EFFICIENCIES, PRODUCTIVITY, NUTRIENT LOSSES AND GREENHOUSE GAS EMISSIONS FROM NEW ZEALAND DAIRY FARMS IDENTIFIED AS HIGH PRODUCTION, LOW EMISSION SYSTEMS

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Abstract
Dairy farming in New Zealand (NZ) is under increasing scrutiny due to growing environmental concerns. Considerable investments have been made in the search for sustainable land management options and opportunities for mitigation of greenhouse gas (GHG) emissions and nutrient losses. According to farmers, high production, low emission systems are hard to run, but a small number of farmers are currently doing this. The objective of this study was to identify and examine dairy farms that were highly productive and profitable while maintaining reduced GHG emissions. These systems carried reduced stock numbers (i.e. less than 3.3 cows/ha). Two farms in the Waikato region and two in the Southland region were identified. The whole-farm system models FARMAX® and OVERSEER® were used to examine feed flow and nutrient balances, as well as the profitability of these systems. Although differing in size, all farms tended to be reliant on home grown feeds for most of their needs; imported feed ranged from 2.2 to 9.7% of total feed consumed. Stocking rates ranged from 2.5 to 3.3 cows/ha, annual production ranged from 377 to 464 kg milksolids (MS)/cow, and operating profits ranged from 1600 to 2350 NZ$/ha. Wintering policies (i.e. the use of an off-farm block of land for dry cow wintering and young stock) differed between regions; the Waikato farms used these blocks only for young stock whereas the Southland farms used them for young stock and dry cows. Despite these differences, emissions intensity ranged from 8.4 to 9.6 kg CO_2-e/kg MS, well below the average NZ farm range (11 – 13 kg CO_2-e/kg MS). Farms with lower emissions intensity tended to be more profitable and achieve greater feed conversion efficiencies (kg MS/kg DM consumed). Although low stocked dairying may require a higher level of managerial skill to be successful, these systems were associated with low emission levels and highly competitive farm profitability. These farms are commercial working examples of the opportunities for highly profitable, emission efficient farms.

Keywords: dairy, livestock emissions, stocking rate, profitability.

Introduction
Dairy farming in New Zealand (NZ) is under increasing scrutiny due to growing environmental concerns. Agriculture as a whole is the largest source of greenhouse gas (GHG) emissions (particularly methane and nitrous oxide), accounting for about 48% of

NZ's total emissions in 2007 (Ministry for the Environment, 2010). The dairy sector has been deemed responsible for about 36% of agricultural GHG emissions (Ministry for the Environment, 2010). Hence, a reduction in methane (CH_4) emissions from livestock and nitrous oxide (N_2O) emissions from grazed pastures are critical components of any attempt to reduce GHG emissions from pastoral agriculture.

Effectively, with the Emissions Trading Scheme (ETS) promptly approaching, considerable investments have been made in the search for sustainable land management options and opportunities for mitigation of GHG emissions and nutrient losses. However, the required reduction in environmental impact needs to be compatible with the sustained contribution of the sector to NZ's economy and with high farm profitability to ensure continuity. Comprehensive reviews on different aspects of methane (Beauchemin et al. 2008) and N_2O (Luo et al., 2010) abatement strategies and technologies largely agree on the need for holistic approaches to mitigation and the lack of readily available, whole farm system strategies to be applied in the short term.

Several whole-farm modelling exercises have examined the effects of a number of on-farm, managerial mitigation strategies (Beukes et al., 2010, 2012; Dynes et al., 2011; Gregorini et al., 2010). Among the several scenarios tested, increasing cow, herd and land-use efficiencies enables potential reductions in stocking rates (SR) (i.e. 3.0 to 2.3 cows/ha; Beukes et al., 2010). These results suggest that a) important trade-offs occur between CH_4 and N_2O emissions when attempting to mitigate emissions via feeding strategies, and b) that improved feed conversion efficiency (FCE) without increases in animal numbers, have shown promise as effective mitigation strategies. These results are consistent with findings from the Resource Efficient Dairying (RED) farmlet trial (Ledgard et al., 2006; Luo et al., 2006), where farm systems that increase milk production while remaining profitable and minimise negative effects on the environment are worthy of evaluation.

In the NZ dairy industry, an overall decline in the number of herds over time has occurred in synchrony with sustained increases in herd size, SR, milk production and imported feed and N fertiliser use (NZ Dairy Statistics, 2010-11). These trends in intensification were led by the concurrent interaction of several on-farm processes such as a) increased SR to increase pasture utilisation, b) increased nitrogen (N) fertiliser use to support greater SR and c) the incremental use of imported supplements, with an emphasis on milksolids (MS) production per ha (Clark, 2010). Increased use of imported feed was partly a response to several unusually dry summers and the recent availability of palm kernel expeller (PKE). However, pasture-based dairying with appropriate grazing management continues to be capable of achieving high levels of milk production per cow whilst maintaining high levels of pasture performance (i.e. production, utilization, and nutritive value) (Macdonald et al., 2008, Baudracco et al., 2010) and profitability (Macdonald et al., 2011).

Seemingly, low stocked dairy systems require a high level of managerial skills to achieve optimum pasture utilisation and maintenance of feed quality, which suggests that high production, low emission systems are hard to manage (and hence to identify). However, we have observed that a small number of farmers are running these systems. The objective of this scoping study was to identify and examine dairy farms that were highly productive and profitable while maintaining reduced GHG emissions. Because methane and nitrous oxide are intrinsically driven by livestock dry matter (DM) consumption and N fertiliser supply, respectively, these systems needed to carry reduced stock numbers (i.e. less than 3.3 cows/ha) and a relatively low N fertiliser load.

Materials and Methods

Identification of Farms

An extensive search was undertaken to identify suitable farms using DairyNZ's extension team and the DairyBase data collection system (www.dairybase.co.nz). This web-based package records physical and financial farm data. Criteria for the selection of these specific dairy farms included a) a predominantly pasture-based system with low levels of imported feed and N fertiliser use, b) high milksolids (MS) production per cow and per ha, c) fertile cows with a certain genetic merit (i.e. high breeding worth, BW), and d) farms with competitive operating profits, leading to systems with fewer, efficient cows producing more MS from equivalent amounts of energy intake. Expectedly, these overall criteria would aid in identifying profitable dairy farms with emissions intensity (EI; kg CO_2-e/kg MS) of 9.5 or less.

The search for the above desirable systems proved to be a difficult task; less than 5% of the farms within the database explored held potential for further review. Once identified, potential candidates were contacted, and following farmers approval, comprehensive on-farm interviews were conducted.

A critical focus of this scoping study was to gain a better understanding of the farmer's decision making processes and practices that led to the condition of high production combined with low emission. Therefore, current farming practices, rather than exploring a number of alternative mitigation strategies or scenarios, were examined in this modelling exercise.

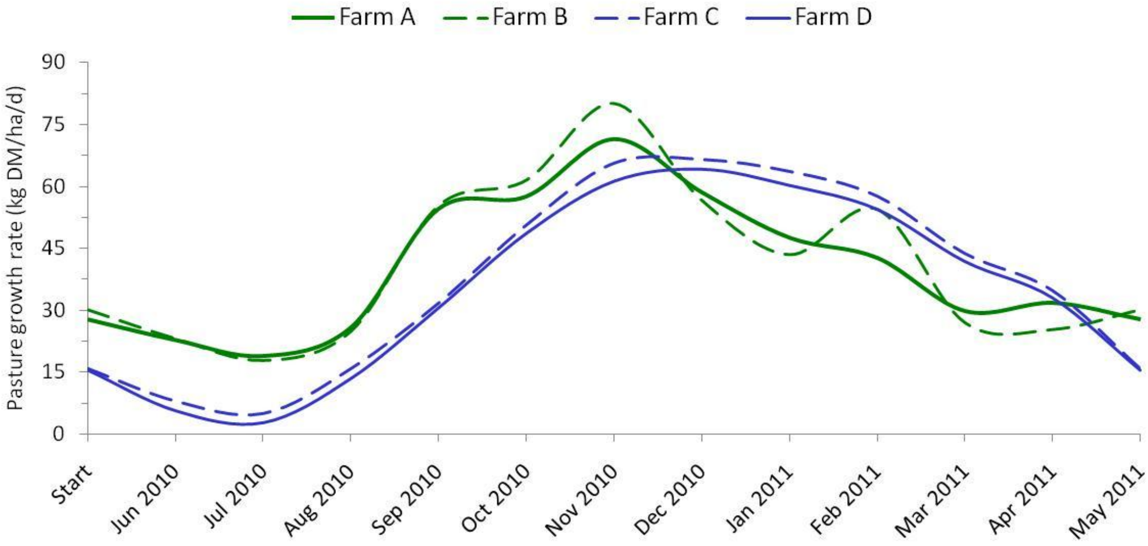
Models Used

A simulation approach was adopted using whole-farm decision support models. Farmax® Dairy Pro (www.farmax.co.nz; Farmax herein) was used to examine feed flow, nutrients offered and required, key physical indicators, and economics from the selected dairy farms (Bryant et al., 2010). The model has been independently validated (Bryant et al., 2010). The biological feasibility (i.e. matching feed supply with feed demand) of the varying stocking policies for these farms was determined using Farmax according to monthly pasture growth rates and the use of supplemental feed, home-grown or imported. The farms were assumed to be in a steady state in terms of opening and closing numbers (June 1, 2010 to May 31, 2011); a price of $5.20/kg MS was used for the economic outputs.

The whole-farm nutrient budget model OVERSEER® (www.overseer.co.nz; Overseer herein) was used to examine the environmental outputs and nutrient losses of the systems. Overseer is a decision support model designed to assist users in developing nutrient budgets and to examine alternative scenarios at a farm scale on an annual basis. The GHG model built within Overseer is based on algorithms similar to those used for NZ's national inventory, modified to allow for on-farm management strategies. The model is increasingly being used as a tool to estimate on-farm GHG emissions from pastoral systems (Wheeler et al., 2008).

For the purpose of this modelling exercise, GHG reported include CH_4 emissions from livestock, N_2O emissions from animal excreta, fertiliser and effluents, and CO_2 emissions from fuel and electricity use, as well as the indirect contribution of lime and fertiliser processing and manufacturing.

Figure 1. Pasture growth rates (kg DM/ha/d) of four dairy farms identified as high production, low emission systems. Output from Farmax.



Background Information and Modelling Assumptions

All the farms were seasonal, spring-calving dairy systems located on relatively flat land, except for farm B, which had a more rolling to hilly contour. In addition to the inherent assumptions within Farmax and Overseer, a number of assumptions were made. Farms A through D received 1200, 1490, 1150 and 1150 mm of rainfall per year, respectively (NIWA 10-yr average values reported in DairyBase and farmer's own records).

Pasture growth rates (kg pasture DM/ha/d) were obtained from the nearest Farmax Library adjusted for feed requirements and management (Waikato), or from farmers own records (Southland) (Figure 1). Mean energy concentrations of pasture were assumed to be 10.7 and 11.2 MJ ME/kg DM for Waikato and Southland, respectively.

Effluents from farms A through D were stored and sprayed on 20, 10, 52 and 54 ha, accounting for about 21, 14, 28 and 18% of the milking area (i.e. the area grazed exclusively by lactating cows). For modelling purposes, these areas were blocked separately from the non-effluent areas on the milking area. Forage crops were grown on Farms B through D; 3.5 ha of turnips grazed during the summer (January and February; Farm B), and 5.0 ha of swedes and 23.0 ha of kale grazed during the winter (August and September; Farms C and D, respectively). The efficiency of forage crop utilisation was 75, 80 and 80% for turnips, swedes and kale, respectively.

Wintering policies (i.e. the use of off-farm blocks of land) were different among farms; all farms had their growing stock grazing off-farm whereas the non-lactating cows were on-farm in the Waikato (i.e. within the milking area) and sent off-farm in the Southland farms. None of the young stock were raised (i.e. beyond weaning) on the milking area; hence, GHG emissions from this category were not considered. Regardless of wintering policy, productive, economic and environmental performances were based on the original wintering policies of these farms.

In order to assess the environmental impact from these farms on comparable wintering policies, a second phase of this modelling exercise included the effects of retaining the wintering (dry) herd on the milking area for the Southland farms. This was achieved by using existing resources on farm (i.e. maximizing pasture utilisation), and whether in the presence of feed shortages during the dry period, pasture baleage was imported to cover for this deficit. The economic implications of maintaining the non-lactating herd on the milking area were considered beyond the scope of this modelling exercise, and were not examined. Comparisons between farms are solely on a numerical basis; no statistical comparisons were possible due to the limited nature of the exercise.

Table 1. Key descriptive and productive indicators of four dairy farms identified as high production, low emission systems; data from Farmax.

	Farm			
	A	B	C	D
Location	Waikato	Waikato	Southland	Southland
Effective area, ha	93	72	185	299
N applied, kg/ha	58	178	119	129
Pasture produced, t DM/ha/yr	14.9	15.1	13.9	13.1
Initial pasture cover[1], kg DM/ha	1781	1903	1867	1805
Crops grown, ha	-	3.5	5.0	23.0
Cows, 1st July	265	240	531	749
SR[2], cows/ha	2.80	3.21	2.76	2.44
Days in milk	268	262	265	266
BCS[3] at calving	4.7	4.9	4.9	5.0
Liveweight (LW), kg/ha	1203	1386	1286	1132
Milksolids, kg/cow	408	377	446	463
Milksolids[4], kg/ha	1117	1212	1232	1124
Milksolids, kg/kg LW	0.93	0.87	0.96	0.99
CSR[5], kg LW/t DM	88.2	88.3	94.4	90.8

[1]1st June. [2]Stocking rate at peak lactation. [3]Body condition score, mean value. [4]Supplied to factory. [5]Comparative stocking rate, kg LW per tonne of available feed DM.

Results

Two farms in the Waikato (farms A and B) and two in Southland (farms C and D) were identified as potential high production, low emission dairy systems. The farms identified in the Waikato produced more grass, particularly during winter and early spring, whereas the farms in Southland produced more grass during mid-summer and autumn (Figure 1 and Table 1). The amount of N fertiliser applied varied among farms, with the least and greatest amounts applied in the Waikato farms (Table 1). Except for farm A, all farms grew forage crops to supplement either summer (farm B) or winter (farms C and D) grazing.

Although differing in size, all farms tended to be reliant on home grown feeds for most of their needs; imported feed ranged from 2 to 10% of feed consumed (Table 2). Farm B relied on more supplements and imported feed than did the other 3 farms. Also, the amount of feed required to produce a unit of MS was greatest for farm B, with the least FCE. Overall, these farms were highly profitable (Table 3), particularly when the price received for MS considered ($5.20) was much lower than the 2010/11 average dairy co-operative payout price ($7.89; New Zealand Statistics 2010-11).

Table 2. Pasture and total intake of four dairy farms identified as high production, low emission systems; data from Farmax.

	Farm			
	A	B	C	D
Location	Waikato	Waikato	Southland	Southland
Pasture consumed, t DM/ha	12.5	13.5	12.1	10.3
Forage crops, t DM	-	43.8	70.0	173.0
Forage crops consumed, t DM/ha	-	0.45	0.30	0.46
Conserved feed[1], t DM	90.5	41.1	94.6	359.2
Conserved feed consumed[1], t DM/ha	0.73	0.43	0.38	0.88
Imported feed, t DM				
Pasture baleage	-	-	72.2	-
Maize silage	30.0	60.0	-	-
Other	50.0	90.0	-	94.2
Imported feed consumed, t DM/ha	0.64	1.55	0.32	0.27
Total feed consumed, t DM/ha	13.9	15.9	13.1	11.9
Total supplements/feed consumed, %	9.9	15.2	7.7	13.5
Imported feed/feed consumed, %	4.6	9.7	2.5	2.2
Feed conversion efficiency[2]	12.8	13.6	11.1	11.1

[1]Harvested from the milking area. [2]FCE = kg DM consumed/kg MS.

Table 3. Profitability[1] of four dairy farms identified as high production, low emission systems; data from Farmax.

	Farm			
	A	B	C	D
Revenue, $				
Net milk sales	536,710	450,880	1,177,831	1735,799
Net livestock sales	26,384	20,676	89,008	93,300
Total revenue	563,093	471,556	1,266,838	1829,098
Expenses, $				
Wages	114,660	101,871	224,910	322,371
Stock expenses	47,872	41,507	104,026	149,667
Supplementary feed	33,518	43,384	55,413	121,904
Grazing and run-off	32,294	32,470	109,698	158,272
Other farm working expenses	104,480	93,196	230,355	379,357
Overheads	21,779	16,980	43,295	69,601
Depreciation	32,550	25,200	64,750	104,650
Total operating expenses	387,153	354,609	832,447	1,305,822
Operating profit, $	175,941	116,947	434,391	523,276
Operating profit, $/ha	1,892	1,624	2,348	1,750

[1]Milksolids price of $5.20/kg MS.

Losses of N via leaching accounted for 20% (farm D) to 38% (farm A) of N applied (Table 4). However, N conversion efficiency, a measure of N in product relative to total N inputs, was exceptionally high for farm A (41%) compared with farm B (29%); farms C and D were intermediate. Annual GHG emissions from the selected farms (A through D) were estimated to be 9.5, 12.0, 10.4, and 9.5 t CO2-e/ha and 8.6, 9.9, 8.6, and 8.5 kg CO2-e/kg MS, respectively. Because wintering policies were different among farms, estimated emissions from farms C and D are shown as adjusted (Table 4); these adjusted values were increased by 9.3%.

Table 4. Annual nitrogen (N) losses and greenhouse gas (GHG) emissions of four dairy farms identified as high production, low emission systems. Farms C-adj and D-adj represent farms C and D but with non-lactating cows on the milking area during the dry period. Output from Overseer.

	Farm					
	A	B	C	D	C-adj	D-adj
Nitrogen, kg N/ha						
Applied	58	178	119	129	119	129
Leached	22	52	27	26	33	31
N_2O emissions	5.9	7.6	6.7	5.8	7.2	6.3
Farm surplus N[1]	113	198	134	127	148	144
NCE[2]	41	29	38	36	35	33
GHG, t CO_2-e/ha						
Methane emissions	6.0	6.8	6.2	5.6	6.9	6.2
Nitrous oxide	3.0	4.0	3.5	3.1	3.7	3.4
CO_2 emissions	0.6	1.1	0.7	0.8	0.8	0.8
Total emissions	9.5	12.0	10.4	9.5	11.3	10.4
GHG, kg CO_2-e/kg MS[3]	8.6	9.9	8.6	8.5	9.4	9.3

[1]Extra N in the system, a potential contributor to losses. [2]N conversion efficiency = N in product relative to total N inputs. [3]Emissions intensity.

Discussion

The efficiency of pasture-based dairying systems is largely driven by annual pasture production, pasture utilisation, and feed conversion. The aim of this scoping study was to identify and characterise dairy farms that were highly productive and profitable while maintaining reduced GHG emissions. Except for wintering policies, no attempt was made to evaluate alternative mitigating scenarios within each farm. Also, the short-termed, small scale nature of this modelling exercise implies certain caution when extrapolating these results to longer periods of time. Notwithstanding these limitations, the current modelling exercise provided commercial working examples of the opportunities for highly profitable, emission efficient farms, particularly farms A in the Waikato, and C and D in Southland.

As noted above, identifying suitable farms that fitted the criteria of high production, low emission proved to be a difficult task; less than 5% of the farms within the database used held potential for further review. Also, identifying suitable farms in the North Island proved difficult due to comparatively warmer and drier summers, leading to shortages in pasture supply of a given nutritive value during this period and extending these effects into early autumn. These effects, in turn, lead to shorter lactations unless supplementary feed is used to extend lactation length (Holmes et al., 2002). These effects were not seen, however, in the selected farms; lactation lengths among farms ranged from 262 to 268 days in milk (Table 1).

Traditionally, improved farm profitability has largely been a consequence of increased pasture utilisation from increased SR (McMeekan, 1950; Bryant, 1990). Stocking rate controls the tension between providing the required feeding levels to achieve high levels of milk production per cow and maintaining high levels of pasture utilisation required to optimize farm profitability. However, farms with similar operating profits (formerly known as economic farm surpluses; EFS) have exhibited a broad range of MS productions per cow and per hectare (Silva-Villacorta et al., 2005; Macdonald and Hedley, 2010). These results were partially attributed to the large proportion of variable costs associated with herd size, leading to SR, at which operating profits were optimised, to be lower than those required for optimum MS production (Macdonald and Hedley, 2010). Furthermore, with competitive MS prices, McCall and Clark (1998), Penno (1998) and Clark (2010) have shown that competitive operating profits could be achieved with low SR, provided high per cow MS production at low costs remains a focus.

Consistent with the above, three out of the four selected farms achieved the desirable objective of being highly profitable, productive, and emissions efficient, as reflected in Figure 2. Lower emissions intensity (kg CO_2-e/kg MS) farms tended to be more profitable (Figure 2a), achieve greater feed conversion efficiencies (kg MS/kg DM consumed) and N conversion efficiencies (amount of N in product/total amount of N input) (Figure 2b), carry lower liveweights (LW) per unit of land (Figure 2c) and achieve an almost 1:1 ratio of MS production per kg LW (Figure 2d). Emissions intensity ranged from 8.4 to 9.6 kg CO_2-e/kg MS, well below the average NZ farm range (11 – 13 kg CO_2-e/kg MS; Overseer). These findings are consistent with low stocked, low N fertiliser use farming practices, along with production per cow and per hectare that were greater than the average for NZ during the 2010/11 season (334 kg MS/cow and 923 kg MS/ha, respectively).

The farmers selected were characterised as highly organised, committed, flexible, knew how and when to delegate farm chores to trained staff, and were open to seek new farming practices and opportunities (White et al., 2011). A highly proactive approach to the ever-changing nature of pasture management, along with timely decisions, was a common feature among these farmers (White et al., 2011). A number of on-farm observations and practices may also account for some of the low estimated emissions reported. Maize silage was used in the Waikato farms, where the SR, particularly in farm B, were greater than those in Southland. The use of maize silage as a supplemental dietary source has contributed to a reduction in N_2O emissions per unit of MS produced (Luo et al., 2010). Alternatively, the Southland farms carried lower stock numbers, but relied heavily on topping (i.e. removing excess pasture growth) to maintain pasture quality during the growing season; the use of extra fuel was not accounted in the current exercise.

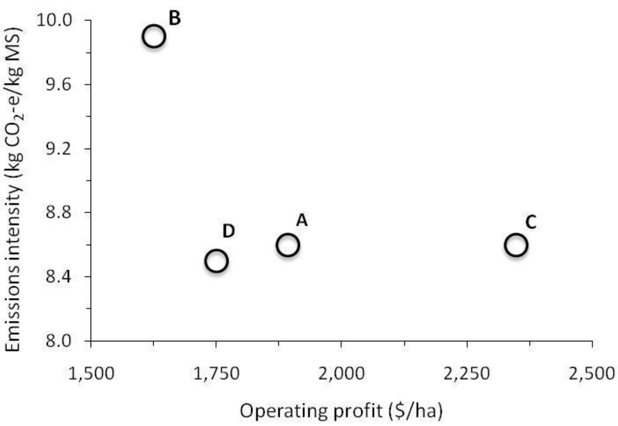
Optimum SR has been defined in a number of ways. One such definition is that which, when combined with appropriate management, is capable of achieving the target amount of feed at calving ensuring that all cows attain a BCS of 5.0 at calving and a BCS of 4.0 or above at mating (Macdonald and Hedley, 2010). These targets were attained by the selected farms in the current modelling exercise. Breeding worth, a measure of genetic merit of these herds, was 85, 106, 100 and 100 for cows on farms A through D, respectively.

Efficient cows offer an opportunity to reduce nutrient losses via a) a decrease in the proportion of energy and N coupled with maintenance or b) a more efficient utilisation of nutrients (Woodward et al., 2011). Nitrogen utilisation efficiency in lactating dairy cows is often 20 to 30%, with 70 to 80% of dietary N contributing to environmental pollution and lost revenue (Moorby and McConochie, 2002). If greater proportions of dietary N were captured in milk, as opposed to being deposited in urine, N losses via volatilisation and denitrification of ammonia (NH_3), N_2O and nitrate (NO_3) leaching could be reduced (Luo et al., 2010). The selected farms were efficient in terms of N utilisation, farm A in particular. Low stocking policies along with reduced N fertiliser loads and high producing cows largely contributed to this achievement.

A reduction in SR per se may lead to responsible environmental stewardship, but may also lead to a sizeable reduction in profits. The losses of pasture quality along with losses in cow performance are a consequence of inferior pasture management. Alternatively, the farms selected opted for nutritional diets with a high intake potential, capable of producing 1 kg MS per kg liveweight without compromising profitability. Although low stocked dairying often requires a high level of managerial skill to be successful, these systems were associated with low emission levels and highly competitive farm profitability. These farms are commercial working examples of the opportunities for highly profitable, emission efficient farms.

Figure 2. Emissions intensity (kg CO_2-e/kg MS) and a) operating profit ($/ha), b) N conversion efficiency (N in product/total N input), c) liveweight (LW; kg/ha), and d) a measure of productivity (kg MS/kg LW) of four dairy farms identified as high production, low emission systems.

a)



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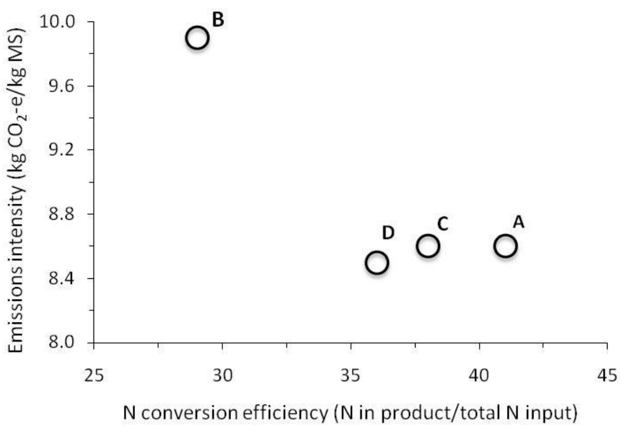

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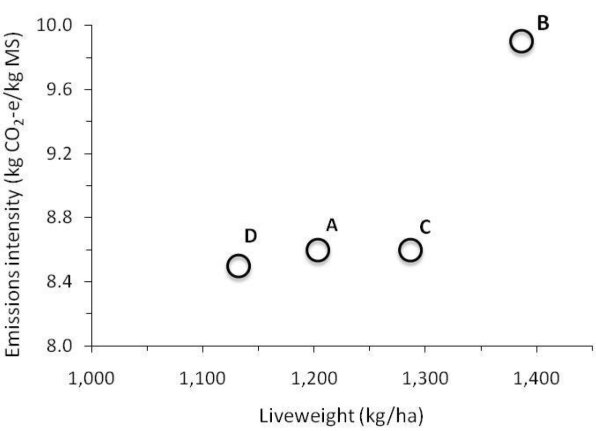

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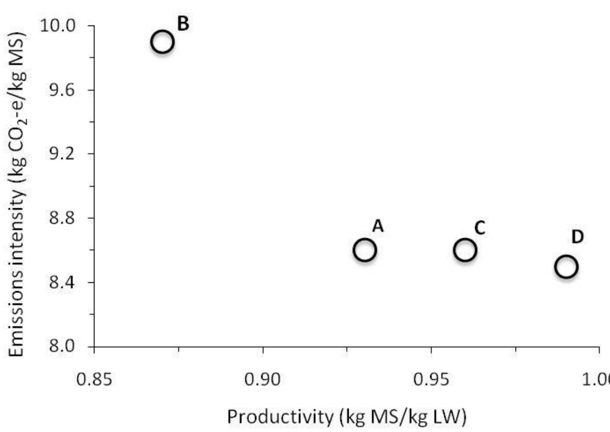

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