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Carbon footprint of two unique farms, compared with industry averages

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Abstract

Three years of data from a North Island breeding property (Onetai) and a South Island finishing property (Highlands) were modelled in Farmax and Overseer[®], to estimate production, profitability and GHG emissions. On an annual basis, each hectare of Onetai averaged more than 100 kg meat and 25 kg of fibre across three years, worth \$420/ha. On Highlands, each hectare produced 200 to 327 kg of meat and 20 kg of fibre, with revenue on average \$737/ha, but varying between \$433/ha in a drought and almost \$900/ha in better seasons. GHG emissions (in CO₂ equivalents CO₂-e) ranged from 3106 to 3302 kg/ha at Onetai, and from 3043 to 5067 kg/ha at Highlands. The dramatic variation on the finishing farm was due to varying numbers of store stock purchased and finished according to available forage. Industry data for similar class farms modelled using the same software averaged around 3600 kg CO₂-e/ha. Similar farms (\$339/ha) were less profitable than Onetai, and finishing farms were less profitable than Highlands (\$467/ha). Per hectare, all farms emitted similar amounts of GHG to literature values, but study farms produced more meat and greater financial returns. Greater efficiency of production is better for the pocket and the planet.

Introduction

Global and domestic drivers for environmental change are affecting the NZ pastoral sector, which is critical to the economy and also the dominant land use (Beef and Lamb New Zealand 2016). The pastoral sector accounted for 49% of NZ's total emissions in 2016 (Ministry for the Environment 2018). Although pastoral farming systems are perceived to have less environmental impact (Tilman *et al.* 2002), sustained improvements in production from increased inputs cause increased emissions to air and water (Lambert & Snow 2011). Alternative land use on flat and rolling country resulted in sheep and beef farms in more challenging environments moving to finishing, relying on other businesses to breed young stock. Co-dependency between breeding and finishing farms, and growing pressure to account for environmental losses will require a holistic evaluation of environmental efficiency.

Emissions from sheep and beef systems are largely methane and nitrous oxide. Methane is generated through ruminant digestion, and emissions are largely a function of total feed consumed (Hammond *et al.* 2009). Nitrous oxide is emitted from soils and is affected by urinary nitrogen excretion, other sources of nitrogen (fertiliser, biological fixation), and soil type. Reductions in methane emissions from livestock (Pinares-Patiño *et al.* 2009) and nitrous oxide emissions from grazed pastures (Luo *et al.* 2010), hold promise to reduce greenhouse gas (GHG) emissions in the long term. The effect of management changes on GHG emissions from temperate grazing systems is not known. The current study investigated theoretical semi-extensive to intensive sheep and beef farm systems and two case-study farms, to estimate total GHG emissions and intensity of emissions.

Methodology

Modelling farm systems

Modelling of farms was developed from industry

data to estimate production outputs, profitability and GHG emissions, and model outcomes were compared with two case-study farms. Data for modelling the case-study farms described below, were collected using a measurement protocol for growth rates and quality of pasture and forage, and animal performance over a period of three years. The biophysical characteristics and the gross margin per ha (\$/ha) of all farms were modelled using the farm-scale model Farmax (version 6.4.5.23) (White *et al.* 2010). To determine methane and nitrous oxide emissions, the farms were then modelled using the nutrient budget model Overseer[®] (version 6.2.0) (Wheeler *et al.* 2003). These models are deterministic in nature, as the model outcomes are fully determined by parameter values and initial conditions set, without the inherent randomness of stochastic models. The annual GHG emissions per hectare (kg CO₂-e/ha) and per unit of net animal product (emissions intensity; kg CO₂-e/kg net product grown), were compared across the range of farms. For calculating GHG emissions intensity, “product” was the sum of the total quantity of carcass weight grown on the farm (whether or not it was sold in that year), plus the total quantity of wool produced.

Theoretical farms

Modelling of theoretical farms was undertaken using survey data. The Beef + Lamb New Zealand (B+LNZ) Sheep and Beef Farm Survey, henceforth referred to as the Farm Survey, is a sample survey of more than 500 commercial sheep and beef farms gathering information on stock sales, purchases, production and financial accounts. This sample is randomly selected and stratified by farm size, location and topography to equivalent farm demographics collected by Statistics New Zealand.

A range of sheep and beef farm systems were selected to represent climate, topography, elevation and productive potential. Four farm classes (<https://beeflambnz.com/data-tools/farm-classes>) were selected (Table 1). Of an estimated total of 11,295 sheep and beef farms in NZ, around 5,655

Table 1 Characteristics of Beef + Lamb NZ farm classes 2, 3, 5 and 6 that run sheep and beef cattle in North and South Island on rolling or hill country.

Farm Class	2	3	5	6
Location	South Island	North Island	North Island	South Island
Topography	Hill country	Hill country	Easy contour	Easy contour
Farm system	Extensive Breeding	Extensive Breeding	Intensive Finishing	Intensive Finishing/breeding
Soil fertility	Low/moderate	Low	Moderate	Moderate
Estimated number of farms	810	1065	1275	2505
Stock units (SU/ha)*	2-7	6-10	8-15	6-12+
	Low	Medium	High	Medium

*Stocking units are standardised rates which allow direct comparison of stocking rate regardless of stock class and are usually based on the number of stock wintered (Fleming, 2003).

are in these four classes. Critically, they represent extensive breeding systems and intensive finishing systems from the North and South Islands (B+LNZ, 2012). Farm Survey data for each of these classes were used to generate two theoretical farms providing a broad range in systems performance. An “average farm” was simulated as the average of all the farms for that class in the Farm Survey, while a “poor farm” was calculated as the average of a subset of farms in the lowest 10% based on gross margin for that class. Note that this is based purely on profitability defined by gross margin and does not reflect farmer behaviour.

Case-study farms

Highlands is a South Island breeding and finishing property (Class 6) located on the east coast, 30 km inland from the city of Timaru in South Canterbury. It is a 400 ha property (150-300 m above sea level) with 80% rolling flats and 20% steep hills with a small area of forestry. The Pareora river runs through approximately 1 km of the farm, with riparian areas fenced off. The property receives 600 mm of annual rainfall, with regular summer dry conditions and drought risks.

Onetai is an extensive North Island property located on the west coast of the North Island, 86 km southwest of Te Kūiti. Although the land is more typical of a Class 4 property, it has very low soil fertility (Olsen P=6), thus many performance attributes map this property to Class 3. It is a 1574-ha (estimated 890 ha pastoral) property with 20% rolling, 40% medium slope (i.e. easy hill) and 40% steep hill country. The non-pastoral areas are a mix of plantation forestry and native bush on medium and steep hill slopes, with deep ravines to stream beds. The property has an average rainfall of 2000 mm, with a distribution of approximately 1600 mm in the coastal zone, through to 2300 mm on the inland side of the property (0-400 m above sea level).

Results

Theoretical farms

The effective area of the theoretical farms ranged from 269 to 3,312 ha, depending on class (Table 2). All theoretical farms were breeding/finishing units; trading cattle and dairy heifers ranged from 22 to 77% of the cattle

carried on-farm during winter (Table 2). A small proportion of deer were present on only one farm class (South Island hill country) and given there were only 164 SU (3.3% of total), deer were omitted from this analysis. The range in feed supply per hectare was substantial, with extensive (Class 2 and 3) farms growing 1,300-5,300 kg DM/ha and intensive farms (Class 5 and 6) growing 4,200-6,600 kg DM/ha. Weaning percentage and weaning live weight (LW) of lambs were similar for the average extensive farms (Classes 2 and 3; 118 and 117%, and 25.4 and 24.1 kg LW, respectively). Average extensive farms weaned 25 more lambs per 100 ewes that were 2 kg heavier than the extensive poor farms. Performance from poor and average South Island farms was similar (both 29 kg LW at weaning with 3% less lambs weaned for poor), whereas the North Island average farm weaned 25% more and 3 kg heavier lambs than the poor farms. Cattle consumed 20-50% of feed supply across all farms. Calf weaning percentage on average farms was 7-8% higher than poor farms across all farm classes. Calf weaning weight was the same on intensive North Island farms (Class 5) but was 28 kg heavier for the average versus poor farms in South Island hill country (Class 2).

Most farm classes had the same stock classes contributing to the number of livestock wintered, excluding deer (Table 3). The exception was the poor South Island extensive farm, which had a flock of wethers. The ratios of stock in each class were similar between average and poor farms across all classes, although total numbers did vary from 2900 SU for the poor intensive North Island farm to 7,400 SU for the average South Island extensive properties.

GHG emissions varied between farms from 787 to 3,658 kg/ha (Table 4). GHG emissions per hectare across all farms was positively correlated with total production per hectare ($R^2 = 0.75$). Emissions intensity of GHG decreased as the feed consumed per kg of product decreased ($R^2 = 0.98$). Production per hectare (meat and fibre) and per unit of feed eaten were highest from intensive farms (Table 4), which produced 50% more product per hectare and were 25% more efficient than extensive farms. Within farm classes, average farms produced 35-60% more product per hectare than poor farms, although production efficiency (kg DM/kg product) was only 3-20% better for the average farms.

Table 2 Theoretical farm characteristics for farm classes 2,3,5 and 6 modelled for 'average' and 'poor' farms, and two case-study farms during three years (Y1, Y2, Y3).

Farm class	Class 2		Class 3		Class 5		Class 6		Onetai			Highlands				
	average	poor	average	poor	average	poor	average	poor	Y1	Y2	Y3	Y1	Y2	Y3		
Effective area (ha)	1599	3312	791	645	273	269	450	622	891	891	891	891	361	361	361	
Feed supply (kg DM/ha _{eff})	2418	1161	5220	3556	6280	5034	5422	3712	4450	4490	4822	4822	6278	3452	5470	
Pasture	226	72	47	58	396	363	742	441	28	67	154	3285	3080	3330	3330	
Forage crops & supplements	7300	7182	7405	4477	3096	2597	4927	4514	7239	8537	8603	4357	1842	4125	4125	
Total stock units at 1-Jul	(4.6)	(2.2)	(9.4)	(6.9)	(11.3)	(9.7)	(10.9)	(7.3)	(8.1)	(9.6)	(9.7)	(12.1)	(5.1)	(11.4)	(11.4)	
(SU/ha _{eff} , b)	74:26:0	78:22:0	69:31:0	65:35:0	54:46:0	71:29:0	80:17:3	79:21:0	64:36:0	60:40:0	63:37:0	32:68:0	51:49:0	28:72:0	28:72:0	
Sheep:Cattle:Deer	2457	1115	5031	3423	6485	5202	6011	4014	4537	4665	4623	7197	4136	7129	7129	
Feed eaten (kg DM/ha _{eff})*																
Sheep:																
% feed supply eaten*	69	74	65	60	50	64	76	73	54	59	58	30	52	23	23	
% yearlings successfully mated	-	-	-	-	50	-	30	-	-	-	-	-	-	-	-	-
Lamb weaning %	118	95	117	90	125	100	130	127	108	103	108	126	141	163	163	
Lamb weaning live weight (kg)	25.4	23.3	24.1	22.8	29.3	26.4	29.4	29.2	28	28	28	33.5	32.2	36.0	36.0	
% of lambs sold prime	54	32	48	30	82	70	83	70	88	61	77	78	60	100	100	
Lamb carcass weight (kg)	17.0	17.2	16.7	16.5	17.2	16.6	17.0	16.6	16.7	16.9	16.9	18.8	17.5	20.3	20.3	
Ewe replacements	27	24	29	32	25	19	24	26	38	31	31	40	42	45	45	
(% of breeding flock)																
Cattle:																
% feed supply eaten*	31	26	35	40	50	36	21	27	37	41	42	70	48	76	76	
Calf weaning %	84	76	84	76	86	79	84	75	65	78	81	-	-	-	-	
Calf weaning live weight (kg)	238	210	210	200	237	237	238	215	190	188	211	-	-	-	-	
% weaners sold store at weaning	10	17	-	5	-	-	-	-	43	35	17	-	-	-	-	
% SU wintered trading/grazers	31	22	26	24	77	66	32	45	16	25	5	100	100	100	100	
Cow replacements	17	10	21	18	17	20	13	11	22	25	23	-	-	-	-	
(% of breeding herd)																

All numbers are average for Class 2 to 6, actual data for Onetai and Highlands, estimated using Farmax.

The differences in gross margin per hectare were greater than those for either production or production efficiency (Table 4). For example, the gross margin per hectare from the intensive North Island farm was 10 times that of the extensive South Island poor farms. Within each class, the gross margin of the average farms was 30-60% higher than the poor farms.

Case-study farms

Highlands run 70-75% cattle and produces around 9 tonnes of dry matter/ha per year. The farm produces 30% more total dry matter than average South Island intensive farms while net meat production was nearly twice that of the average farm. However, dairy support means total product sales from the farm were half that of the average farm. On Highlands the weaning rate of lambs was 143%, while total GHG emissions (3043, 4949 and 5067 kg CO₂-e /ha) were up to 30% higher than total emissions from average Class 5 farms and emissions intensity was 20% lower. The impact of a spring drought on the financial returns to the business was notable (Table 4). Feed eaten decreased by 40%, net product decreased by 34% and GHG emissions by 40%. Early sales of trading cattle and store lambs are key strategies to manage drought, which together with lower pasture production resulted in a drop in total production (meat and fibre) and GHG emissions.

Average pasture production per hectare on Onetai (4,650 kg/ha), was midway between the poor and average extensive North Island (Class 3) farms. The

Table 4 Theoretical farm production indices for each farm class for ‘average’ and ‘poor’ farms, and two case-study farms during three years (Y1,Y2,Y3).

Farm class	Class 2		Class 3		Class 5		Class 6		Onetai			Highlands		
	average	poor	average	poor	average	poor	average	poor	Y1	Y2	Y3	Y1	Y2	Y3
Product sold (kg/ha/yr):														
Meat (CW)	66.9	24.4	124.7	73.8	321.6	172.0	162.2	101.1	72.4	55.9	76.7	93.3	79.8	110.5
Fibre (greasy)	16.5	8.8	28.6	19.1	31.5	33.7	41.2	25.7	20.4	19.6	25.9	13.8	12.5	14.1
Net product grown (kg/ha/yr):														
Meat	63.0	23.3	122.7	73.0	239.1	146.8	174.64	115.0	108.3	100.1	119.3	326.9	206.1	319.8
Fibre	16.5	8.8	28.6	19.1	30.7	31.7	41.3	25.7	24.5	26.6	27.4	21.0	19.2	19.9
Total	79.5	32.1	151.3	92.0	269.7	178.5	215.9	140.7	132.8	126.8	146.8	347.9	225.3	339.7
Feed conversion efficiency:														
kg DM eaten/kg CW sold	36.7	45.7	40.4	46.4	20.2	30.3	37.1	39.7	62.7	83.4	60.2	77.1	51.8	64.5
kg DM eaten/kg net product grown	30.9	34.7	33.3	37.2	24.0	29.1	27.8	28.5	34.1	35.4	146.8	19.8	23.0	21.6
Financial (\$):														
Revenue/ha	256	111	511	307	929	600	764	470	549	629	665	1478	994	1443
Variable costs/ha	119	56	172	130	358	219	297	192	180	193	208	582	561	560
Gross margin/ha	137	55	339	177	571	381	467	278	369	436	458	896	433	882
Gross margin/SU wintered	30	26	36	25	50	40	43	38	45	46	47	74	84	77
Feed costs (% Expenditure)	36	32	9	11	46	30	44	43	27	25	23	83	84	74
Animal costs (% Expenditure)	27	29	37	35	21	30	22	24	42	39	39	8	7	9
GHG emissions (kg CO ₂ -e):														
Total GHG/ha _{eff}	1618	787	3658	2528	3541	3136	3628	2499	3302	3111	3106	5067	3043	4949
Total GHG/SU wintered	354	363	391	364	312	325	331	344	406	325	322	420	596	433
GHG/kg CW sold	24.2	32.3	29.3	34.3	11.0	18.2	22.4	24.7	45.6	55.6	40.5	54.3	38.1	44.8
GHG/kg net product	20.4	24.5	24.2	27.5	13.1	17.6	16.8	17.8	24.9	24.5	21.2	13.4	12.6	13.3
GHG/kg DM eaten	0.66	0.71	0.73	0.74	0.55	0.60	0.60	0.62	0.73	0.67	0.67	0.70	0.74	0.69

cow somewhere! Thus, breeding cow emissions will occur somewhere in New Zealand. The low emissions of finishing cattle are due to transfer of emissions between the breeding and finishing farms rather than an inherently efficient system.

The theoretical farms ranged from 78 to 23% breeding cattle. We reiterate that these were average farms within class and some original farms may only have trading cattle. Highlands never has breeding cows. Trading cattle at Onetai varied from 5% to 25% in these three years (Table 2). Increasing proportions of trading cattle was associated with reduced emissions across all theoretical farms. To understand this further, the farm models were manipulated to have 100% trading cattle, or 100% breeding cows. Farming trading cattle only reduced the intensity of GHG emissions by 11% to 31% relative to solely breeding cows. There was considerable variation, with greater reductions modelled on less-intensive farms. Trading is a strategy used for economic reasons, to cope with year-to-year variation in rainfall and could be a practical way to reduce GHG emissions. However, the practicality will vary between farms, and the financial risk will vary from year to year.

One of the major benefits of beef cows, especially in hill country is that they significantly improve pasture

quality by removing rank herbage of low feed value. Without this class of stock, pasture quality could deteriorate, reducing growth rates of any trading cattle or sheep. Thus, it is possible the estimated increase in gross margin by swapping breeding cattle for trading cattle will be overestimated. Dyer *et al.* (2015) explored grazing sheep in rangeland in Canada where previously only cattle had been grazed. They concluded sheep would contribute little in terms of GHG emissions but would bring benefits, including biodiversity. New Zealand farmers have already exploited the potential for grazing sheep and cattle together, but the current modelling suggests they can manipulate proportions depending on relative returns and GHG emissions. Management policies at Highlands have focused on maximising forage production per mm of rainfall and moved from an 80:20 sheep to cattle ratio, to the current 20:80 ratio. This is a flexible forage utilisation and profit-driven system. Although highly efficient, it relies on other farms for replacement ewes and trading cattle. Below average lamb weaning % is possibly a consequence of purchasing in-lamb ewes with poor performance.

A proportion of beef is currently derived from dairy stock (Schreurs *et al.* 2014). Using the dairy industry more as the breeding herd could increase trading stock numbers

while reducing emissions for beef and dairy alike. Such a system has been investigated by Murphy et al. (2017) in Ireland, who showed that slaughtering Holstein-Friesian bulls at 19 months of age after finishing on pasture, with a small amount of concentrate supplement, was the most profitable compared against other systems including indoor finishing and *ad libitum* concentrates. New Zealand farmers can probably learn little about grazing dairy bulls from Irish systems, although that system achieved a very efficient 8.9 to 14.9 kg CO₂ per kg of carcass, with 10.5 for bulls on pasture.

Case studies of sheep and beef farms over three years in the United Kingdom (Hyland et al. 2016) showed enterprises could decrease carbon footprint by increasing production efficiency. Improved efficiency of use of fertiliser, concentrate feeding and bedding decreased carbon footprint by 15 and 30.5% for beef and lamb systems respectively. Farms with the lowest footprint carried less livestock and showed better animal productivity. Those case studies bear little resemblance to these in New Zealand, where sheep and beef enterprises are more extensive, animals graze outdoors, stocking rates are a function of soil type, fertility, climate, altitude, slope and aspect. "Bedding", for example is unheard of in New Zealand!

Within New Zealand, both Highlands and Onetai were more efficient than average farms of an equivalent class. To reduce GHG emissions and remain profitable, these enterprises have limited capacity to reduce inputs with respect to farms overseas, however the differences between lowest 10%, average and case-study farms indicate opportunities to increase production, profitability and GHG efficiency. More forage eaten by high-value stock with potential for rapid growth rates during a time of plenty like spring, and less supplement fed to lower numbers of adult stock during winter are rules of thumb to gauge both profitability and GHG emissions. It is therefore possible to reduce whole-farm GHG emissions using practical and well-understood changes to farm management. As with many GHG mitigation strategies in agriculture, the reductions will be small compared to reductions in other industries. If adopted by many farmers however, they could make an important contribution to reducing emissions of this country. Moreover, the reductions in emissions are achievable, consistent across farm types, and most importantly profitable.

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