg N/ha). The cropping scenarios all have a significant net decrease in organic N. The greatest loss was on the maize/oats silage block at -564 kg N/ha, followed by the harvested fodder beet block at -406 kg N/ha. The 20 ha fodder beet blocks had significantly higher losses of organic N compared with the optimised scenario (243-257 kg N/ha and 162-168 kg N/ha lost respectively). There was minimal difference between the autumn and spring grazed blocks for both systems.

All blocks had similar amount of N fertiliser applied, which ranged from 151 to 175 kg N/ha. The maize/oats silage had the most N applied at 175 kg N/ha, however this excludes the 250 kg/ha of Cropzeal 15P incorporated at cultivation for maize silage. This was applied one month before the reporting year used for the Overseer ™ model, because the whole rotation is slightly more than one year (13 months). However, the additional 34 kg N/ha applied still has an effect on total N loss to water for the reporting year.

Chapter 6:

Discussion

This chapter has summarised and explained the key results of the study. This discussion has first explained the results of the initial economic analysis, which modelled the various cropping scenarios at 20 ha. A more detailed discussion of the optimised system has been made in section 6.3. The results of the environmental analysis have been discussed for each of the proposed, existing and optimised systems in section 6.5. Comparisons of the findings with literature were made where appropriate.

6.1 Physical performance

Table 27 shows a summary of the physical key performance indicators for the existing scenario and the four proposed scenarios. The initial investigation of 20 ha of crop on the milking platform revealed that fodder beet was the most suitable crop to increase milk production, which increased by 11.8%. The wheat (fed) scenario did not result in a significant increase in production compared with the existing scenario. The maize/oats silage scenario had only a slight increase in milk production by 16 kg MS/ha. As expected, the wheat (sold) scenario had a significant decrease in milk production as a result of a reduced milking platform. However, when only the remaining pasture area is considered, production was slightly greater than the existing scenario at 1,790 kg MS/ha, and had the same stocking rate of 3.49 cows/ha. The additional 60 t DM/ha of silage made on-farm and fewer cows to feed it to enabled slightly increased milk production per cow. For the purposes of this study it may have been appropriate to maintain the area of silage made on-farm at 120 t DM/ha for each scenario. This would have isolated the effects of incorporating each crop, instead of having other variables also having an influence on performance.

Table 27: Summary of physical key performance indicators

Key performance indicator	Existing	Fodder beet	Maize/oats silage	Wheat (fed)	Wheat (sold)
Stocking Rate	3.49	3.80	3.54	3.54	3.05
Milk Solids per ha (kg)	1,779	1,989	1,795	1,785	1,566
Milk Solids per cow (kg)	511	524	507	505	513
Feed offered (kg DM/kg MS)	11.3	11.2	12.2	11.3	11.4
Feed eaten (kg DM/kg MS)	10.5	10.4	10.9	10.5	10.5
Pasture eaten per pastoral ha (t DM/ha)	14.8	15.1	14.4	15.5	14.5

6.1.1 Metabolisable energy production and utilisation

A major contributor to the increased productivity of the fodder beet is the high ME content (12.5 MJ ME/kg DM) compared with 10.8 and 10.0 MJ ME/kg DM for maize and oats silage respectively. Wheat has the highest ME content at 13.0 MJ/kg DM, however the DM yields are significantly lower than the other crop scenarios. Using the assumed DM yield, ME content and utilisation rate shown in

Table 7, the utilised ME supply from each crop was calculated (Table 28). The ME consumed from pasture was based on the pasture ME consumption assumptions discussed in section 3.5.2.

Table 28 provides insight into the reasons for the high performance of fodder beet. High yields, feed quality and very high utilisation (95%) resulted in superior ME consumption per hectare. Spring grazed fodder beet had by far the highest ME consumption at 356,250 MJ ME per hectare. This was followed by harvested and autumn grazed fodder beet at 299,250 and 273,125 MJ ME/ha respectively. The combined ME consumption of maize/oats silage was 253,000/ha, despite this rotation having the highest overall DM yields of 32.0 t DM/ha. Among the feed crops, wheat had the lowest ME utilised per hectare at 124,410 MJ/ha. Despite a superior utilisation rate of 100%, the low DM production of 9.6 t DM/ha resulted in low ME consumed. ME consumption of pasture was lower than all the feed crops except wheat, at 190,611 MJ/ha.

Table 28: Utilised ME production per hectare

Land use	**ME consumed**
	(MJ/ha)
Pasture	190,611
Fodder beet (spring grazed)	356,250
Fodder beet (autumn grazed)	273,125
Fodder beet (harvested)	299,250
Maize silage	178,200
Oats silage	75,000
Wheat	124,410

6.1.2 Pasture eaten per pastoral hectare

FARMAX® calculated the total pasture eaten per effective hectare (160.1 ha). As expected, the existing 100% pastoral system had the greatest amount pasture eaten (Table 14), as there was no area removed for crops. However, when this was converted to the amount of pasture eaten on a per hectare of pasture basis, the results help explain the differences in milk production.

The wheat (fed) scenario had slightly higher, although very similar, milk production to the existing scenario (1,785 and 1,779 kg MS/ha respectively). This is despite the wheat itself having significantly less ME consumed compared with pasture (Table 28). A major factor leading to the surprisingly high milk production is greater pasture consumption per hectare of pasture, by 0.7 t DM/ha. The additional utilisation of pasture for the wheat (fed) scenario completely compensated for the low wheat yields. The likely explanation for this is improved pasture management. The wheat was fed from January to May during the late-lactation feed deficit. The stocking rate was very similar to the existing scenario (3.54 and 3.49 cows/ha respectively), although on 20 ha less pasture. The higher stocking rate on a pastoral hectare basis is one of the reasons for the increase in pasture intake per hectare of pasture. The periods of pasture surpluses were better utilised than with the existing scenario. The model calculate there was a significantly reduced amount dead matter in the pasture for the wheat (fed) scenario. This would have resulted in increased pasture production and quality. A smaller increase in pasture intake per pastoral hectare of 0.3 t DM/ha was modelled for the fodder beet scenario. The autumn grazed fodder beet was effective in filling the late lactation feed deficit, which contributed to the significant increase in overall stocking rate to 3.80 cows/ha. This was a contributing factor to the increase in overall milk production to 1,989 kg MS/ha. As with the other proposed scenarios, maintaining the APC above the minimum level of 1,700 kg DM/ha during the last month of lactation was the limiting factor to increasing stocking rate and milk production further. The availability of fodder beet during this time facilitated a significant increase in productivity.

The same cannot be said for the maize/oats scenario. Pasture intake was 0.4 t DM/ha lower on a pastoral hectare basis compared with the existing. The reasons for this are unclear. The supplementary feed was allocated during early and late lactation, and the stocking rate per pastoral hectare was the same as the wheat (fed) scenario. The likely reason for the reduced pasture consumption is that pasture was under-allocated when modelling the system. This was a limitation in comparing different systems with FARMAX®. The additional utilised ME from maize and oats silage combined (Table 28) should have resulted in a significant increase in stocking rate, however this was not seen. The study would have been more conclusive in the comparative benefits of each crop if the pasture consumption per pastoral hectare had stayed constant. However, in the case of the wheat (fed) and fodder beet scenarios, the variations on a pastoral hectare basis likely indicate some genuine improvements in pasture management. It was expected that this would have also been observed for the maize/oats silage scenario because the crop was also fed during early and late lactation feed deficits.

The wheat (sold) scenario had 0.3 t DM/ha lower pasture consumed per pastoral hectare than the existing. However, an additional 60 t DM of pasture silage was made on-farm. This equates to an additional 0.42 t DM/ha, which makes this scenario similar to the existing. Because the wheat was not fed on-farm, the wheat (sold) scenario is effectively the same system as the existing, except on reduced land area. As expected, milk production was the lowest for this scenario at 1,566 kg MS/ha. However, when the 20 ha of wheat is excluded, productivity increases to 1,790 kg MS; slightly higher that the wheat (fed) and existing scenarios.

6.1.3 Feed conversion ratio

The FCR of each system is a major determinant of milk production. Due to the superior ME content, the FCR on a feed eaten basis was the lowest for the fodder beet scenario at 10.4 kg DM/kg MS. The existing system was slightly higher at 10.5 kg DM/kg MS. The FCR was the highest for the maize/oats silage scenario as a result of the low ME content of the feed.

The differences on a feed offered basis were even more significant as it took into account the utilisation rate of the feed crops, as well as ME content. As expected, the maize/oat silage scenario had the highest FCR at 12.2 kg DM/kg MS compared with 11.3 kg DM/kg MS for the existing. This is an 8.0% increase and represents a major decrease in production efficiency. This is the result of a major proportion of the feed allocated being low quality with low utilisation rates. The fodder beet scenario was also superior at 11.2 kg DM/kg MS on a feed offered basis. This is a result of high ME content and high utilisation rates. This was also despite increased pasture silage imports as stocking rate increased, which also has a low utilisation rate of 75%. Surprisingly, there was no difference between the FCR of the existing and wheat (fed) scenario at 11.3 kg DM/kg MS. Wheat was the highest quality feed and had 100% utilisation. However, it is possible that the proportion of wheat in the diet was not significant enough to have a quantifiable effect on FCR.

The higher production per cow for the fodder beet scenario (524 kg MS/cow) may have contributed to the superior FCR. Greater production per cow means a higher proportion of the ME consumed is used for milk production and a lower proportion used for maintenance (Waghorn, 2007). The study would have been more conclusive if production per cow had been kept constant so that the change in FCR was a result of the crop itself.

6.2 Financial performance

A summary of the financial performance of the existing system and the four proposed scenarios, assuming $6.00/kg MS is shown in Table 29. The fodder beet scenario was the most profitable system as a result of increased milk production and reduced cost of production. Increased NCI was the major driver of increased profitability. Although total expenses increased also, the additional milk production outweighed this and reduced the overall cost of production to $3.74/kg MS.

Table 29: Summary of financial key performance indicators

Key performance indicator	Existing ($)	Fodder beet ($)	Maize/oats silage ($)	Wheat (fed) ($)	Wheat (sold) ($)
Net cash income/ha	10,936	12,228	11,047	10,996	10,184
Expenses/ha	6,953	7,446	7,484	7,140	6,723
Operating profit/ha	3,984	4,782	3,563	3,856	3,461
Cost of production (per kg MS)	3.91	3.74	4.17	4.00	4.29

The maize/oats silage was the least profitable crop to grow and feed on-farm. This is consistent with the findings of De Ruiter et al. (2010b) who found the operating profit was significantly less on a Taranaki dairy farm growing forage crops including maize silage. The main reason cited in this study was there was no significant increase in milk production, despite a significant increase in DM production. This indicated a decrease in FCR, as found by this study. The operating profit was significantly reduced due to the increase in feed crop costs.

6.2.1 Cost of production

The other cropping scenarios all had reduced profitability. The major reason for this is that there was no significant increase in milk production compared with the existing, while FWE significantly increased due to crop expenses. Because productivity was similar, the cost of production was the major determinant of relative profitability. The maize/oats silage scenario had a high cost of production ($4.17/kg MS), mainly due to the high cost of the cropping area itself ($4,005/ha). The wheat (sold) scenario had the highest cost of production at $4.29, although this does not into account that the wheat was not fed on-farm, therefore did not contribute to milk production.

The cost of the feed crops per MJ ME utilised is shown in Table 30Table 30 which takes into account the DM yields, feed quality, utilisation rate and direct costs of production. Maize and oats silage are by far the most expensive feed crops at 1.61 and 1.52 cents/MJ ME utilised respectively. The weighted average cost for this rotation is 1.58 cents/MJ ME. This is significantly greater than the other feed crops. The autumn and spring grazed fodder beet is less than half this amount due to reduced crop expenses ($2,007/ha) and greater ME utilised per hectare. Wheat had moderate costs per MJ ME utilised, at 1.18 cents/MJ ME. Wheat was the cheapest cropping rotation at $1,470/ha. However, the lower DM yields made it less cost effective than fodder beet, although significantly better than maize and oats silage. This contributed to the wheat (fed) being more profitable than the maize/oats silage scenario.

Table 30: Cost of feed crops per MJ ME utilised

Feed crop	Cost per MJ ME utilised (cents)
Fodder beet (spring grazed)	0.56
Fodder beet (autumn grazed)	0.73
Fodder beet (harvested)	1.09
Maize silage	1.61
Oats silage	1.52
Wheat	1.18

The financial performance of each scenario is governed by production economics. Martin and Woodford (2005) state that profitability is maximised by increasing the level of inputs until the cost of doing so equals the additional income generated from the additional input. The maize/oats silage scenario could have been more profitable than the existing scenario if it had resulted in a significant increase in milk production. If this was the case, having a greater cost of production may still have resulted in greater overall operating profit, as long as the milk price is greater. However, the lack of production response meant that the additional revenue from using this strategy was less than the additional cost. In contrast, the incorporating fodder beet resulted in a significant increase in milk production. The increased variable costs of incorporating fodder beet was less than the additional revenue generated. Profitability will be maximised by growing the maximum area possible of fodder beet.

6.2.2 Fixed costs

The increased milk production from fodder beet resulted in a lower cost of production as the fixed costs of the system were spread out over more milksolids. The fixed costs were deemed to be wages irrigation, repairs and maintenance, rates, insurance and administration, totalling $430,704 for all five systems. Table 31 shows that the greater milk production on the fodder beet scenario reduced the fixed costs on a per kg MS basis by 16 cents/kg MS. This almost accounts for the whole difference in overall cost of production between these two scenarios of 17 cents/kg MS (Table 29). All of the variable expenses that were calculated based on cow numbers (such as animal health and silage imports) increased by 9.0%, which reflects the increase in stocking rate. The increase in total milk production was slightly greater than the increase in these variable expenses (11.8%) as a result of the increase in production per cow (524 kg MS compared with 511 kg MS). The maize/oats and wheat (fed) scenarios had very similar fixed costs of production to the existing system, as milk production was not significantly different. As with the overall cost of production, the wheat (sold) scenario had the highest fixed costs per kg MS.

Table 31: Fixed costs per kilogram of milksolids

Scenario	Fixed costs ($/kg MS)
Existing	1.51
Fodder beet	1.35
Maize/oats silage	1.50
Wheat (fed)	1.51
Wheat (sold)	1.72

6.3 Optimised system

After identifying that fodder beet was the most suitable crop for increasing profitability, the areas of fodder beet were increased so that daily cow intakes were increased to the recommended maximum. The purpose of this was to determine the maximum extent that incorporating forage crops could increase profitability on the LUDF. A summary of the physical and financial performance of this optimised system is shown in Table 32.

Table 32: Summary of physical and financial performance of optimised system

Physical performance	
Stocking rate (cows/ha)	3.96
Milk production (kg MS/cow)	543
Milk production (kg MS/ha)	2,149
Pasture eaten per pastoral ha (t DM)	15.7
FCR (feed eaten) (kg DM/kg MS)	10.2
FCR (feed offered) (kg DM/kg MS)	11.0
Financial performance	
Net cash income/ha	13,210
Expenses/ha	7,842
Operating profit/ha	5,368
Cost of production ($ per kg MS)	3.65

6.3.1 Physical performance

Compared with the existing scenario, milk production increased by 20.8% to 2,149 kg MS/ha. This was achieved by increasing the stocking rate to 3.96 cows/ha and production per cow to 543 kg MS. As expected, this scenario had the lowest FCR at 10.2 kg DM (eaten)/kg MS because fodder beet was a greater proportion of the diet. This is a substantial improvement compared with the existing scenario.

The quantity of pasture eaten per pastoral hectare increased to 15.7 t DM/ha; a significant increase compared with the existing system at 14.8 t DM/ha. This indicates that the increased milk production is not solely from high ME yields from fodder beet, but from greater pasture utilisation. Figure 21 shows that from September until the end of the season in May, the APC is significantly lower than the existing system. A lower APC indicates that more pasture per pastoral hectare has been allocated and consumed.

The pasture utilisation could have been improved in the existing system by harvesting more silage on-farm and feeding it out in late lactation. In the optimised scenario, the fodder beet fulfils a similar function to silage made on-farm, however on a larger scale. The crop removes pasture from the rotation and is fed out during times of feed deficits. Figure 21 shows that the APC declined at a much slower rate during late lactation when fodder beet was used. This was despite a significantly higher stocking rate and was achieved through feeding 6.0 kg DM/cow/day of fodder beet during this period. A lower peak APC for the optimised system also reduced the proportion of dead and stem material in pasture during the summer months. This had significant feed quality benefits which contributed to the increased FCE and milk production.

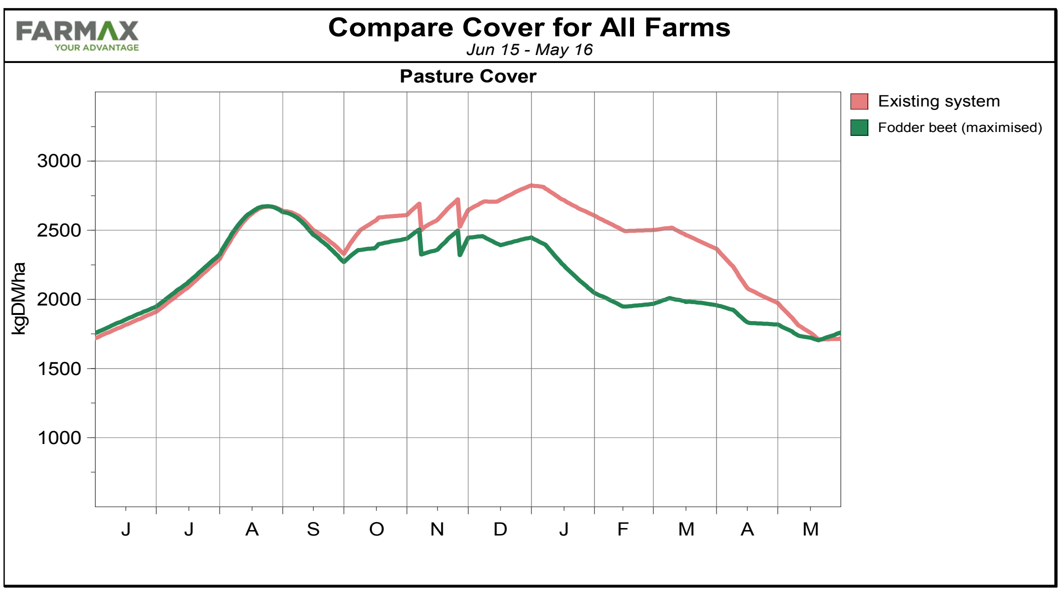


Figure 21: Average pasture cover for existing and optimised scenarios

6.3.2 Financial performance

Assuming \$6.00/kg MS, the operating profit increased by \$1,384/ha to \$5,368/ha. This is a 34.8% increase compared with the existing scenario; an overall increase of \$221,644. The major contributor to this was that NCI increased by \$2,274/ha to \$13,210/ha. This more than outweighed the increase in FWE of \$889/ha. The major increase in expenditure was \$79,246 in feed crop costs, averaging \$2,338 per hectare of crop. The suitability of harvested fodder beet was not investigated in the initial FARMAX® modelling with 20 ha of feed crop. However, the results of the linear programme confirmed that harvested fodder beet was more profitable than pasture at a milk payout of \$4.00/kg MS or above

(Table 23). Harvested fodder beet has lower yields than spring grazed beet due to the loss of leaf DM during harvest. However, in this study, there were major advantages to seasonal feed availability as it was fed between the spring and autumn grazed fodder beet. It is highly likely that the high stocking rate achieved would not have been possible without this feed buffer. The linear programme did not account for these differences in monthly feed availability, although still calculated that it was profitable. Maize and oats silage and wheat have the greatest flexibility in when they are fed as they can be stored for long periods of time. The timing of fodder beet grazing is also relatively flexible, however the requirement for a spring sowing date makes certain times of the year more suitable than others. Feeding in early lactation the following year results in greater yields than in late lactation, due to the extended growing period. Due to the minimal fodder beet research in New Zealand, it is uncertain whether fodder beet could be grazed during mid-lactation, which would greater than 12 months after the sowing date. There would be concerns regarding feed quality, particularly with the leaf producing seed-head (J. Gibbs, personal communication, September 3, 2014). For this reason, it was assumed the spring grazed fodder beet was grazed until the end of November. Harvested fodder beet was an ideal feed during mid-lactation as it can be stored for up to six months without losing quality (Gibbs et al., 2015).

The variable costs that were calculated on a cost per cow basis, including animal health, breeding and electricity increased by 13.4% for the optimised scenario compared with the existing. This reflects the increase in stocking rate. The N and non-N fertiliser expenses were 20.6% and 21.2% less than the existing system respectively. This was the result of the total pastoral area decreasing by 21.2% and the fertiliser expenditure for fodder beet being included in the feed crop expenses. This study may have underestimated the fertiliser expenditure for the optimised scenario as it did not account for increased export of nutrient off-farm though greater milk production. It is possible that for this level of production to maintained, fertiliser inputs may need to be increased otherwise a sustained decrease in soil fertility may occur. However, it is unlikely that an increase in fertiliser expenditure would outweigh the additional milk solids income.

As with the other scenarios, the cost of off-farm grazing was the greatest variable expense at $361,627 or $2,259/ha. This represents 29% of total farm working expenses, although at 5.8 t DM offered per hectare (Table 19) it accounted for 22% of the total feed offered. The regrassing expenditure increase by $6,549 to $14,374 as an additional 17.9 ha was regrassed. It is likely that the overall pasture productivity would increase as a result of the greater area of new pasture. Farmax® does not capture these additional benefits, nor does it consider that the worst performing pasture paddocks will be the ones to be sown into crop. There model may therefore be underestimating the potential increase in milk production. Regrassing costs could be reduced if one or more of the fodder beet blocks were followed a crop the following season. This could be done for several consecutive years at a time if soil conditions permit.

6.4 Sensitivity to risk

An important part of this study was the sensitivity analysis using various milk payouts. The milk price paid to New Zealand dairy farmers for the 2014/2015 was a significant decrease compared with the 2013/2014 season. The dairy industry is currently preparing for another low payout for the 2015/2016 year. The sensitivity analysis showed that even at a very low payout of $4.00/kg MS, fodder beet was still able to increase the profitability on the farm. Table 33 shows the operating profit was $644/ha greater for the optimised system compared with the existing. Excluding the maize/oats silage scenario, the other proposed systems were still profitable, although less so than the existing. This shows that the optimised fodder beet scenario would not expose the farm to greater milk price risk. This is achieved by the very low cost of production of $3.65/kg MS. However, if the increased fertiliser inputs are needed for the fodder beet system as discussed in section 6.3.2, then the profit advantage would be reduced. Furthermore, any unexpected increase in variable costs, particularly those related to cow numbers, may have a greater impact on profitability for the optimised scenario compared with the existing. This is due to the greater system intensity and total expenses of the optimised system, which would result in a greater decrease in profitability.

Table 33: Operating profit at $4.00/kg MS

Scenario	**Operating profit**
	($/ha)
Existing	425
Fodder beet	803
Maize/oats silage	-13
Wheat (fed)	285
Wheat (sold)	327
Optimised	1,069

The results of the linear programme confirmed the results of the sensitivity analysis modelled on FARMAX®. The optimised areas of each fodder beet type was calculated as the most profitable combination at milk payouts of $4.00/kg MS and above. At $3.00 and $3.50/kg MS, maximum profit was achieved by reducing milk production by not growing harvested fodder beet. At $2.50/kg MS, it was most profitable to only grow spring grazed fodder beet. This was because of its very low cost of production per MJ ME utilised (Table 30).

At $4.00/kg MS, the wheat (sold) scenario became more competitive with the other scenarios, with operating profit of $327/ha. This was assuming the wheat price remained at $400/tonne. The model shows how wheat sales help diversify the business and reduce the impact of the lower milk payout. However, because a major market for feed wheat is the dairy industry, it is likely the price of wheat would also decrease as dairy farmers reduce their costs.

A limitation with the linear programme is that it only calculated the income from milk sales. In reality, the proportion of income from stock sales becomes more significant as the milk price decreases. The FARMAX® analysis showed the optimised scenario had $66/ha more income from stock sales compared with the existing. This was not accounted for by the linear programme and would have made the fodder beet scenarios more competitive.

6.5 Environmental analysis

This section has discussed the projected N leaching as modelled by Overseer ™. The modelling projected that the N leaching would increase when crops were incorporated on-farm. Table 34 shows existing system had the lowest leaching at 34 kg N/ha. The optimised system had the largest increase in leaching at 44 kg N/ha. Table 35 shows the N leaching for the Templeton non-effluent block that was used for the cropping blocks.

Table 34: Summary of N leaching per hectare

	Existing	**Fodder beet**	**Maize/ oats silage**	**Wheat (fed)**	**Wheat (sold)**	**Optimised**
N leached (Kg N/ha)	34	41	41	39	37	44

Table 35: N leaching on Templeton non-effluent block used for crop

Block	**N leached (kg N/ha)**
Existing (pasture)	34
Maize/oats silage	96
Wheat	36
Fodder beet (spring grazed)	23-25
Fodder beet (autumn grazed)	72-77
Fodder beet (harvested)	42

6.5.1 Wheat (sold) scenario

The rationale behind selling wheat instead of feeding it on-farm was to export N off-farm which should contribute to overall lower leaching for the farm. However, Overseer ™ still projected and increase in leaching to 37 kg N/ha. A contributing factor was the slightly increased N leaching of the wheat block compared with the original pasture block, as shown in Table 35 (36 and 34 kg N/ha respectively). However, the main factor was increased leaching on the remaining pasture blocks on the wheat (sold) scenario. The remaining pastoral area on the Templeton non-effluent block had projected leaching of 38 kg N/ha; a significant increase compared with the existing. The other pastoral blocks had increases in leaching of 2 to 5 kg N/ha. This was surprising, given the relatively similar farm system and stocking rate on the pastoral area as the existing system. The increase is possibly due to the slightly increased milk production per pastoral hectare. A limitation with the Overseer ™ is that the level of milk production that is inputted into the model has a major effect on the leaching outcome, even if all other farm inputs are kept the same. The model assumes the increased milk production is the result of increased pasture growth and consequently the calculated biological N fixation. For the Templeton non-effluent block, the N fixation by clover increased by 6 kg N for the wheat (sold) scenario. This increased the amount N that can be leached.

6.5.2 Wheat (fed) scenario

As expected, the wheat (fed) scenario had greater leaching than the wheat (sold) scenario, at 39 and 37 kg N/ha respectively. The additional CP fed to cows resulted in greater urinary N deposition, which contributed 30 kg N/ha of the total N leached for the farm overall, compared with 28 kg N/ha for the wheat (sold) scenario. The remaining 9 kg N/ha leached for both systems included all other sources of leaching, such as N fertiliser inputs, mineralisation and biological fixation. In comparison, the leaching excluding urine patches was only 5 kg N/ha for the existing scenario. Table 24 shows the wheat (fed) scenario had the highest N inputs from imported supplements, at 50 kg N/ha, which includes the wheat made on-farm and imported pasture silage. This is greater than the other scenarios which ranged from 26 to 33 kg N/ha from supplements. The transfer of N from the wheat block to the pastoral blocks significantly increased the leaching on the pasture blocks. The Templeton non-effluent block had leaching of 40 kg N/ha for the wheat (fed) scenario compared with 34 kg N/ha for the existing. The significantly increased milk production per pastoral hectare was a major driver for the increased leaching on the pastoral blocks. The Overseer ™ model assumed increased pasture production and increased biological fixation by 20 kg N/ha for the Templeton non-effluent block.

The wheat blocks had the same N inputs and outputs for both the wheat farm systems. Although there is no urine deposition on the wheat blocks, the leaching is relatively high as a result of other sources of N. The N inputs as fertiliser was greater than the existing scenario as a whole (159 and 137 kg N/ha respectively). Another major source of plant available N is from mineralisation of organic N. Table 25 shows the decrease in the organic N pool was 251 kg N/ha. Overseer ™ calculated that 69% of this mineralisation is from cultivation. In contrast, the Templeton non-effluent block for the existing scenario had a net increase in the organic N pool of 52 kg N/ha. Mineralised N and fertiliser N combined make up the majority of the total N leaching on the wheat block. A further risk of conventional cultivation is the degradation of soil structure (Di & Cameron, 2002). Pasture increases organic matter in the soil and improves soil structure. However, the loss in organic matter from cultivation for the wheat crop would still be sustainable as it is in rotation with permanent pasture.

6.5.3 Maize/oats silage scenario

The maize/oats silage scenario had the same N leaching to the fodder beet (20ha) scenario, at 41 kg N/ha. A contributing factor was the very high leaching of the maize/oats silage block of 96 kg N/ha; the highest of the pastoral and cropping blocks for all scenarios. Fertiliser N inputs were the highest of all blocks at 175 kg N/ha, which reflects the large quantity of N exported to the pastoral blocks (449 kg N/ha). The model predicted that the majority of N inputs would come from a major reduction in the soil organic N pool. The total N loss in organic N was 564 kg N/ha, of which 233 kg N/ha (41%) was mineralisation from cultivation. It is possible that the model calculated the remaining 331 kg N/ha of mineralisation based on plant requirements to produce the DM yields expected. The large amount of plant available N resulted in significant leaching losses. At the whole farm level, the overall net gain in the organic N pool was only 7 kg N/ha. This was significantly less than the existing (79 kg N/ha) and the other proposed cropping scenarios, which had similar net increases of 39 to 46 kg N/ha.

Although the maize/oats silage block had significantly higher leaching than the fodder beet blocks, the leaching at the whole farm level was the same. The maize/oats silage scenario had significantly reduced biological N fixation of 135 kg N/ha compared with 211 kg N/ha for the fodder beet scenario. This is the result of the model predicting significantly lower pasture production at 21.4 and 25.0 t DM per pastoral hectare respectively. These figures are both significantly greater than that assumed in the FARMAX® simulations and therefore the model may be overestimating the biological fixation.

6.5.4 Fodder beet scenario

The initial fodder beet scenario incorporating 10 ha each of spring and autumn grazed fodder beet had significantly higher leaching than the existing scenario. There is the perception that fodder beet results in significant N leaching as stocking rates while grazing are very high. While this was the case for the autumn grazed fodder beet (77 kg N/ha), the spring grazed fodder beet had relatively low leaching (25 kg N/ha). For both crops, the majority of the leaching was from sources other than urine patches. Leaching from urine patches was contributed only 4 and 12 kg N/ha of the total N leached for the spring and autumn grazed fodder beet blocks respectively. As with the other cropping blocks, there was a significant decrease in the organic N pool (257 and 243 kg N/ha respectively). Cultivation results in a significant amount of mineralised, easily leached N. It was assumed that both crops would be grazed for only three hours per day and then returned to pasture. This was based on the guideline by Gibbs (2014) that less than two hours of grazing is required for 5 kg DM/cow to be consumed. This reduces the amount of urine deposited and effectively "mines" nutrients from the fodder beet block to the pastoral blocks (Gibbs et al., 2015, p. 243). These factors explain why the majority of leaching was not from urine deposition.

A reason for the greater leaching for the autumn grazed crop is that it was sown two months earlier than the spring grazed crop. Cultivating during summer when there is less rainfall may have reduced the projected leaching for the spring grazed block. The autumn grazed crop also had two months of fallow ground during June and July which are the months of highest rainfall in Canterbury. Significant amounts of drainage and N leaching occurs during winter fallow periods where there is no N uptake from plants (Di & Cameron, 2002).

6.5.5 Optimised scenario

As expected from the results of the initial fodder beet simulation, the optimised fodder beet scenario had the highest projected leaching at 44 kg N/ha. Due to the lower yields of the autumn grazed fodder beet compared with the spring grazed crop, the area of this crop was the largest at 13.3 ha. This crop also has the highest leaching which contributed to the high figure for the farm overall. The addition of harvested fodder beet was also a significant contributor, as leaching was relatively high at 42 kg N/ha. Although there was no urine deposition, the major reason was very large reduction in the organic N pool by 406 kg N/ha. This was much larger than the grazed fodder beet and possibly is because there is no organic N returned to the soil through animal faeces.

On a whole farm level, the total N leaching from urine patches was only 2 kg N/ha greater than the existing scenario (31 and 29 kg N/ha respectively). This is significant as the stocking rate was dramatically increased by 0.47 cows/ha, resulting in a greater amount of urine patches. This indicates significantly reduced urinary N concentration as observed by Bryant et al. (2014) and Ledgard (2006). The overall increase in leaching was predominantly due to an 8 kg N/ha increase in N loss to water from non-urinary sources.

The optimised scenario was the only system that had a projected overall net decrease in the organic N soil pool (-11 kg N/ha) as shown in Table 24. This indicates that the area of crop was large enough to outweigh the additions of organic matter made by pasture. A large overall net decrease would be viewed as unsustainable in the long-term as a gradual degradation in soil structure would result. However, the decrease modelled for this scenario is likely too small to be of concern.

6.5.6 N leaching efficiency

Incorporating feed crops into the dairy system on the LUDF has consistently increased overall N leaching regardless of which crop is modelled. This study also found that the kg N leached per tonne of milksolids also increased. This metric is referred to as the "environmental efficiency" (Ledgard et al., 2006, p. 266). The rationale is that the additional milk production achieved from greater DM yields of feed crops may outweigh the additional N leaching of forage crops. However Table 36 shows the existing system had the greatest environmental efficiency of 19.1 kg N leached per t MS. The optimised scenario had the next greatest efficiency of 20.5 kg N/t MS, despite having the highest overall leaching. The additional milk production outweighed the greater leaching compared with the other proposed scenarios. The wheat (sold) scenario had the lowest environmental efficiency, however this does not account for feed exported off-farm. The maize/oats silage scenario also had poor environmental efficiency as there was a significant increase in N leaching without a significant increase in milk production.

Table 36: N leaching per tonne of milksolids

	Existing	**Fodder beet**	**Maize/ oats silage**	**Wheat (fed)**	**Wheat (sold)**	**Optimised**
N leached (kg N/t MS)	19.1	20.6	22.8	21.8	23.6	20.5

Chapter 7:
Conclusions

This chapter has summarised the major findings of the study. This research aimed to help fill the gap in the literature surrounding the integration of crops in a dairy system, and identify its suitability for the LUDF. The practical considerations and risks of implementing the proposed strategy on the LUDF have been discussed.

7.1 Profitability

The study found that only fodder beet resulted in increased profitability. Figure 22 shows the operating profit for each scenario. Maximising the fodder beet resulted in a significant increase in profitability to $5,368/ha; a 35% increase compared to the existing. The maize/oats silage and wheat (fed) scenarios had significantly reduced operating profit as a result of increased farm working expenses and only a minimal increase in milk production. The wheat (sold) scenario had reduced expenses, however significantly reduced income which significantly decreased profitability.

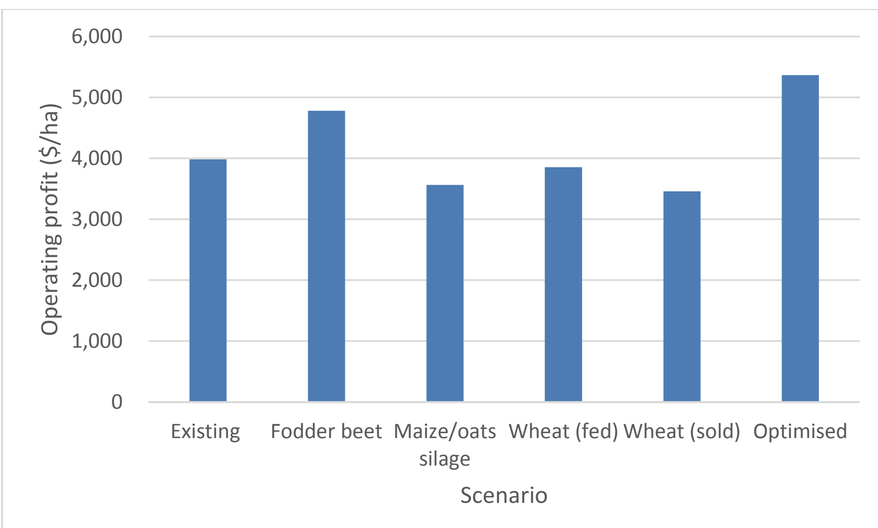


Figure 22: Operating profit

Fodder beet had three major advantages relative to the other cropping options. The first is the superior yields of ME and utilisation resulting in a significant increase in milk production. The high feed quality resulted in a significant increase in FCE for the optimised system compared with the other scenarios. The second advantage was the 0.9 t DM/ha increase in pasture consumption on the remaining pastoral blocks. This was achieved through greater pasture utilisation and improved management of pasture surpluses. This finding was not anticipated and shows that the crop integrates effectively into a dairy system. Feeding large quantities of fodder beet in the optimised scenario enabled stocking rate to be increased by 0.47 cows/ha which resulted in improved grazing management. The outcome was increased milk production to 2,149 kg MS/ha; a 20.8% increase compared with the existing scenario. This demonstrates the value of whole farm systems theory (section 2.2) where the interactions and synergy of the various elements of the system are analysed as a whole. A change in one part of the system was shown to have positive effects on others.

The third advantage of fodder beet was the low cost of production both on a per kg DM basis and, more importantly, on a per MJ ME utilised basis. The optimised system was remarkably resilient at low milk prices as the cost of production was significantly reduced to $3.65/kg MS compared with $3.91 for the existing system. Intensification of farm systems has traditionally resulted in increased costs of production, however with this strategy, the opposite occurred. These factors combined resulted in a 35% increase in operating profit. This represents a total increase in profitability of $221,644.

Despite the high DM yields of the maize and oats silage rotation, there was no significant increase in milk production. This was due to poor FCE and is consistent with the trial done by De Ruiter et al. (2010b). This was the result of both poor feed quality and utilisation of both crops. The addition feed crop costs resulted in significantly reduced operating profit. The wheat (fed) scenario had similar milk production to the existing scenario despite wheat having lower DM production than pasture. This was partially outweighed by the superior utilisation and feed quality of wheat. However, one of the main advantages of wheat was the flexibility in the timing of feeding. It was entirely fed during the second half of lactation, when the APC is approaching the minimal level of 1,700 kg DM/ha. Wheat supplementation during this time enabled stocking rate to be increased slightly, resulting in small increase in overall milk production. However, as with the maize/oats silage scenario, the increase in feed crop costs resulted in a lower operating profit than the existing situation.

The sensitivity analysis (Table 22) found the wheat (fed) scenario was more profitable than the wheat (sold) scenario at a milk price of $5.00/kg MS and above. This indicates that it may be profitable to import feed wheat on the LUDF, while maintaining the 100% pastoral milking platform. Further research should be done into the potential gains in profitability and susceptibility to risk of this strategy.

7.2 Nitrogen leaching

All of the proposed feed crop scenarios had greater leaching than the existing system. Figure 23 shows the projected N leaching for each scenario.

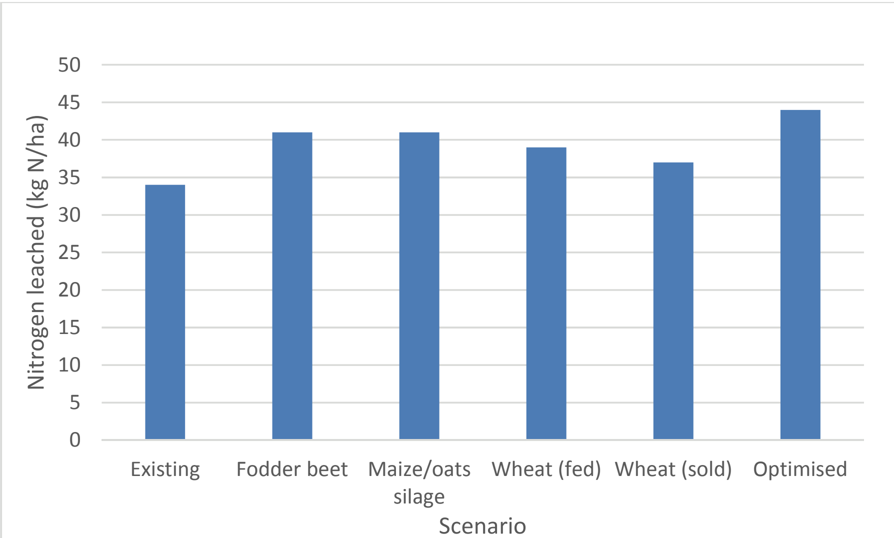


Figure 23: Nitrogen leaching

The optimised system was calculated to have the greatest leaching at 44 kg N/ha, compared with 34 kg N/ha for the existing system. Most of the increase was from the fodder beet blocks themselves from non-urinary sources of N. Cultivation results in significant amounts of mineralisation of organic N, which is then easily leached. Due to the short grazing duration per day, leaching from urine patches was a small proportion of the N leached on the cropping blocks. The autumn grazed crop had significantly greater leaching than the spring grazed crop. This crop had two months of fallow during winter before being regrassed. This is an extended amount of time where there is no plant uptake of N and large leaching losses.

The maize/oats silage block had the highest leaching of any block as a result of a significant reduction in the organic N pool. This increased overall N leaching for that scenario to 41 kg N/ha. Surprisingly, exporting N off-farm through wheat sales did not reduce overall N leaching. N leaching of the wheat block was 36 kg N/ha, and the N loss on the pastoral blocks increased for both the wheat (fed) and wheat (sold) scenarios. A contributing factor was increased pasture production resulting in greater biological N fixation. This finding was unanticipated, however is supported by the differences in pasture allocated per pastoral hectare as calculated by FARMAX® (Table 14).

There is evidence to suggest that the N concentration in urine decreased by feeding low CP crops. Under the optimised system, leaching from urine patches only increased by 2 kg N/ha, or 6.9%. This was despite a 13.4% increase in stocking rate. The overall increase in leaching was predominantly due to non-urinary sources.

7.3 Implications of integrating feed crops

One of the major barriers to implementing the optimised system on the LUDF is the significant increase in N leaching. Such an increase will not be permitted in the Selwyn-Waihora catchment in the near future. From 2022, the LUDF will have to submit a Farm Environment Plan detailing nutrient management (Environment Canterbury, 2014b). The plan must include practical steps being taken to reduce N leaching. It is unlikely that the proposed integration of fodder beet would be permitted. It is still unknown how strict the final regulations will be in the coming years, so it is difficult to provide a definitive recommendation for the LUDF in regard to integrating fodder beet.

The optimised scenario included predominantly grazed forages, with limited additional feeding out with machinery. The maize/oats silage scenario required more expenditure on machinery for feeding out throughout the season. This study was focussed on calculating operating profit, however an investment analysis on any additional capital expenditure needs to be carried out to account for this. Similarly, the wheat (fed) scenario would require the installation of in-shed feeding. It is also possible that an additional labour unit would be required for the additional feeding out under the maize/oats silage scenario.

7.4 Limitations of research

This study was based on farm systems modelling on computer-based software. A field trial that was able to measure milk production and profitability may have in different results to that predicted by FARMAX®. Similarly, lysimeter installations on the LUDF would be able to accurately measure the actual N leaching. However, both FARMAX® and Overseer ™ have been developed for New Zealand conditions and have extensive field research results underpinning how the outcomes are calculated. Because Overseer ™ is now a regulatory tool for Canterbury farms, it was the most suitable tool to use for this study, regardless of its perceived accuracy. A limitation with the FARMAX® model and linear programme was that it assumed CP was never limiting. In reality, CP deficiency may have occurred, especially during the summer months when the pasture CP content is lower. The optimised scenario is most likely to have CP deficiency as the proportion of the diet as fodder beet was high. Peak daily production per cow was also very high, which increases cow demand for CP as a proportion of the diet (DairyNZ, 2010).

A limitation with the research methodology was the lack of controlled variables. This reduced the ability to confidently isolate the effects of incorporating the different crops. Milk production per cow should have been maintained constant, with only the stocking rate being increased or decreased in response to feed supply. Scenarios with higher production per cow, such as the fodder beet scenarios, had an unfair advantage as the proportion of feed used for maintenance is less, increasing the FCE. Increasing production per cow rather than stocking rate also avoids increasing certain per cow expenses such animal health and grazing. These factors led to a bias toward fodder beet. However, it is likely that this bias was not significant enough to have changed the finding that fodder beet was most suitable for increased profitability.

7.5 Future research

Future research into integrating feed crops onto LUDF milk platform needs to include a field trial to confirm the predicted changes in production modelled in this study. Modelling studies are based on assumptions which may or may not accurately project what is seen in the field (Benton, 2014). A field trial could also investigate the effects on the day-to-day operational management of the farm, which are not captured in a farm simulation. Feeding large quantities of fodder beet may result in other issues that have not been considered by the models. Potential concerns include an increase milk fever and mastitis (Gibbs et al., 2015).

While the economic analysis of this study has concentrated on changes in operating profit, it would be useful to do an investment analysis comparing internal rate of return (IRR) and net present value (NPV). This would take into account the costs of debt servicing and taxation.

The main limiting factor with implementing the optimised system is the regulations on N leaching. More research needs to be done with Overseer ™ to determine if there are alternative strategies where fodder beet could be grown without increasing leaching losses. This could include the construction of a feed pad or cow housing. This would reduce the N loss on the pastoral blocks and could allow for the inclusion of fodder beet if there is minimal difference in overall leaching. Even without additional infrastructure, there is the potential to incorporate spring grazed fodder beet. For the optimised scenario, the projected leaching was only 23 kg N/ha; substantially less than the pastoral blocks. A new simulation on FARMAX® and Overseer ™ should be done with just this crop to identify the gains in profitability and the effect on overall N loss. This was also by far the most profitable crop. There may also be potential to increase the daily intake of the grazed crop to 7 kg DM/cow/day during lactation (Gibbs et al., 2015). Modelling the crop on less well drained soil types may further reduce leaching losses, however these will be less suitable for fodder beet.

Because the main cause of leaching on the cropping blocks was cultivation, there may potential to import feed crops to avoid this. This was outside the scope of this study, however may be an effective way to increase milk production without such a significant increase in N leaching. This study indicated that low CP feed crops can reduce the urinary N concentration. However, there may still be an overall increase in leaching as additional N is being imported onto the farm as supplements. All future research needs to be done in conjunction with Overseer ™ as this software governs what will be permitted. Other environmental effects, such as greenhouse gas, could also be investigated using the software. This will especially of interest if agriculture becomes included in the Emissions Trading Scheme.

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Appendices

Appendix 1: Fodder beet direct costs

Item	Details	Rate			Cost		Total cost ($/ha)
Spray out pasture	Roundup	4	L/ha	@	$11.22	/L	$44.88
	Application				$20.00	/ha	$20.00
Cultivation	Plough				$138.00	$/ha	$138.00
	Cambridge roll				$30.00	/ha	$30.00
	Power harrow				$153.00	/ha	$153.00
Sowing	Precision drill				$135.00	/ha	$135.00
Seed	Fodder beet cultivar	4	kg/ha	@	$30.00	/kg	$120.00
Pre-emergence herbicide							
	Roundup	1	L/ha	@	$11.22	/L	$11.22
	Nortron	4	L/ha	@	$29.39	/L	$117.56
	Lorsban	0.35	kg/ha	@	$119.13	/kg	$41.70
	Application cost				$20.00	/ha	$20.00
Post-emergence herbicide							
1st application	Goltix	1.5	kg/ha	@	$110.00	/kg	$165.00
	Betanal Forte	1.1	L/ha	@	$127.20	/L	$139.92
	Lorsban	0.35	kg/ha	@	$119.13	/kg	$41.70
2nd application	Goltix	1.5	kg/ha	@	$110.00	/kg	$165.00
	Betanal Forte	1.2	L/ha	@	$127.20	/L	$152.64
	Lorsban	0.35	kg/ha	@	$119.13	/kg	$41.70
	Versatil	1	L/ha	@	$51.87	/L	$51.87
	Application cost	2		@	$20.00	/ha	$40.00
Fertiliser							
	Cropzeal 16N (incorporated)	175	kg/ha	@	$0.71	/kg	$124.43
	Ag Salt (incorporated)	125	kg/ha	@	$0.40	/kg	$50.00
	Urea (1st application)	90	kg/ha	@	$0.58	/kg	$51.75
	Urea (2nd application)	90	kg/ha	@	$0.58	/kg	$51.75
	Urea (3rd application)	90	kg/ha	@	$0.58	/kg	$51.75
	Application cost	4		@	$12.00	/ha	$48.00
Total							**$2,006.85**

Appendix 2: Maize silage direct costs

Item	**Details**	**Rate**			**Cost**		**Total cost ($/ha)**
Spray out pasture	Roundup	4	L/ha	@	$11.22	/L	$44.88
	Application				$20.00	/ha	$20.00
Cultivation	Plough				$138.00	/ha	$138.00
	Maxi-till	2		@	$45.00	/ha	$90.00
	Cambridge roll				$30.00	/ha	$30.00
Sowing	Precision drill				$125.00	/ha	$125.00
Seed	100,000 seeds/ha	38	kg/ha	@	$13.80	/ha	$524.40
Pre-emergence herbicide							
	Atrazine	3	L/ha	@	$5.96	/L	$17.88
	Trophy NF	3	L/ha	@	$17.87	/L	$53.61
	Application cost				$20.00	/ha	$20.00
Fertiliser							
	Cropzeal 15P (incorporated)	250	kg/ha	@	$0.83	/kg	$207.25
	Urea (1st application)	110	kg/ha	@	$0.58	/kg	$63.25
	Urea (2nd application)	110	kg/ha	@	$0.58	/kg	$63.25
	Application cost	3		@	$12.00	/ha	$36.00
Harvesting and stacking					$980.00	/ha	$980.00
Silage stack covering					$170.00	/ha	$170.00
Inoculant					$280.00	/ha	$280.00
Total							**$2,863.52**

Appendix 3: Oat silage direct costs

Item	Details	Rate			Cost		Total cost ($/ha)
Sowing	Direct drill				$100.00	/ha	$100.00
Seed	Oats (white)	89	kg/ha	@	$0.65	/kg	$57.85
Weed, pest and disease							
1st application	MCPA	3	L/ha	@	$12.39	/L	$37.17
	Opus	0.5	L/ha	@	$34.61	/L	$17.31
2nd application	Opus	0.5	L/ha	@	$34.61	/L	$17.31
	Amistar	0.5	L/ha	@	$100.87	/L	$50.44
	Application cost	2		@	$20.00	/ha	$40.00
Fertiliser							
	Cropzeal 16N (with drill)	150	kg/ha	@	$0.71	/kg	$106.65
	Urea (1st application)	55	kg/ha	@	$0.575	/kg	$31.63
	Urea (2nd application)	55	kg/ha	@	$0.575	/kg	$31.63
	Application cost	2		@	$12.00	/ha	$24.00
Harvesting and stacking					$550.00	/ha	$550.00
Covering					$77.00	/ha	$77.00
Total							**$1,140.97**

Appendix 4: Wheat direct costs

Item	Details	Rate			Cost		Total cost ($/ha)
Spray out pasture	Roundup	4	L/ha	@	$11.22	/L	$44.88
	Application				$20.00	/ha	$20.00
Cultivation	Plough				$138.00	/ha	$138.00
	Maxi-till	2		@	$45.00	/ha	$90.00
	Cambridge roll				$30.00	/ha	$30.00
Sowing	Conventional drill				$75.00	/ha	$75.00
Seed	Feed wheat	120	kg/ha	@	$1.11	/kg	$133.20
Fertiliser							
	Cropmaster 11	200	kg/ha	@	$0.79	/kg	$158.68
	Urea (1st application)	100	kg/ha	@	$0.58	/kg	$57.50
	Urea (2nd application)	100	kg/ha	@	$0.58	/kg	$57.50
	Urea (3rd application)	100	kg/ha	@	$0.58	/kg	$57.50
	Application cost	4		@	$12.00	/ha	$48.00
Weed, pest and disease							
1st application	Cougar	0.75	L/ha	@	$66.60	/L	$49.95
	Glean	15	g/ha	@	$0.63	/L	$9.45
2nd application	Opus	0.5	L/ha	@	$34.61	/L	$17.31
	Amistar	0.75	L/ha	@	$100.87	/L	$75.65
3rd application	Opus	0.5	L/ha	@	$34.61	/L	$17.31
	Amistar	0.5	L/ha	@	$100.87	/L	$50.44
	Application cost	3		@	$20.00	/ha	$60.00
Harvest					$280.00	/ha	$280.00
Total							**$1,470.36**

Appendix 5: Regrassing direct costs

Item	Details	Rate			Cost		Total cost ($/ha)
Spray out pasture	Roundup	4	L/ha	@	$11.22	/L	$44.88
	Application				$20.00	/ha	$20.00
Sowing	Direct drill				$100.00	/ha	$100.00
Seed	Perennial ryegrass	18	kg/ha	@	$9.45	/kg	$170.10
	White clover	4	kg/ha	@	$15.00	/kg	$60.00
Post emergence herbicide	Pulsar	6	L/ha	@	$12.35	/L	$74.09
	Application				$20.00	/ha	$20.00
Total							**$489.07**

Appendix 6: Linear programme

Milk price $4.00/kg MS				**Pasture**	**Maize/oats silage**	**Fodder beet (spring grazed)**	**Fodder beet (autumn grazed)**	**Fodder beet (harvested)**	**Wheat (fed)**	**Wheat (sold)**
Land	160.1	>=	160.1	1	1	1	1	1	1	1
Gross margin ($/ha)	0		0	5,024	3,181	8,456	5,813	5,383	2,020	2,064
Total Gross Margin	$ 858,145		0							
Land area (ha)				126.2	0.0	11.7	13.3	8.9	0.0	0.0