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# Intensification of New Zealand beef farming systems

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ABSTRACT

This study used whole-farm management, nutrient budgeting/greenhouse gas (GHG) emissions and feed formulation computer tools to determine the production, environmental and financial implications of intensifying the beef production of typical New Zealand (NZ) sheep and beef farming systems. Two methods of intensification, feeding maize silage (MS) or applying nitrogen (N) fertiliser, were implemented on two farm types differing in the proportions of cultivatable land to hill land (25% vs. 75% hill). In addition, the consequences of intensification by incorporating a beef feedlot (FL) into each of the farm types were also examined.

Feeding MS or applying N fertiliser substantially increased the amount of beef produced per ha. Intensifying production was also associated with increased total N leaching and GHG emissions although there were differences between the methods of intensification. Feeding MS resulted in lower environmental impacts than applying N even after taking into account the land to grow the maize for silage. Based on 2007/08 prices, typical NZ sheep and beef farms were making a financial loss and neither method of intensification increased profitability with the exception of small annual applications of N, especially to the 75% hill farm. These small annual additions of N fertiliser (<50 kg N/ha/yr applied in autumn and late winter) resulted in only small increases in annual N leaching (from 11 to 14 kg N/ha) and GHG emissions (from 3280 to 4000 kg $CO_2$ equivalents/ha). Limited N applications were particularly beneficial to 75% hill farms because small increases in winter carrying capacity resulted in relatively large increases in the utilisation of pasture growth during spring and summer than the 25% hill farms. Intensification by incorporating a beef feedlot reduced environmental emissions per kg of beef produced but considerably decreased profitability due to higher capital, depreciation and labour costs. The lower land-use capability farm type (75% hill) was able to intensify beef production to a proportionally greater extent than the higher land-use capability farm (25% hill) because of greater potential to increase pasture utilisation associated with a lower initial farming intensity and inherent constraints in the pattern of pasture supply.



## 1. Introduction

Sheep and beef farming occupy nearly 10 million ha of the 15.3 million ha used for agriculture and forestry in NZ (Anon., 2009; Mackay, 2008). New Zealand sheep and beef farming practices, like most agricultural sectors in most countries, are intensifying (Mackay, 2008). Major drivers of intensification include increasing costs (operating, regulatory and compliance), steeply rising land values and the removal of price support for agricultural products during the general deregulation of the NZ economy in the 1980s (MacLeod and Moller, 2006). New Zealand farming, again similar to farming in other countries, increases its production from the same land area by (1) adopting technologies that improve the growth and utilisation of pastures and crops grown on farm (e.g. increased fertiliser application, irrigation), and/or (2) buying in feed that has been grown elsewhere (e.g. grains, silages). New Zealand's climate and land resources, however, have some unique attributes that shape its farming systems and how they can be intensified.

New Zealand's temperate climate has allowed the development of farming systems almost exclusively based on the grazing of perennial pastures. Even though pasture diets do not maximise per animal production, it is profitable because feed and capital costs are much lower than systems where animals are fed in confinement. Conversely, NZ's pasture-based farming systems are challenged by the variation and uncertainty of feed supply because of inter- and intra-annual variation in pasture growth rates. Farmers adapt to this variation by timing lambing/calving so the period of maximum pasture growth in spring coincides with maximum

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feed demand. In practice, however, the number of animals available to take advantage of spring growth is limited by the number of animals able to be successfully fed during the winter (i.e. winter carrying capacity). This is because, even though winter diets are often supplemented with hay, silage and forage crops, winter pasture growth rates are typically 5–6 times lower than those in late spring/early summer (Baars, 1976; Radcliffe, 1974, 1976). This results in feed supply in late-spring/summer exceeding demand to some degree on most NZ farms.

Approximately half of NZ's agricultural land is flat to rolling and half is hill to steep (Mackay, 2008). For farms with flat to rolling topography, some of the spring surplus of pasture can be conserved as hay or silage for feeding during feed deficits. However, for farms with higher proportions of hill to steep land, where it is not possible to use tractors, a greater proportion of the spring surplus is lost to senescence and decay. Not only is there a loss of quantity but the quality (e.g. digestibility) of the remaining biomass is also lower which reduces animal production (Litherland and Lambert, 2007). To varying degrees, therefore, NZ pastoral farms are characterised by inefficiency where the amount of feed consumed is less than the amount grown. Minimising this inefficiency, by adopting technologies that increases winter carrying capacity, is often the key to intensification of NZ farming systems.

Dairy farming is typically the most intensive form of pastoral farming in NZ and the most significant technologies that have allowed the dairy industry to intensify production per hectare over the last 2–3 decades are the use of nitrogen fertiliser to increase pasture growth and supplementary feeding with maize silage (Basset-Mens et al., 2009). Nitrogen has been particularly important for increasing pasture growth in late winter/early spring when soil nitrogen levels can be relatively low but demand for pasture is increasing rapidly because animals are in early lactation (Bartlett and McKenzie, 1982). Maize silage has provided dairy farmers with a relatively low-cost feed that is low in protein but moderate in energy – characteristics that complement NZ's typically high protein ryegrass/white clover pastures very well (Kolver et al., 2001).

The increasing pressure to intensify production in the sheep and beef farming sector may result in the widespread adoption of intensification technologies that are now considered standard practice by the dairy industry. Historically, improved sub-division (smaller paddocks) and phosphate fertilisers were important intensification technologies (Smallfield, 1956). More recently, tactical applications of nitrogen fertiliser have also lead to increased hill country carrying capacity (Clark and Lambert, 1989; Gillingham et al., 2007; Nie et al., 1998). Even though maize silage has not been widely adopted in the sheep and beef sector in NZ to date, it has been found that supplementing grazing beef animal diets with maize and/or cereal grains can significantly increase live weight gain (Boom and Sheath, 1998, 1999; Muir et al., 1998). Research into the implications of intensification has currently shifted from a production focus (Mace, 1980), to the direct detrimental impacts on natural resources (Ledgard et al., 2003) such as soil, water, and the atmosphere and the flow-on effects on biological systems. The higher stocking rate and/or changes in animal type that usually result from intensification has led to increasing losses of nutrients to ground and surface water (Hoogendoorn et al., 2008; McDowell et al., 2006; Monaghan et al., 2005, 2007b), deterioration of soil physical quality (Betteridge et al., 2003; Roach and Morton, 2005), contamination of waterways with pathogens and sediment (McDowell et al., 2006) and increasing greenhouse gas emissions (Hoogendoorn et al., 2008; Waugh et al., 2005).

Further intensification will lead to greater environmental impacts unless systems and management practices that mitigate such impacts are adopted. For example, on- and off-pasture feeding of maize and cereal silages and grains to beef animals is common in many North American and European countries but rarely practiced in NZ because of the need to keep feed and capital costs low. Shifts in world commodity prices and/or increased regulatory constraints may drive NZ farmers to consider confined animal feeding during winter because it presents an opportunity to capture animal excreta, and redistribute it evenly on pasture. Patchiness of animal excreta return is the major driver of nitrate leaching in NZ pastures (Ledgard et al., 1999). There is already evidence of this occurring in the dairy industry with the proliferation of 'herd homes' for feeding during wet periods (Longhurst et al., 2006).

The objective of this study was to explore, using farm simulation (Farmax® Pro), feed formulation (Be$tFeed™) and nutrient budgeting (OVERSEER®) models, potential production, environmental, and financial implications of three technologies (maize silage, nitrogen use or feedlot) that could intensify beef production from NZ hill country sheep and beef farms. These intensification strategies were applied to two farm types that differed in land-use capability as represented by varying the proportions of cultivatable land to hill land. In addition, these on-pasture intensification strategies were contrasted with the incorporation of an off-pasture feedlot into each of the farm types.

## 2. Methods

### 2.1. Models used

Farmax® Pro (version 6.2.15.2, www.farmax.co.nz) was the primary tool used in this modelling exercise. Built from the model Stockpol (Marshall et al., 1991), this whole-farm management software lets the user explore the consequences of changes to farm stocking policy. The key function of Farmax Pro is to determine if the planned stocking policy is *biologically feasible*. Farmax Pro determines biological feasibility by first calculating the minimum whole-farm pasture cover required to meet animal demand (NB: the term "pasture cover" when used in a farm pasture management context refers to pasture mass and not vegetation cover over the soil). Then, if pasture cover predicted from the balance of whole-farm feed supply and demand is below or excessively above the minimum required the farm is declared 'infeasible' and the user explores changes in management required to achieve feasibility e.g. buy in supplementary feed, increase pasture growth with fertiliser.

Farmax Pro is a metabolisable energy (ME) based model. On the feed supply side, Farmax Pro treats the whole-farm (minus areas allocated to crops) as if it is a single paddock of pasture comprising green, stem and dead tissue pools. All pools are defined by user modifiable values for ME. If more than one pasture block is specified then the whole-farm paddock is a weighted average of the block pasture quality characteristics. For each block, the user enters monthly values for pasture growth rate or selects from a NZ regional database library included with Farmax Pro. It is assumed that this is the growth of pasture at a pasture cover of 1800 kgDM/ha. Pasture growth rates are scaled down as pasture cover changes from this assumed optimum. This is incorporated to accommodate the effect of low leaf area on growth at low pasture covers and the effect of shading at high pasture covers. The loss of pasture mass due to senescence and decay is also modelled in Farmax Pro. An increasing proportion of biomass is transferred from the green to the stem and dead pools as pasture cover increases, especially in the spring to summer period if pasture cover exceeds 2400 kgDM/ha. Numerous supplementary feeds may also be incorporated; their timing, quality (ME) and quantity are specified by the user.

On the feed demand side, animal ME requirements are based on equations contained within Parks (1982). ME requirements are summed for the whole-farm and are influenced by the number of animals, live weight, live weight gain, sex and physiological status (pregnant, lactating, dry). Pregnancy requirements are derived from the day of pregnancy and total birth weight and lactation requirements are based on size of animal and weaning percentage. Meeting ME requirements can be limited by intake. Farmax Pro calculates potential intake and does not allow it to be exceeded. Farmax Pro does not, however, determine if protein requirements are met by the diet on offer because the NZ farming systems are pasture-based and typically have excessively high protein contents (Pacheco and Waghorn, 2008). Farmax Pro assumes a normal distribution of animal attributes such as live weights and lambing/calving dates when the farm is initially set up. However, the model appropriately skews distributions depending on policies implemented.

Be$tFeed™ (version 5.1.00), a supplementary feed and animal requirements decision support tool (Pacheco, 2002), was developed to help sheep and beef farmers make informed decisions about *short-term* supplementary feeding. It does this by calculating the nutrient requirement for a particular breed and class of stock to achieve specified levels of performance. Then it determines if the user-specified available quantity and quality of a base feed (typically pasture in NZ) is sufficient to meet animal requirements in terms of energy, protein and neutral detergent fibre. If it is not sufficient, the model then determines the least cost formulation of base feed and available supplement(s) that meets the animal's nutritional requirements. Energy and protein requirements are calculated as the sum of the requirements for maintenance and productive purposes and are based on published Australian feeding standards for ruminant animals (Anon., 1990). The model also determines if required daily dry matter intake (DMI) exceeds possible maximum daily DMI based on published data (Anon., 1980). The optimization problem in Be$tFeed is solved by using a genetic algorithm approach. The settings for population size, crossover probability, mutation probability and maximum number of generations were 50, 0.5, 0.1 and 1000.

Be$tFeed was used to aid Farmax Pro in the modelling of off-pasture intensification (i.e. incorporating a feedlot). Be$tFeed was used *before* Farmax Pro modelling to determine a feasible per animal daily ration of pasture silage and maize silage that met their energy and protein requirements and maximum intake restrictions given animal age, live weight and target rate of live weight gain. It was assumed that the pasture silage made on farm and the maize silage bought in had the same cost. These daily rations were then summed to determine the monthly and total amount of pasture and maize silage to feed to the animals contained in the feedlot created in Farmax Pro.

The nutrient budget model OVERSEER® (Version 5.2.6.0, http://www.agresearch.co.nz/overseerweb/) was used to determine the environmental impacts of intensifying the farming systems. The stocking policy, management decision and farm physical characteristic information from the Farmax Pro modelling was used to parameterize OVERSEER. OVERSEER is a farm-scale model that develops budgets for major soil nutrients (N, P, K, S, Ca, Mg and Na) for most NZ farming enterprises (Wheeler et al., 2006). The primary purpose of the model is to prepare reports from which the user can make decisions on nutrient requirements for a farm and/or blocks of land within a farm. Of interest to this modelling exercise is the ability to calculate nitrate leaching and on-farm emissions of greenhouse gases – methane, nitrous oxide and carbon dioxide (Wheeler et al., 2008).

The model is constructed from a series of empirical submodels, the data for which has largely been derived from NZ field experiments. Of importance to this study are nitrogen losses to the environment. OVERSEER recognises that the major driver of N leaching losses in grazing systems is urine N deposition. The amount of N deposited as urine is determined by animal N intake and how that N is partitioned to animal products and excreta. Excreta partitioning to dung and urine is determined by the N concentration of the diet. N concentration in pasture in NZ is dependent on species composition (which is closely associated to topography), and N fertiliser application. The submodel is expanded to the farm scale by including N losses from other sources such as dung and fertiliser (ammonia volatilisation) and transfers to lanes, effluent ponds and feed pads.

A metabolisable energy (ME) intake submodel determines pasture intake by animals. For sheep and beef animals, OVERSEER uses 'stock units' to estimate annual ME requirements with one stock unit being equivalent to an intake of 6000 megajoules (MJ) ME/yr (Woodford and Nicol, 2004). The number of stock units differs for different stock classes. For example, a breeding cow is $\sim$5 stock units compared to $\sim$1 stock unit for a breeding ewe. OVERSEER contains a stock unit calculator which takes into account flock/herd size, animal live weight, fecundity and trading policy to calculate total farm stock units.

Farm methane emissions from animals are calculated according to the national inventory method for animal enteric $CH_4$ emissions where estimates of monthly digestible dry matter intake (DDMI) for different animal types are multiplied by $CH_4$ emission factors (Anon., 2008b). The model accounts for different pasture types that have different emission factors. For good quality pasture (e.g. dominated by *Lolium perenne* and *Trifolium repens*) and supplementary feeds the emission factor is 26.5 g $CH_4$/kg DDMI whereas lower quality pasture (dominated by *Agrostis capillaris*) has an emission factor of 34.5 g $CH_4$/kg DDMI (Wheeler et al., 2008). Methane emissions from dung patches and effluent ponds are also estimated.

Nitrous oxide emissions are based NZ Intergovernmental Panel on Climate Change (IPCC) inventory methodology (Anon., 2008b) and are estimated from the size of N excreta and effluent inputs multiplied by emission factors. Also included are estimates for direct and indirect $N_2O$ losses from fertiliser (Wheeler et al., 2008).

When calculating environmental emissions, OVERSEER is confined to those occurring within the farm boundary. For example, OVERSEER accounts for the nitrate leached and nitrous oxide emitted from pastures and crops grown on the farm but not from the land used to grow purchased supplementary feed crops that are grown off the farm. However, OVERSEER does estimate embodied $CO_2$ emissions (Wells, 2001). Embodied emissions are generated by on-farm activities as well as emissions associated with products supplied to or sent from the farm. Examples relevant to this study include embodied emissions for fertiliser and feed supplements bought into the system (Wheeler et al., 2008).

### 2.2. Base farming systems

Although there is considerable variation in the characteristics of NZ sheep and beef farms, the systems modelled in this study needed to be reasonably representative. To this end, the base stocking policies were based on data collected by the Meat and Wool NZ (M&WNZ) Economic Service surveys (Anon., 2008a). Two hypothetical 400 ha farms, located in the Manawatu region of NZ's North Island (NI), were created within Farmax Pro and represented M&WNZ's NI Intensive Finishing and NI Hill Country categories (R. Webby, pers. comm. 2008). The survey data had their stocking policy and land area scaled to make the farms of equal size (400 effective ha). The farms physically differed in the proportion of hill country land that could not be cultivated for crops or be used for conserving pasture as silage or hay. One farm comprised 25% hill and 75% flat land (H25) and the other 75% hill and 25% flat land (H75). Details of stocking policy and animal management are provided in Table 1 and purchase months and numbers of finishing beef animals for the base farms are shown in Table 2. Average pasture growth data without added nitrogen (N) fertiliser for the flat

**Table 1**
Physical and management characteristics of the two base farms used in the modelling exercise. The farms were the same size (400 effective ha) but differed in the proportion of hill land that could not be cultivated for crops or used for conserving pasture supplements. One farm comprised 25% hill and 75% flat land (H25) and the other 75% hill and 25% flat land (H75). Abbreviations and explanations: s.u. = stock unit (see Appendix 1 for definition); animals numbers are number wintered unless stated otherwise; weaning % is the number weaned to number ewes/cows mated; bull calves were Friesian and purchased.

| Characteristic | Units | H25 | H75 | Characteristic | Units | H25 | H75 |
|---|---|---|---|---|---|---|---|
| Sheep stock units | s.u. | 2608 | 2560 | Area | Flat ha | 300 | 100 |
| Beef stock units | s.u. | 3032 | 2069 | | hill ha | 100 | 300 |
| Ewes | No. | 1623 | 1692 | Average rainfall | mm/yr | 1000 | 1000 |
| Lambing | Mid date | 28 August | 2 September | Average annual temperature | °C | 13.3 | 13.3 |
| Weaning | Date | 26 November | 1 December | Pasture | t DM/ha/y | 8.8 | 8.3 |
| Wean percent | % | 130 | 118 | Kale | Ha | 15 | 5 |
| Rams | No. | 28 | 28 | | t DM util./ha | 11 | 11 |
| Lambs | No. sold | 2203 | 1981 | | Date sown | 15 October | 15 October |
| Av. wean wgt | kg | 31 | 27 | | Date fed | June-August | June-August |
| Cows | No. | 33 | 68 | Pasja forage | Ha | 15 | 5 |
| Calving | Mid date | 3 September | 9 September | | t DM util./ha | 7 | 7 |
| Weaning | Date | 3 March | 9 March | | Date sown | 1 November | 1 November |
| Wean percent | % | 84 | 84 | | Date fed | June-February | June-February |
| Calves | No. | 106 | 68 | Silage | Ha | 30 | 10 |
| Av. wean wgt | kg | 237 | 211 | | t DM util./ha | 3.3 | 3.3 |
| Heifer calves | No. | 52 | 34 | | Date made | October-December | October-December |
| 1-Year heifers | No. | 66 | 54 | | Date fed | June-August | June-August |
| 2-Year heifers | No. | 94 | 47 | | | | |
| Breeding bulls | No. | 7 | 4 | | | | |
| Steer calves | No. | 54 | 34 | | | | |
| 1-Year steers | No. | 54 | 34 | | | | |
| 2-Year steers | No. | 46 | 28 | | | | |
| Bull calves | No. | 128 | 54 | | | | |
| 1-Year bulls | No. | 128 | 54 | | | | |
| 2-Year bulls | No. | 126 | 72 | | | | |

**Table 2**
The stock class, time of year and number of finishing beef animal purchased for each level of intensification of the H25 and H75 farms. Farms were intensified by sequentially increasing the number of finishing beef animals purchased above base levels by the percentages below.

| Farm type | Stock class | Month | Percentage increase in number of finishing beef purchased (%) | | | | | | | | | Feedlot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 10 | 30 | 50 | 70 | 100 | 125 | 150 | 200 | |
| H25 | Bull calves | December | 33 | 36 | 43 | 50 | 56 | 66 | | | | 33 |
| | Bull calves | June | 92 | 101 | 120 | 138 | 156 | 184 | | | | 92 |
| | 1-Year bulls | May | 112 | 123 | 146 | 168 | 190 | 224 | | | | 112 |
| | Steer calves | May | 13 | 14 | 17 | 20 | 22 | 26 | | | | 60 |
| | 1-Year strs | May | 17 | 19 | 22 | 26 | 29 | 34 | | | | 170 |
| | 2-Year strs | July | 12 | 13 | 16 | 18 | 20 | 24 | | | | 0 |
| H75 | Bull calves | December | 53 | 58 | 69 | 80 | 90 | 106 | 119 | 133 | 159 | 53 |
| | 1-Year bulls | May | 18 | 20 | 23 | 27 | 31 | 36 | 41 | 45 | 54 | 18 |
| | Steer calves | April | | | | | | | | | | 55 |
| | Steer calves | May | | | | | | | | | | 56 |
| | 1-Year strs | May | 8 | 9 | 10 | 12 | 14 | 16 | 18 | 20 | 24 | 185 |
| | 2-Year strs | July | 13 | 14 | 17 | 20 | 22 | 26 | 29 | 33 | 39 | 0 |

land were obtained from a cutting trial near Marton (Radcliffe, 1976) and the hill land pasture growth rates were from a trial at Ballantrae near Woodville (A. Litherland, personal communication 2008). The area-weighted average pasture growth profiles of the H25 and H75 farm types are shown in Fig. 1 and the pasture conservation and cropping practices are given in Table 1.

### 2.3. Intensifying production

In Farmax Pro intensification was achieved by increasing animal numbers rather than increasing the rate of live weight gain. Although typical NZ hill farms contain both sheep and cattle (as shown in the M&WNZ Economic Service Surveys), this study was set up to investigate the effects of intensifying beef production on NZ farms. Therefore, sheep numbers were held constant and only finishing beef animal numbers (Friesian bulls and beef steers) were increased. Intensification was achieved by increasing the number of animals purchased rather than increasing the number of purchase events or increasing breeding stock. After the animal purchases were increased, the farms became biologically infeasible due to a feed deficit created by the increased demand. The feed deficits were then met by either feeding purchased maize silage (+MS) or by increasing pasture growth rate by applying nitrogen (+N) as urea. A series of increments in the number of finishing beef animals purchased (up to 200% above base level), was examined (Table 2).

### 2.4. On-pasture intensification – feeding maize silage

For each level of intensification, sufficient MS was fed in Farmax Pro for the farm to become feasible with the increased stock numbers (Table 3). These farm systems are denoted as "H25 + MS" and "H75 + MS". There were no limitations to the supply of MS imposed because the MS was bought-in, however, because this was a study of beef farming intensification it was assumed that it could only be fed to finishing beef animals. Typical NZ sheep and beef

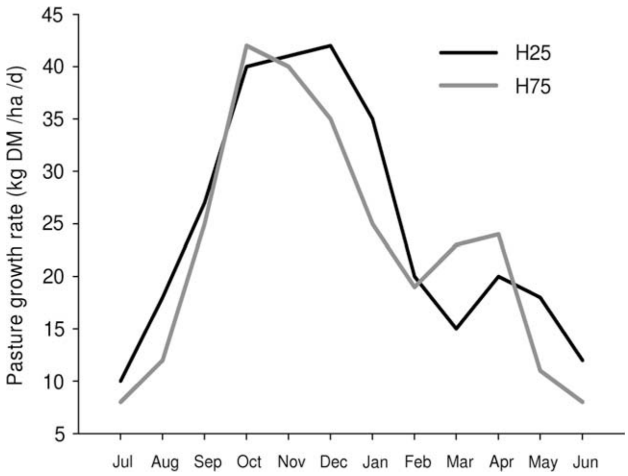


**Fig. 1.** Average area-weighted farm pasture growth rates for the H25 and H75 farms. H25 and H75 refer to the land-use capability of the farms modelled. One farm comprised 25% hill and 75% flat land (H25) and the other 75% hill and 25% flat land (H75).

farming practice is to maximise pasture intake and only feed supplements when pasture growth is insufficient to meet animal demand (Rattray et al., 2007). Accordingly, the feeding of MS was restricted to cool season months – April–September in NZ. MS was specified with an energy content of 10 MJME/kg DM. Be$tFeed™ was used to ensure that the proposed daily feed intake and protein content of the total diet offered were appropriate. It was assumed that the MS was fed in troughs placed in paddocks.

### 2.5. On-pasture intensification – nitrogen fertiliser

The second option for meeting the greater farm feed demand from intensification was applying N to increase pasture growth. These farm systems are denoted as "H25 + N" and "H75 + N". The same percentage increases in finishing beef animal numbers were used for the +N as the +MS simulations. Nitrogen was only applied in autumn (March–May) and late winter/spring (August–October) (Table 4) because that is often when pasture growth is limiting animal production and reliable responses to N can be achieved (O'Connor, 1982). It was assumed that applying N only increased growth and did not influence pasture quality. Conservative N response rates were used – 10 kg DM/kg N applied in spring and 5 kg DM/kg N applied in autumn (Ball and Field, 1982; O'Connor, 1982). Nitrogen was first applied to the flat land and, if the feed deficit was not met, then applied to hill land. Industry recommended best practice states that applications rates should not exceed 50 kg N ha/application and 200 kg N ha/yr (Anon., 2002, 2008c). For this modelling exercise, the recommended per application limits for nitrogen were not exceeded but the yearly recommendation was exceeded at the highest levels of intensification.

### 2.6. Off-pasture intensification – feedlot simulation

Incorporating confined animal feeding into the existing farm system was investigated as one of the options for intensifying beef production of the farms. These farm systems are denoted as "H25 + FL" and "H75 + FL". The level of intensification was set by limiting the capacity of the feedlot to that which could be supported by the amount of pasture silage that could be produced on the flat land of the base farm.

The H25 + FL and H75 + FL farms were modelled in Farmax Pro by creating two farms – one representing the base farm and the other the feedlot. Finishing beef animals were transferred between the two as required. Only beef steers were fed in the feedlot as bull animals are typically not confined due to their behavioural characteristics and production of lower value meat (MacNeil et al., 1989). There were two age groups of animals fed in the feedlot. The first group, nine-month old beef steers, were transferred from the base farm to the feedlot on 1 June and transferred back to the base farm on 1 October. They remained on the base farm until slaughter at 530–550 kg live weight in February to April the following year at 17–19 months of age. This group was returned to pasture for finishing to utilise the increase in pasture growth in spring and summer. The second group, 20-month old beef steers, was purchased on 1 May, and went straight into the feedlot where they were fed and finished over the winter months with all animals slaughtered by 30 September at typical NZ live weights of 580–600 kg (Gleeson and Morris, 2003).

The diet fed in the feedlot was a mixture of made-on-farm pasture silage and bought-in maize silage. Be$tFeed was used to calculate appropriate daily proportions of maize and pasture silage in the diet of both age groups of animals. The objective was to achieve a rate of live weight gain that would allow the mobs to meet their target live weights for slaughter (at least 1 kg per day). The nine-month old steers were fed a diet of 5.5 kg DM pasture silage and 2.5 kg DM maize silage per day. The 20-month old steers were fed a diet of 4 kg DM pasture silage and 7.5 kg DM maize silage.

### 2.7. Environmental impacts

The farm system, cropping, stock policy and fertiliser information from the Farmax Pro simulations were entered into OVERSEER

**Table 3**
Maize silage fed (t DM) by month and annual total for each level of intensification for the H25 + MS and H75 + MS farms. Farms were intensified by sequentially increasing the number of finishing beef animals purchased above base levels by the percentages below.

| Farm type | Month | Percentage increase in number of finishing beef purchased (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 10 | 30 | 50 | 70 | 100 | 125 | 150 | 200 |
| H25 | April | 0 | 0 | 0 | 50 | 75 | 80 | | | |
| | May | 0 | 0 | 30 | 60 | 80 | 140 | | | |
| | June | 0 | 15 | 30 | 60 | 85 | 150 | | | |
| | July | 0 | 15 | 55 | 60 | 80 | 150 | | | |
| | August | 0 | 15 | 55 | 50 | 80 | 145 | | | |
| | September | 0 | 15 | 30 | 50 | 80 | 145 | | | |
| | Total Fed | 0 | 60 | 200 | 330 | 480 | 810 | | | |
| H75 | April | 0 | 0 | 0 | 0 | 15 | 10 | 25 | 35 | 80 |
| | May | 0 | 0 | 0 | 0 | 18 | 25 | 35 | 50 | 80 |
| | June | 0 | 0 | 0 | 12 | 19 | 35 | 45 | 60 | 80 |
| | July | 0 | 0 | 11 | 14 | 19 | 40 | 50 | 65 | 90 |
| | August | 0 | 0 | 9 | 15 | 19 | 40 | 50 | 65 | 90 |
| | September | 0 | 4 | 7 | 12 | 17 | 35 | 45 | 60 | 90 |
| | Total Fed | 0 | 4 | 27 | 53 | 107 | 185 | 250 | 335 | 510 |

**Table 4**
Total annual tonnes and average kilograms of nitrogen per ha applied (as urea) to the H25 + N and H75 + N farms for each level of intensification. Farms were intensified by sequentially increasing the number of finishing beef animals purchased above base levels by the percentages below.

| Farm type | Total | Percentage increase in number of finishing beef purchased (%) | | | | | | | | | Feedlot |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 10 | 30 | 50 | 70 | 100 | 125 | 150 | 200 | |
| H25 | Flat | 0 | 6 | 36 | 48 | 60 | 96 | | | | 0 |
| | Hill | 0 | 0 | 0 | 0 | 15 | 24 | | | | 0 |
| | Farm | 0 | 6 | 36 | 48 | 75 | 120 | | | | 0 |
| | kg N/ha | 0 | 15 | 90 | 120 | 188 | 300 | | | | 0 |
| H75 | Flat | 0 | 2 | 4 | 13.5 | 21 | 16 | 20 | 20 | 20 | 0 |
| | Hill | 0 | 0 | 0 | 0 | 0 | 18 | 36 | 42 | 75 | 0 |
| | Farm | 0 | 2 | 4 | 13.5 | 21 | 34 | 56 | 62 | 95 | 0 |
| | kg N/ha | 0 | 5 | 12 | 34 | 53 | 85 | 140 | 155 | 238 | 0 |

to calculate annual nutrient balances, nitrate leaching and greenhouse gas emissions. The soil type specified for both farm types in OVERSEER was a melanic sedimentary soil (Kiwitea silt loam). The soil had a phosphorus (Olsen) concentration of 16 ppm with >100 mm water holding capacity in the root zone. Single superphosphate fertiliser (percentages of elemental N, P, K and S were 0, 9, 0, 11) was applied annually to the flat block and biennially to the hill block at a rate of 250 kg/ha. For the +FL farms the effluent was collected from the feedlot and evenly sprayed back over the flat land block at medium application rates (12–24 mm soil depth penetration).

OVERSEER only accounts for on-farm N leaching. Under +MS intensification nitrogen can be leached and $N_2O$ emitted from the land growing the maize. Nitrogen losses from maize crops can vary considerably depending on fertiliser management, climate and soil type. In a recent study in the Taupo region of NZ, first year trial results indicated greater than 200 kg N/ha can be leached under a combination of maize and annual ryegrass (Betteridge et al., 2007). This study was conducted on freer draining soil in a higher rainfall zone than the present study. Alternatively, Williams et al. (2007) incorporated nitrate leaching of 75 kg N/ha/yr from the land that grew maize silage in a study comparing solely-pasture fed vs. MS supplemented dairy farming and a life-cycle assessment study by Basset-Mens et al. (2009) of dairy farming in the Waikato region of NZ used a figure of 47 kg N/ha/yr. For the current study, 75 kg N/ha/yr was added to the calculations of whole system N leaching. We assumed a maize silage yield of 20 t DM/ha (Densley et al., 2005).

Luo et al. (2008) determined that in the Waikato region of NZ, on average 0.1 kg $N_2O$ is emitted per tonne of maize silage produced. This value was used in the present study to add the $N_2O$ contribution from the maize silage land to total system $N_2O$ and GHG emissions assuming a global warming potential for $N_2O$ of 310.

### 2.8. Financial outcomes

Financial pre-tax profit or loss was calculated for each level of intensification as the difference between total farm revenue and total farm expenses. Total farm expenses included repairs and maintenance, vehicle expenses, standing charges, administration, drawings, depreciation, interest on borrowing and numerous working expenses (Appendix 1). Farmer equity of land and improvements was set at 95% which is typical of NZ sheep and beef farms (Anon., 2007). It was assumed that the farmer expected no return on equity (i.e. the opportunity cost of equity was not added as an expense) because most NZ farms are family businesses where the farm is passed from one generation to the next generally not available for sale.

Average NZ 2007/08 sheep and beef price schedules (supplied by Farmax® Ltd Helpdesk) and 2008 expense prices were used in the calculation of profit/loss (Chaston, 2008). It was assumed that there were no permanent employees but casual labour was hired to meet the extra workload incurred from intensifying beef production and that the feedlots required one full-time casual employee for 5 months. Feedlot development was assumed to be funded completely from borrowing (Appendix 1). To examine the impact of price variability on profitability, calculations were also made assuming positive and negative shifts of 25% in the beef schedule, cost of maize silage and price of urea.

### 2.9. Data treatment

Although nominally the same, the percentage increase in purchases of finishing beef animals used for H25 and H75 farm types did not result in the same level of intensification because of the inherent differences in stock policy between the two types of base farm. These were primarily differences in stocking rates, purchase/sale dates and balance of bulls to steers. To make valid comparisons between the farm types, the average annual finishing beef stocking rate (FBSR; adjusted animals per ha) was used to represent the level of intensification. Furthermore, for each level of intensification, average annual live weight per animal was used to weight H25 steer and bull numbers against H75 steer and bull numbers. These weighted animal numbers were used in the calculation of FBSR.

## 3. Results

### 3.1. Limits to intensification

For the H25 + MS and H75 + MS farms, increasing finishing beef purchases to greater than 100% and 200%, respectively, resulted in biologically infeasible farms regardless of the amount of MS fed unless it was fed at times outside the predetermined April to September feeding period. The daily intakes of the finishing beef animals often approached but did not exceed the theoretical maximum daily intakes. Protein requirements, even for those animals fed high maize silages diets, were always met.

The +N farms had the minimum amount of N applied so that the FBSRs achieved by the +MS farms were biologically feasible (Table 4). At the highest FBSRs for H25 and H75, N application rates exceeded those recommended by Code of Practice for fertiliser use set by NZ Fertiliser Manufacturers' Research Association. Further applications would have most likely resulted in minimal increases in pasture growth relative to N losses (Ball and Field, 1982).

The maximum number of animals able to be fed in the feedlot depended on balancing the feedlot's annual pasture silage requirement with the need to maintain biological feasibility of the base farm's stocking policy in Farmax Pro. An area of 60 ha of pasture silage, assuming a yield of 3.3 t DM/ha (Howse et al., 1996), 5%

wastage at feeding (Stevens and Platfoot, 2005) and time out of grazing from mid October to mid-December, achieved this balance and allowed for considerable intensification of finishing beef production of both the H25 and H75 farms.

### 3.2. Production

The amount of MS or N required to fill the feed deficit created by the different percentage increases in purchases of finishing cattle varied considerably. On a whole-farm basis for the on-pasture H25 and H75 farms, the highest levels of intensification required inputs of 810 and 510 t DM/yr of MS (Table 3) and 300 and 238 kg N/ha/yr (Table 4). For the H25 + FL and H75 + FL farms, 190 and 235 t DM/yr of MS was required (Table 5). Applying these amounts of N increased annual pasture production by 20% and 16% above unfertilised area-weighted annual pasture values of 8.8 and 8.4 t DM/ha/yr for the H25 and H75 farms.

The impact of intensification on pasture consumption differed between farm types and intensification methods. The general trend for intensification by adding MS was for pasture consumption to initially increase then decrease at higher stocking rates (Fig. 2a). Pasture consumption for the H25 + MS farms was always higher than that of the H75 + MS farms. There was no difference in pasture consumption between the feedlot farms and their grazing +MS counterparts. Meeting the demand of increased beef stocking rates by adding N resulted in a pasture consumption increasing linearly at the same rate for both the +N farm systems (Fig. 2a).

Compared to the base farms, all forms and levels of intensification led to increased pasture utilisation (Fig. 2b). At any given FBSR, pasture utilisation was always lower for H75 than the H25 farm but the overall increase in pasture utilisation was greater for the H75 farm. As FBSR increased, there were declining marginal increases in pasture utilisation toward a maximum (Fig. 2b). At the highest levels of FBSR for the H25 farm pasture utilisation declined. There was no consistent difference between pasture utilisation between the H25 + MS and H25 + N farms. That pattern was repeated for the H75 farms at lower FBSR and at higher FBSR there was consistently higher pasture utilisation in the H75 + MS than in the H75 + N farms (Fig. 2b).

Increasing FBSR increased beef production (Fig. 2c) and at any given level of intensification and the H25 farm achieved slightly higher production than the H75 farm. All +FL farms achieved higher beef production than their on-pasture counterparts at the equivalent FBSR (Fig. 2c). As FBSR increased, both farm types achieved greater beef production per unit of pasture growth (Fig. 2d). For added MS, there was a linear increase in beef production per unit pasture grown with increasing FBSR. In contrast, there were declining marginal gains in beef production per amount of pasture grown in the +N farms (Fig. 2d).

### 3.3. Environmental

Regardless of farm type and intensification method, on-pasture intensification increased nitrate leaching. However, increasing finishing beef animal numbers by feeding MS resulted in much smaller increases in annual nitrate leaching compared to intensification by applying N (Fig. 3a). For example, a 100% increase in FBSR on the H25 + MS farm resulted in a 60% increase in nitrate leaching compared to a 170% increase for the H25 + N farm. The effect of farm type on nitrate leaching depended on the method of intensification. Nitrate leaching was consistently higher from H25 + MS farms than the H75 + MS farms at the same FBSR but with intensification by applying nitrogen, there was greater nitrate leaching from the H75 + N farm than from the H25 + N farm, especially at higher levels of intensification (Fig. 3a). The +FL farms had lower (H75) or the same (H25) annual nitrate leaching compared to their on-pasture counterparts at the same FBSR.

Intensification by feeding MS resulted in a small decrease in N losses per unit of production but intensification by applying N increased N losses (Fig. 3b). The feedlot farms achieved less nitrate leached per kg beef carcass produced than their grazing counterparts at the same FBSR.

Within each farm type and method of intensification, annual total (Fig. 3c) and the components of GHG emissions (Fig. 4) increased as FBSR increased. For the farms that were intensified by feeding MS, total GHG emissions increased linearly with increasing FBSR and the H25 farm, at the same FBSR, had slightly higher total GHG emissions than the H75 farm. For the farms intensified by applying N, total GHG emissions also increased with FBSR but at a much greater rate than the +MS farms. This time, the H25 farm, at the same FBSR, had lower total GHG emissions than the H75 farm (Fig. 3c).

Methane was the greatest contributor to GHG emissions followed by nitrous oxide and carbon dioxide. The rate of increase in methane emissions was essentially the same for all farm types and on-pasture methods of intensification. Nitrous oxide, and to a lesser extent carbon dioxide, were the main contributors to the trends in GHG emissions between farm types and method of intensification (Fig. 4).

Intensification by feeding MS led to lower total GHG emissions per kg of beef production whereas intensification by applying N fertiliser led to increasing GHG emissions per kg of beef production (Fig. 3d). Both the +FL farms achieved lower GHG emissions per kg of beef production than their on-pasture counterparts at the equivalent FBSR (Fig. 3d).

### 3.4. Financial

Using 2007/08 beef schedule prices and 2008 farm expenses, the financial situations for H25 and H75 at base levels of intensification were losses of $25 and $34/ha (Fig. 5e). In general, the impact of intensification via feeding MS or applying N was for further decreases in profitability. There were, however, some low levels of intensification, particularly intensification via applying N, which achieved greater profitability than the base farms. Specifically, the loss achieved at the 10% level of intensification of the H25+N farm was $12/ha less than the base farm and the losses achieved for the 10%, 30%, and 50% levels of intensification of the H75 + N farm were $4, $9 and $4/ha less than the base farm (Fig. 5e). Other key differences based on the 2007/08 schedule prices and expenses included that the H25 farms were more profitable than H75 farms at the same FBSR, intensification by applying N resulted in greater profitability (i.e. less loss) than intensification by feeding MS and the +FL farms were consistently less profitable than their on-pasture counterparts at the same FBSR (Fig. 5e).

**Table 5**
Maize silage (MS) and pasture silage (PS) fed (t DM) by month to beef steers in the feedlots on H25 + FL and H75 + FL farms.

| Farm type | Silage | May | June | July | August | September | Total |
|---|---|---|---|---|---|---|---|
| H25 | MS | 40 | 45 | 40 | 35 | 30 | 190 |
| | PS | 27 | 48 | 45 | 42 | 38 | 200 |
| H75 | MS | 50 | 50 | 50 | 45 | 40 | 235 |
| | PS | 25 | 48 | 43 | 44 | 40 | 200 |

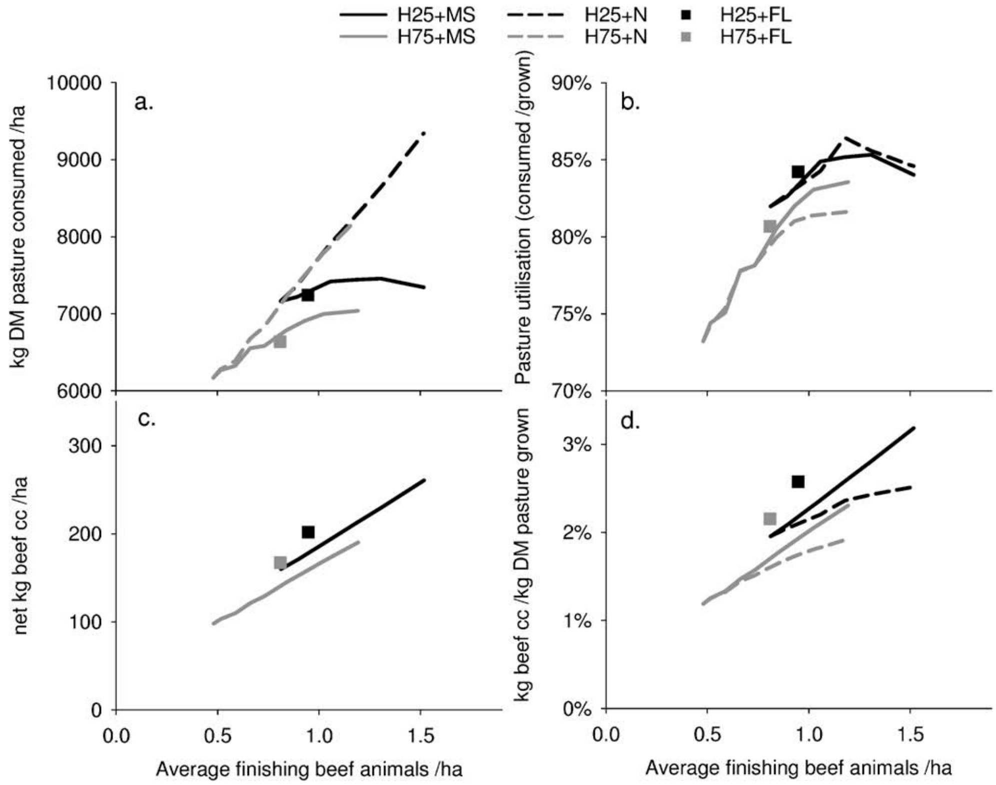


**Fig. 2.** Annual (a) pasture consumption, (b) pasture utilisation, (c) beef production and (d) beef production relative to pasture growth for the modelled farm scenarios. See key for explanation of the lines and symbols of the different scenarios. Graph key abbreviations: beef cc, beef carcass; H25, 25% hill farm; H75, 75% hill farm; +MS, maize silage fed; +N, nitrogen fertiliser applied; +FL, feedlot incorporated into farm. Level of intensification is represented by the weighted average stocking rate of finishing beef animals.

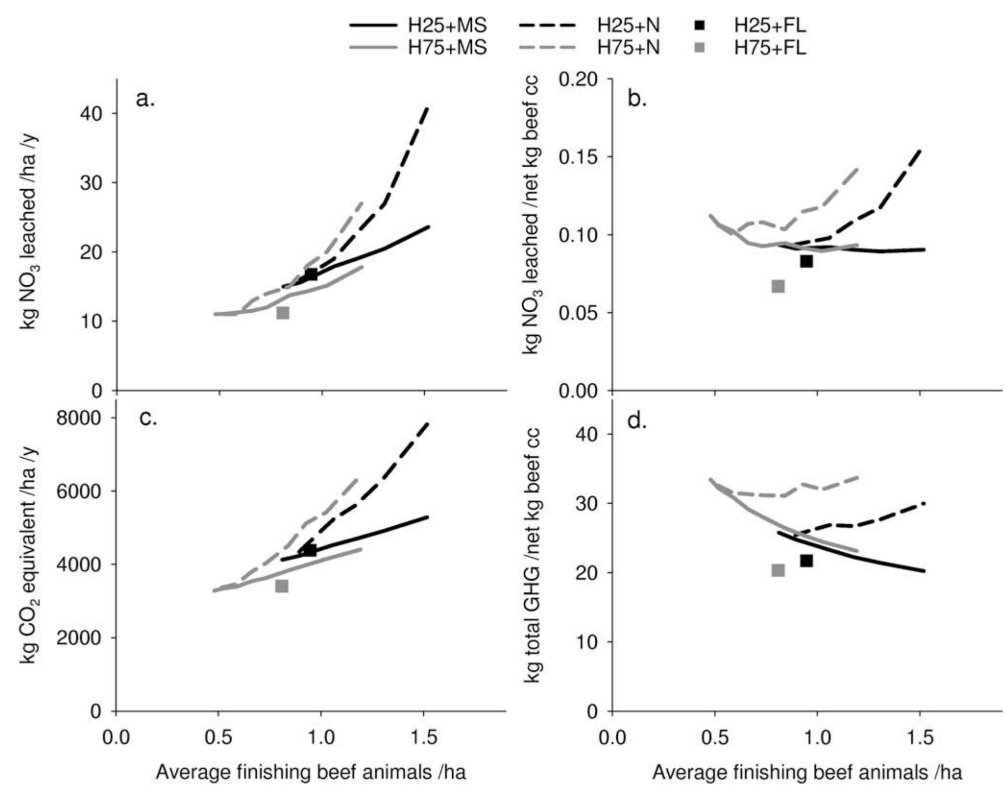


**Fig. 3.** Annual (a) nitrate leaching, (b) nitrate leaching relative to beef production, (c) GHG production, and (d) GHG production relative to beef production for the modelled farm scenarios. Graph key abbreviations: beef cc, beef carcass; H25, 25% hill farm; H75, 75% hill farm; +MS, maize silage fed; +N, nitrogen fertiliser applied; +FL, feedlot incorporated into farm.

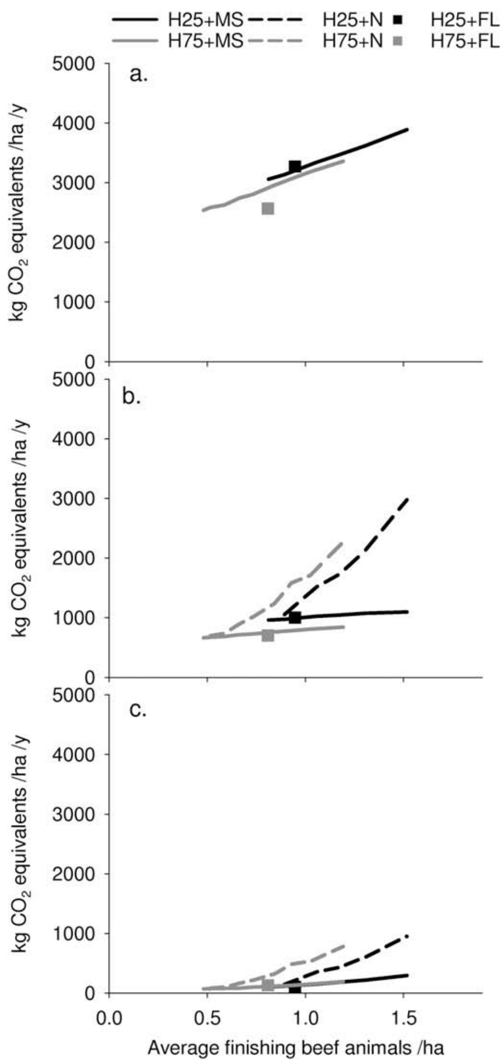


**Fig. 4.** Annual (a) methane, (b) nitrous oxide ($N_2O$) and (c) carbon dioxide ($CO_2$) emissions for 25% hill and 75% hill farms intensified by feeding maize silage, applying nitrogen or establishing a feedlot. $N_2O$ and methane emissions expressed in terms of $CO_2$ equivalents. Graph key abbreviations: H25, 25% hill farm; H75, 75% hill farm; +MS, maize silage fed; +N, nitrogen fertiliser applied; +FL, feedlot incorporated into farm.

To examine the sensitivity of profitability to changes in key input prices, profit/loss calculations were repeated using 25% lower and higher MS, N and beef prices. It was found that regardless of the price of MS or N, all farm types made losses when calculations were based on prices the same or 25% less than the 2007/08 beef schedule (Fig. 5a–f). Only those calculations based on prices 25% higher than the 2007/08 schedule were profitable (Fig. 5g–i). Even at these higher beef prices, profits were eroded with increasing intensification and at no time were the +FL farms profitable.

Profitability was also sensitive to the cost of MS and N. As MS or N input costs increased, the more rapidly profitability decreased with intensification (Fig. 5c, f and i). With 25% lower input prices, some levels of intensification achieved greater profits than the base farms. For example, under 25% higher beef prices and 25% lower N costs, profit for the H75 + N farm was $8, $19, $27, $13 and $20/ha greater than base for the 10%, 30%, 50%, 70% and 100% levels of intensification (Fig. 5g). For the H25+N farm only the 10% level of intensification consistently achieved higher profitability than the base farm. The only other exception was $11/ha greater profit achieved by the 30% increase in the level of intensification under conditions of 25% lower N costs and 25% higher beef prices (Fig. 5g). For the H75 + MS farm with 25% lower MS costs, the 10–50% levels of intensification were more profitable than base whereas for the H25 + MS farm no level of intensification, regardless of MS price, was more profitable than the base farm.

## 4. Discussion

### *4.1. On-pasture beef farming – the production impacts of intensification*

Feeding MS or applying N fertiliser can substantially increase carrying capacity, and therefore, beef production per ha on sheep and beef farms in NZ (Fig. 2c). This agrees with findings from research into intensifying pastoral beef farming systems by feeding maize silage in the USA (Vogel et al., 1989), Australia (Wales et al., 1998) and Argentina (Abdelhadi et al., 2005) and applying nitrogen fertiliser in Ireland (Steen and Laidlaw, 1995). The key advantage of both these approaches to intensification for the NZ situation is that they allow the farm to sustain higher winter stocking rates which results in a greater ability to consume the surplus of pasture that typically occurs in spring and summer. In other words, MS or N helps the farmer to increase the utilisation of pasture grown on farm (Fig. 2b). It has been found that increased pasture utilisation has a positive impact on stock production not only because of greater total pasture quantity consumed per ha but also better control of late spring/summer pasture cover results in less reproductive and dead material within the sward and therefore higher herbage quality (Francis and Smetham, 1985; Litherland and Lambert, 2007).

Marginal increases in pasture utilisation diminished at higher levels of MS feeding because substitution of MS for pasture in the animal's diet ultimately resulted in declining pasture consumption per ha (Fig. 2a). Utilisation also reached a limit at higher stocking rates when N was used to intensify beef production because high levels of N applied in the spring exacerbate the mismatch of feed supply and demand. Inevitably as pasture growth rates increased, some of the herbage material grown was not consumed but became mature, senesced and decayed. In practice, pasture utilisation is also often limited by a compromise between utilisation, pasture growth and the ability to maintain high per animal performance (Webby and Bywater, 2007). At high rates of pasture utilisation animals are forced to graze lower into the sward which simultaneously restricts feed intake (due to smaller quantity obtained per bite and poorer herbage quality consumed, Waghorn and Clark, 2004) and pasture growth (due to reduced leaf area for capturing solar radiation and increased damage to growing points, Parsons and Chapman, 1998).

### *4.2. On-pasture beef farming – the environmental impacts of intensification*

Although intensification by feeding MS resulted increased nitrate leaching (Fig. 3a), it was substantially less than that of the +N farms. On a per kilogram of beef carcass produced basis there was slightly less N leached as FBSR increased (Fig. 3b). NZ pastures typically have protein contents higher than animals require (Litherland and Lambert, 2007; Machado et al., 2005) and adding a low protein feed like MS (7–8% crude protein) helps dilute the total protein content of the diet (Williams et al., 2007). Lower protein levels result in less N being excreted in the urine and, therefore, less nitrate leaching from urine patches (Jarvis et al., 1996).

The large increase in N leaching in the +N farms resulted from the combination of significantly higher N fertiliser inputs and more animals per ha concentrating the surplus N into patches that were

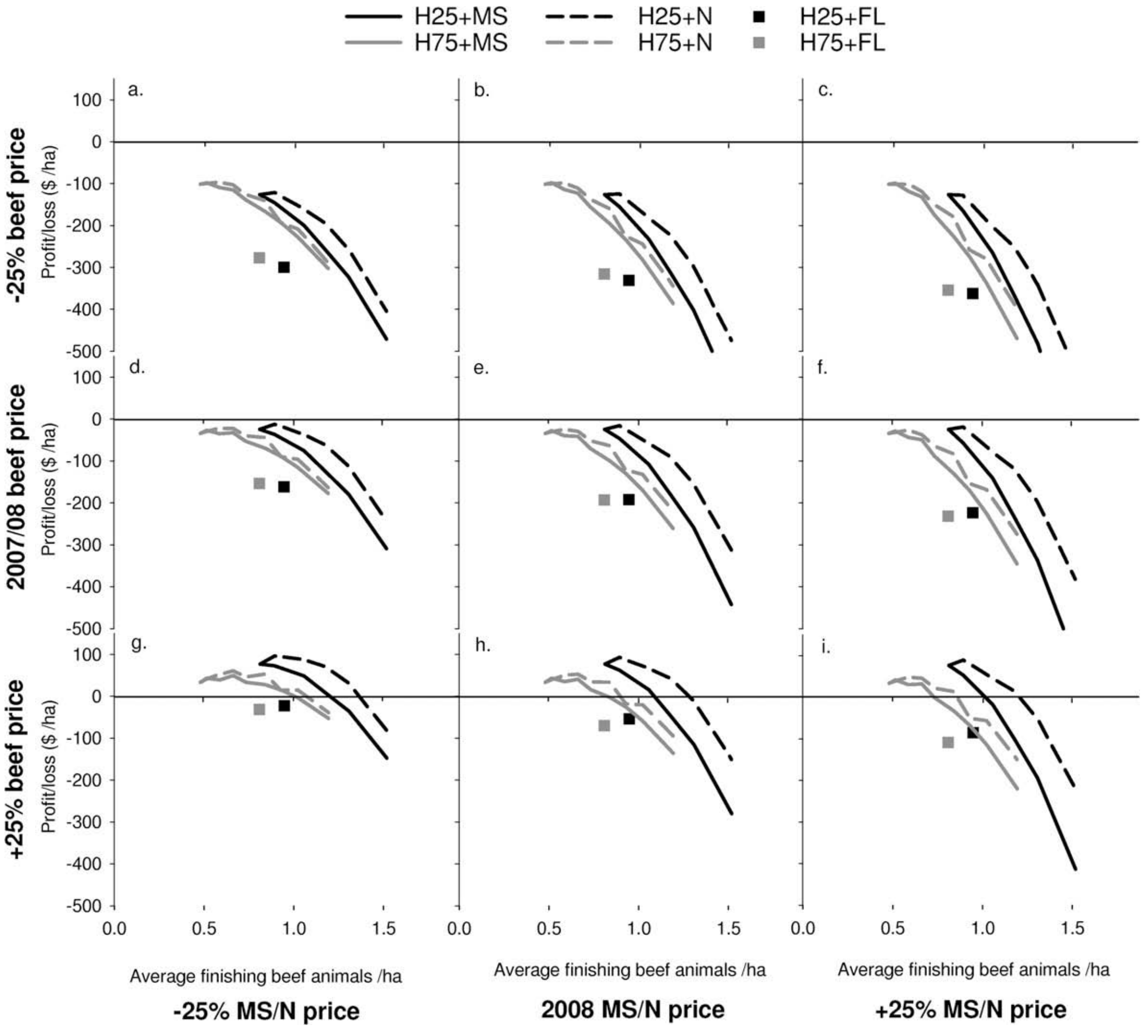


**Fig. 5.** Profit/loss ($/ha) for the modelled farms scenarios using 2007/08 prices for beef, maize silage (MS) and nitrogen (N) and beef prices (e) and expenses that were 25% less than, equal to and 25% greater than 2007/08 values (a–d and f–i). Graph key abbreviations: H25, 25% hill farm; H75, 75% hill farm; +MS, maize silage fed; +N, nitrogen fertiliser applied; +FL, feedlot incorporated into farm.

hot spots for leaching. Applying N to pasture not only increases green leaf growth rate but also herbage N concentration (Litherland and Lambert, 2007). For NZ pastures that typically already contain adequate or excessive protein concentrations for animal maintenance and production, 70–90% of this excess N is converted into ammonia in the rumen and eventually excreted in the urine as urea (Cameron et al., 2007; Holmes et al., 2002). Urine patches contain high concentrations of nitrogen (700–1000 kgN/ha for cattle grazed pastures, Silva et al., 1999), that are usually well in excess of pasture requirements and can ultimately result in 6–20% of N from urine being leached as nitrate (Cameron et al., 2007).

The average nitrogen leaching losses calculated in this modelling exercise were similar to those observed from field measurements. For example, the leaching losses from the H25 farm of this study were 15, 16, 19, 23, 27 and 41 kg N/ha/y under pasture receiving 0, 15, 90, 120, 188 and 300 kg N/ha/y. For comparison, under dairy cattle grazing in Southland NZ, Monaghan et al. (2000) measured leaching losses of 30, 34, 46 and 56 kg N/ha/y under pasture that had nitrogen applications of 0, 100, 200 and 400 kg N/ha/y. While the Monaghan et al. (2000) measurements were slightly higher than those calculated here, Southland is in a higher rainfall zone compared to Manawatu and their intensive dairy farms had higher cattle stocking rates (up to 3 cows/ha). For comparison, a study from a typical Manawatu soil but under sheep grazing measured leaching losses of 13, 34, 46 and 56 kg N/ha/y from paddocks that had nitrogen applications of 0, 100, 200 and 400 kg N/ha/y (Magesan et al., 1996).

Increases in GHG emissions under intensification by feeding MS (Fig. 3c), were largely due to methane rather than nitrous oxide emissions (Fig. 4a and b), and when expressed relative to beef production, total GHG emissions from the +MS farms actually were lower at higher levels of intensification (Fig. 3d). Conversely, applying N had the effect of increasing GHG emissions per kg of beef produced (Fig. 3d). This was primarily due to higher $N_2O$ and $CO_2$ emissions under +N intensification (Fig. 4b and c). The $N_2O$ response has also been observed in sheep-grazed hill pasture soils (Hoogendoorn et al., 2008). Just as with N leaching, the concentration of nitrogen in urine is critical to determining $N_2O$ losses because nitrate (from the hydrolysis and oxidation of urine urea) can be denitrified to produce $N_2O$ gas. Denitrification requires anaerobic conditions (Cameron et al., 2007), therefore, judicious irrigation and grazing decisions and limiting intensification by applying N in areas of NZ that have typically high rainfall (e.g. western regions of South Island) and/or poor soil drainage will help limit GHG emissions from $N_2O$.

Comparison of GHG emissions between studies is difficult due to differences in the assumptions used in the GHG accounting and in the characteristics of the farming systems (Casey and Holden, 2006). In regard to the current study, this is not made any easier by the fact that NZ is relatively unique in the temperate zones of the world in that almost all ruminant livestock are fed outdoors and on a pasture diet. Another temperate region where perennial pasture is the primary feed source for beef farming is Ireland.

Casey and Holden (2006) estimated GHG emissions from three alternative Irish beef farming systems using a 'cradle to farm gate' life cycle analysis approach. They determined that average total GHG emissions from five conventional, five rural environmental protection scheme (REPS: lower stocking rates than conventional; capped N loadings from animals, spread manures and fertilisers; and habitat conservation) and five organic beef farms were 5346, 4372 and 2302 kg $CO_2$/ha/yr.

The total annual GHG emissions determined for the base farms of the current study (4127 and 3280 kg $CO_2$/ha/yr for H25 and H75), were within the range of values determined for the typical Irish beef farms. When the NZ beef farms were intensified by applying N fertiliser, GHG emissions per ha (Fig. 3c), as a result of exponentially increasing $N_2O$ emissions (Fig. 4b), became greater than those of the three Irish systems. It should be noted, however, that per ha comparisons between these countries are not entirely meaningful because NZ beef farming systems have inherently higher stocking density than Irish systems (Table 6). Expressing GHG per stock unit (s.u.) adjusts for differences in farming intensity, and indicates that GHG emissions from typical NZ farms are generally less than those of typical Irish beef farms (Table 6). The only exception to this was at the highest rate of N fertilizer application on the H25 farm.

### 4.3. On-pasture beef farming – the financial impacts of intensification

A key finding from the calculations of financial returns was that, based on 2007/08 sheep and beef schedule and expense prices, typical sheep and beef farming in Manawatu, NZ was not profitable (Fig. 5e). This negative result was consistent with the 2007 survey conducted by NZ's Ministry of Agriculture and Fisheries (MAF). On average, sheep and beef farms in western lower North Island achieved a pre-tax loss of $162/ha for 2006/07 and a forecasted loss of $151/ha for 2007/08 (loss includes cost of drawings and depreciation) (Anon., 2007). Intensifying production by feeding MS or applying N, in general, reduced profitability. However, at any given FBSR, +N farms tended to be more profitable (i.e. achieve a smaller loss) than the +MS farms and, depending on beef price and N cost, some of the lower levels of nitrogen application actually resulted in slightly higher profitability than the no nitrogen base farm (Fig. 5). The main reason for the difference in profitability between +MS and +N systems was that the additional feed supplied by MS cost the farmer $0.25/kg DM compared to $0.16–0.19/kg DM for the extra pasture from nitrogen. There were also higher labour costs associated with feeding out the MS. While these analyses were based on average annual conditions, tactical use of N fertiliser can also be successfully applied in variable environments to buffer some of the risk associated with uncertainty of pasture feed supply (Parker et al., 1994).

The H25 farms were always more profitable than the H75 farms at the same FBSR (Fig. 5). On the H75 farms compared to the H25 farms at the same FBSR, this was due to lower revenue from sheep and higher operating costs associated with supplying the *additional* feed, either by feeding MS or applying N (Fig. 6). In other words, at a given FBSR, lower inherent pasture productivity meant that a greater proportion of the animal's annual diet on the H75 compared H25 farm had to be derived from either MS or N and this came at an extra cost.

### 4.4. On-pasture beef farming – optimal production intensity

Although determining an optimal intensity of beef farming (i.e. optimal stocking rate) was not a primary objective of this study, the curved shape of some of the profit vs. FBSR curves in Fig. 5 suggests limited applications of N fertiliser to intensify beef production will increase the profitability of typical NZ sheep and beef farms. The small magnitudes of the increases in profitability suggest, however, that these farms are already operating at near financial optimality and, in fact, the sensitivity of profitability to input/output prices indicates that there is no one optimal production intensity.

Further evidence of how the financial optimality of production intensity is contextually dependent is illustrated in other studies of beef systems. Crosson et al. (2007), using a linear programming model (the Grange Beef Model), determined that financially optimal calf-to-stocker and calf-to-finish beef systems in Ireland depended on system characteristics and beef price. Financially optimal finishing systems were inherently more intensive than stocker systems at any beef price. As beef price increased, it became financially worthwhile to intensify production by applying more N in calf-to-stocker systems and in calf-to-finish systems to lease additional land. Applying additional N was not an option to intensify the calf-to-finish systems because those systems were already at their upper limit for total N application under EU regulations.

As already mentioned, typical NZ sheep and beef systems generally have greater per ha production intensity than grazing-dom-

**Table 6**
Stocking rate (s.u./ha) and total annual greenhouse gas (GHG) emissions per stock unit (kg$CO_2$/s.u./yr) for the NZ H25 and H75 farms intensified by feeding MS, applying N or incorporating a feedlot and for the average conventional, REPS and organic Irish farms presented in Casey and Holden (2006).

| Variable | Country | Farm type | Percentage increase in number of finishing beef purchased (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 10 | 30 | 50 | 70 | 100 | 125 | 150 | 200 | Feedlot |
| Stock Rt. | NZ | H25 | 14.1 | 14.5 | 15.4 | 16.1 | 16.8 | 18.0 | | | | 15.1 |
| | | H75 | 11.6 | 11.8 | 12.0 | 12.5 | 12.8 | 13.5 | 14.0 | 14.5 | 15.3 | 13.8 |
| | Ireland | Convent. | 12.6 | | | | | | | | | |
| | | REPS | 9.7 | | | | | | | | | |
| | | Organic | 5.4 | | | | | | | | | |
| GHG | NZ | H25 + MS | 293 | 292 | 293 | 293 | 293 | 294 | | | | |
| | | H25 + N | 293 | 300 | 338 | 351 | 379 | 435 | | | | |
| | | H25 + FL | | | | | | | | | | 290 |
| | | H75 + MS | 283 | 284 | 282 | 283 | 283 | 285 | 285 | 286 | 287 | |
| | | H75 + N | 283 | 287 | 288 | 304 | 315 | 335 | 367 | 374 | 418 | |
| | | H75 + FL | | | | | | | | | | 247 |
| | Ireland | Convent. | 424 | | | | | | | | | |
| | | REPS | 451 | | | | | | | | | |
| | | Organic | 426 | | | | | | | | | |

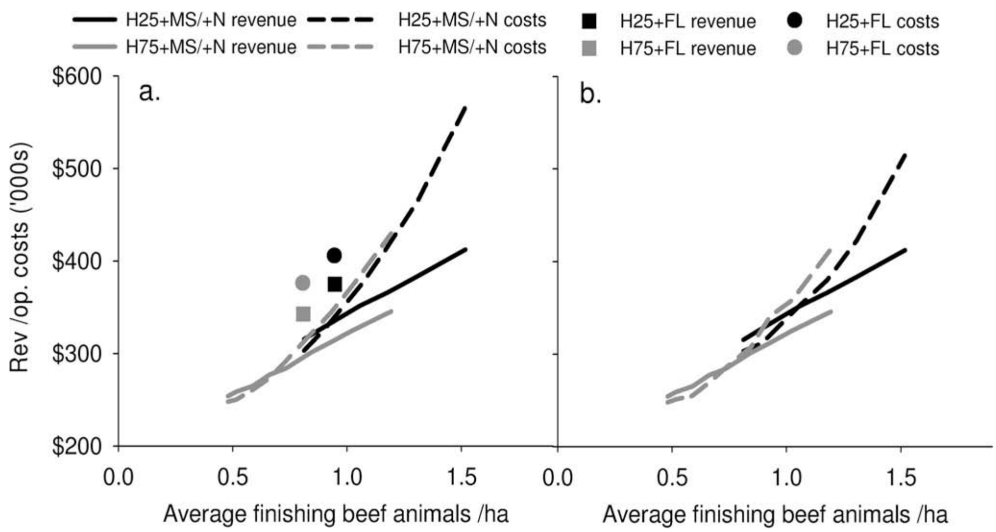


**Fig. 6.** Annual total farm revenue and operating costs for the farms intensified by (a) feeding maize silage (+MS) or establishing a feedlot (+FL) and (b) applying nitrogen (+N). Revenue and expenses based on 2007/08 prices. Graph key abbreviations: H25, 25% hill farm; H75, 75% hill farm. *Note*: legend key for symbol and line descriptions differ to previous figures.

inant systems in Ireland. This is in part due to more favourable climate for growing and grazing pasture year round but also due to political and regulatory differences. New Zealand farmers only receive income from sales, services and/or rentals. Irish farmers, by contrast, also obtain income from governmental incentive programmes, such as REPS and SFP (single farm payment), which essentially pays farmers to modify farming practices and reduce farming intensity so to comply with a range of environmental, animal welfare and food safety regulations.

### 4.5. Off-pasture beef production

The advantage of incorporating a beef feedlot into the NZ pastoral farms modelled here was that most production and environmental indices were either the same or better than the solely on-pasture farms. The production advantages of +FL related to increase feed efficiency from animals growing faster while in the feedlot. Faster growing animals reach killable live weights earlier and, therefore, require less total energy for maintenance over their lifetime (Nicol and Brookes, 2007). The production of the H75+FL farm was particularly advantaged by incorporating a feedlot because it was able to carry more finishing animals than the H25 + FL farm (on average 211 vs. 261 beef steers in the H25 + FL and H75 + FL from May–September). This was due to the H75 base farm having considerably lower pasture utilisation than the H25 base farm (73% vs. 82%; Fig. 2b). By stocking the H75 feedlot with an additional 50 steers, the production potential of this un-utilised pasture was captured when those animals returned to pasture for the spring and summer. Therefore, similar to buying supplementary feed or applying N, incorporating a feedlot in the grazing farms helped increase winter carrying capacity and made better use of the spring pasture surplus.

The environmental advantages of the +FL farms relative to the on-pasture farms related to feedlots providing the opportunity to capture excreted nutrients and then achieve better control over how, when and where those nutrients were returned to soil. Best practice effluent management, as assumed to have occurred here, involves low-rate uniform spraying of effluent over areas that tend to be lower in nutrients (e.g. the silage/hay paddocks), avoiding high drainage times of year (e.g. winter) and/or soil types that are excessively drained (Monaghan et al., 2007a).

The major disadvantage of incorporating a feedlot was that it resulted in considerably lower profitability than on-pasture systems at the same FBSR, regardless of beef schedule and expense prices (Fig. 5a–i). The revenue advantage of the feedlot farms over on-pasture farms was completely eroded by much higher expenses associated with setting-up and operating a feedlot (Fig. 6a and b). It was estimated that $300,000 of capital expenditure was required to build a feedlot capable of feeding up to 300 cattle (including effluent handling equipment). This added to farm depreciation and interest expenses. The feedlot farms also incurred additional labour and operating costs.

### 4.6. Land-use capability and intensification

By either feeding MS or by applying N fertiliser, purchases of finishing beef animals could be increased by up to 100% for the H25 and 200% for the H75 farms. Further increases in FBSR would have been biologically possible but only if predetermined rules around the timing and quantity of feeding or fertilising were relaxed (Sections 2.4 and 2.5). In terms of total farm stocking rate, these changes in finishing beef purchases equated to increases of 27% (from 5640 to 7190 stock units) and 32% (from 4630 to 6130 stock units) for the H25 and H75 farms (see Appendix 1 for definition of a stock unit). Therefore, it would appear that the lower land-use capability farm had a greater potential to intensify production. Determining the impact of land-use capability on intensification is, however, complicated by the fact that (1) low land-use capability and intensity of farming are not necessarily mutually exclusive and (2) it also depends on the method of intensification.

Farm production and stocking policy data used in this study show that farms with a higher percentage of flat land already achieve higher intensity of farming than hillier farms in the same region. Accordingly, the H75 farm had greater potential to intensify production because it was starting from a lower intensity position. Essentially, the H75 farm had greater potential to increase pasture utilisation by adopting intensification practices than the H25 farm. On the second point, neither method of intensification investigated was directly limited by the physical characteristics of the farms, i.e. the MS was made off farm and N could be applied equally as well to flat or hill land. If methods of intensification investigated were constrained to increasing grown-on-farm forage supply, then land-use capability might be a more important factor determining the ability to intensify. Another factor that advantages flat verses hill land is that the energetic costs of grazing are lower on flat than hill land (Nicol and Brookes, 2007). The current version of Farmax Pro does not take the impact of topography on energy requirements into account. If it had then extent of intensification possible on the H75 farm would most likely be less than observed.

## 5. Conclusion

Based on 2007/08 prices, typical NZ sheep and beef farms were making a financial loss and neither method of intensification increased profitability with the exception of small annual applications of N, especially to the H75 farm. Intensifying production was associated with increased total N leaching and GHG emissions although there were significant differences between the methods of intensification. Feeding MS resulted in lower environmental impacts than applying N even after taking into account the land to grow the maize for silage. Intensification by incorporating a beef feedlot reduced environmental emissions per kg of beef produced but considerably decreased profitability due to higher capital, depreciation and labour costs. The lower land-use capability farm type (H75) was able to intensify beef production to a proportionally greater extent than the higher land-use capability farm (H25) because of greater potential to increase pasture utilisation associated with a lower initial farming intensity and inherent constraints in the pattern of pasture supply.

Based on balancing the production, environmental and financial consequences of intensification in this study, there appears to be merit in using limited applications of N fertiliser to intensify beef production. Small annual additions of N fertiliser (<50 kg N/ha/yr applied in autumn and late winter), increased farm profitability without dramatically increasing N leaching or GHG emissions. Limited N applications were particularly beneficial to H75 farms because small increases in winter carrying capacity resulted in relatively larger increases in the utilisation of pasture growth during spring and summer than the H25 farms.

**Table A.1**
Annual profit/loss calculation assumptions for H25 and H75 farms intensified by feeding maize silage (+MS), applying nitrogen (+N) or establishing a feedlot (+FL). Assumptions applied equally across farm types and obtained from the Lincoln University 2008 Financial Budget Manual (Chaston, 2008) unless otherwise stated. All values are in NZ dollars.

| Category | Item | All farm types | Exceptions | |
|---|---|---|---|---|
| Assets | Land value | | $4,000,000 (H25), $3,500,000 (H75) | |
| | Plant/improvements value | $1,000,000 | $300,000[a] (+FL) | |
| | Total stock value | depended on level of intensification | | |
| | Equity (land, plant, improv.) | 95% | 0% (+FL) | |
| Liabilities/expenses | | | | |
| | Interest rate | 8% p.a. | | |
| | Rates | 0.0008 × capital value land and improvements | | |
| Adjustments | Drawings | $50,000 | | |
| | Depreciation | $20,000 | $40,000[b] (+FL) | |
| Admin. exp. | Insurance (stock) | 0.0011 × stock value | | |
| | Insurance (buildings, etc) | $4000 | | |
| | Accountancy and ACC[c] levy | $6500 | | |
| | Other (incl. phone/mail) | $2.5/s.u.[d] | | |
| R&M exp. | Buildings, fences, tracks, etc. | $3.86/s.u. | $4000[e] (+FL) | |
| Vehicle exp. | Fuel | $12,000 | | |
| | Maintenance, registration, etc | $1.67/s.u. | | |
| Working exp. | Casual wages[f] | $15/h | | |
| | Electricity | $0.62/s.u. | | |
| | Animal Health | $3.3/s.u. | | |
| | Shearing | $5.5/sheep s.u. | | |
| | Breeding (ram/bull) | $400/$2200/hd | | |
| | Freight sheep/cattle | $1.5/$20/hd | | |
| | Maize silage (in stack) | $0.25/kgDM | | |
| | Pasture silage (in stack) | $300/ha | | |
| | Weed & Pest | $1.23/s.u. | | |
| Fertiliser exp. | | SuperP | Nitrogen | Lime |
| | Frequency (years) | 1 (flat)/2 (hill) | Varied | 5 |
| | Rate | 250 kg/ha | Varied | 2500 kg/ha |
| | Price[g] | $480/t | $929/t | $18/t |
| | Freight | $19/t | $19/t | $19/t |
| | Spreading | $45/$60/ha | Varied | $45/ha |
| Crop exp. | | Kale | Pasja | PR/WC[h] |
| | Sowing rate | 5 kg/ha | 4 kg/ha | 15/4 kg/ha |
| | Seed price | $22/kg | $18/kg | $10/$12/kg |
| | Spraying cost | $80/ha | $80/ha | $40/ha |
| | Cultivation/drilling cost | $125/ha | $125/ha | $255/ha |
| | Fertiliser | $160/ha | $160/ha | $0/ha |

[a] Feedlot for 300 animals (incl. fencing, bunkers etc), effluent disposal/storage system, feed wagon.
[b] Total depreciation for feedlot and on-pasture parts of the farm.
[c] NZ's Accident Compensation Corporation.
[d] Stock unit = one stock unit is the equivalent to an intake of 6000 MJME/yr. Traditionally, one stock unit is the annual feed consumed by one breeding ewe and one lamb to weaning.
[e] R&M specific to the feedlot infrastructure in addition to the regular on-pasture farm R&M.
[f] In proportion to increase in stocking rate, up to max of 10 months work, 40 h per week, $15/h.
[g] From June 2008 Ballance Agri-nutrients price catalogue (www.ballance.co.nz).
[h] PR/WC = perennial ryegrass and white clover.

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## Appendix 1

See Table A.1.

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