A quantitative case study assessment of the biophysical and economic effects of three different feed management systems in a Northland farmlet trial

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Abstract
A three-year farm-systems trial was conducted in Northland from 2018–2021 with three independent 28-ha farms: 1) PAST: 2.7 cows/ha, no imported feed; 2) PKE: 3.1 cows/ha, palm kernel to meet pasture deficits; 3) PKE-PLUS: 3.1 cows/ha, palm kernel plus other supplementary feeds to meet pasture deficits. On average, cows on the PKE-PLUS farm were fed more supplementary feed and produced more milksolids than cows in the PAST and PKE farms (1328, 916 and 1209 kg MS/ha, respectively). Due to large variability in climate, pasture grown, milk and feed prices, there was no significant difference in mean operating profit ($2,636, $3,053, and $2,939 for the PAST, PKE and PKE-PLUS farms, respectively). The PAST farm had least personnel and machinery hours, and lowest methane emissions per hectare (316, 386 and 412 kg methane/ha, for PAST, PKE and PKE-PLUS, respectively). The low-input system was more affected by climate, whereas supplementary-feed systems were affected by externalities (milk and feed prices). With increasing environmental challenges and the need to ensure appropriate staff, farm systems should be evaluated by considering environmental, personnel and profit, rather than just milk production. Greater production may lead to more hours worked and more methane emissions, without any increase in profit.

Keywords: Supplementary feed, climate, milk, pasture, profitability

Background
With climate change, rainfall in many regions of NZ is predicted to become more variable, (Mullan et al*.,* 2005; Clark et al*.,* 2011) causing changes in seasonal and annual pasture supply (Taylor and Gentilli 1971). To cope with these changes, farmers have increased their reliance on supplementary feed, in particular palm kernel expeller (palm kernel; DairyNZ Economics Group 2016). Palm kernel is a relatively inexpensive, readily available feed source, that fits well with a grazing system as it can be group-fed to dry and lactating cows. However, milk produced from cows fed palm kernel contains elevated levels of specific fatty acids which affect the processability of the milk, consequently increasing production costs and potential risks for export markets (Fonterra Co-operative Group 2017). To constrain the amount of palm kernel fed to lactating cows and manage the associated milk composition changes, Fonterra introduced a grading system known as the Fat Evaluation Index (FEI) with financial penalties from September 2018 (Fonterra Co-operative Group 2017).

Additionally, importing supplementary feeds and exporting milk products to global markets exposes producers to foreign exchange rates and international market volatility (Evans 2004; Dillon et al*.,* 2005). This results in large fluctuations in milk pay-out price and supplementary feed costs that, in turn, affect farm operating profit. A review of industry data from pasture-based farms concluded that increasing the level of supplementary feed offered in grazing systems reduced operating profit (Ramsbottom et al*.,* 2015; Macdonald et al*.,* 2017) and return on assets, (Ma et al*.,* 2019), predominantly due to increases in farm expenses when supplementary feeds are used. However, data from a previous trial at the Northland Agricultural Research Farm (NARF) from 2015–2018 indicated that a farmlet with 2.6 cow/ha and no imported feed had similar operating profits to a farmlet with 3.1 cow/ha that offered 10% of the total feed as palm kernel (McCahon 2019). McCahon (2019) stated that, when accounting for the potential variability of key input prices, the more intensive farmlet returned a greater operating profit in 70% of scenarios investigated using climate change predictions, and could be the farm system of choice for more risk-averse farmers.

However, another key challenge NZ farmers are facing currently is reducing their environmental footprint. With proposed legislated targets and pricing mechanisms for GHG emission (Ministry for the Environment 2022), it is vital to understand the effect that different feed management systems have on these emissions. As feed intake is a key driver of enteric methane emissions in pasture-based systems (Waghorn and Woodward 2006; Pinares-Patiño et al*.,* 2009),

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intensification of grazing systems through concomitant increases in stocking rate and supplementary feed are associated with greater total methane emissions (McCahon 2019).

Following on from an earlier farm system trial at NARF, and with climate change predictions and environmental legislation proposing more challenging scenarios, Northland farmers have questioned the use of additional imported supplementary feeds, other than palm kernel (*e.g.*, dried distiller grain, soyahulls and pasture silage), to enable more feed to be offered during times of shortage (Robinson 2022).

Thus, there was a need to understand the biophysical (*e.g.*, production, time, and GHG emissions) and economic effects of different feed-management systems across seasons with variable climates, milk prices and supplementary feed costs.

Approach

The trial was conducted at NARF (35º56'39"S 173º50'34"E) over three milking seasons (June 2018 to May 2021). Three independent farms (28 ha per farm) were used where paddocks were balanced for soil type, pasture cover and species, geographical location and access to effluent. The predominant pasture species were perennial ryegrass (*Lolium perenne*), Italian ryegrass (*L. multiflorum*), kikuyu (*Cenchrus clandestinus*) and white clover (*Trifolium repens*) and two distinct soil types; Kaipara clay loam and Te Kopuru sand. All experimental procedures were approved by the Ruakura Animal Ethics Committee.

In May 2018, 250 Jersey-Friesian cross cows were randomly allocated to each farm. The farms were 1) PAST: 2.7 cows/ha consuming pasture grown on farm, either *in situ* or conserved and fed as silage, with no imported feed; 2) PKE: 3.1 cows/ha consuming pasture as in Farm 1 with additional feed available as imported palm kernel, offered within the FEI thresholds as regulated by Fonterra (Fonterra Co-operative Group 2017), and 3) PKE-PLUS: 3.1 cow/ha consuming pasture and palm kernel as in Farm 2, with additional alternative supplementary feeds (e.g., dried distillers grain, soyahulls and purchased pasture silage) available. All three farms were managed using the same set of decisions rules. Cows were rotationally grazed with pasture targets (*e.g.*, post-grazing residuals, pre-grazing covers, rotation lengths; Macdonald et al*.,* 2008). Strategies to alter feed supply and/or feed demand were used when feed (post-grazing pasture residuals, rotation length, supplementary feed-on-hand) and animal (milk production, FEI grade, body condition score, and days in milk) factors indicated feed supply did not balance feed demand. These included altering the amount of supplementary feed (*e.g.*, home grown silage, purchased supplements), conservation of pasture for silage, reduce milking frequency (*i.e.*, once daily), removing cull cows, and drying off.

A separate milk vat on each farm allowed for independent measurement of milk production, composition, and FEI levels. Pasture herbage mass (kg DM/ha) was calculated from compressed pasture heights, measured weekly or fortnightly across all treatment paddocks using a rising plate meter (Tru-Test Electronic Plate Meter EC09). The marginal milk production response (MMPR; g milksolids (MS)/kg DM offered) was calculated as the change in MS production (marginal MS production; g MS) between two farms divided by the change in imported supplementary feed offered (kg DM offered) between two farms (Stockdale 2000). The cost of the marginal milk ($/kg MS) was calculated as the cost of the marginal milk produced between farms (change in total farm working expenses between farms; $) divided by the marginal milk produced between farms (kg MS). Operating profit was calculated as the gross revenue less operating expenses including all costs and revenue for each farm. Per cow and per ha metrics were used based on Red Sky benchmarking as outlined in Macdonald et al*.,* (2011). Time spent doing tasks on each individual farm was recorded if they were over and above farm operations that were common to all farms. For example, additional milkings when other farms were milking once a day, or cows were dried off, or time/machinery used when feeding out supplementary feeds. Methane emissions (kg methane per ha) were calculated using OverseerFM.

Animal, feed, economic and environmental variables were analysed using one-way ANOVA, with farm as the fixed effect. Results are presented as least-square mean and standard error of the difference (SED). Data were declared significantly different when $P<0.05$ and a trend when $P<0.1$. Different superscripts denote significant differences.

Results

Pasture growth varied by more than 10% during the three years, with the average for the three farms being 15.4, 13.4 and 14.8 t DM/ha for the 18/19, 19/20 and 20/21 seasons, respectively. In all years, pasture growth was numerically less than the historic (10-year) average for the NARF farm of 15.6 t DM/ha with a prolonged drought in the 19/20 season and a very wet spring and dry summer/autumn in 20/21. Due to the large between-year variation, there was no significant difference in pasture growth between the farms. However, for each season, the PKE farm grew numerically more pasture (15.2 t DM/ha) compared with the PAST (14.4 t DM/ha) and the PKE-PLUS (14.8 t DM/ha) farms.

On average, over the three years, the amount of purchased supplementary feed offered to cows was 0, 837, and 1,253 kg DM per cow in the PAST, PKE and

PKE-PLUS farms, respectively. Palm kernel was the only supplementary feed offered to cows in the PKE farm, whereas cows in the PKE-PLUS farm received palm kernel, dried distillers' grain, soya hulls and purchased pasture silage. The amount of supplementary feed offered per year varied dependent on pasture growth (Table 1).

There was no significant difference in the six-week in-calf rate which was 75, 71 and 73 for PAST, PKE and PKE-PLUS farms, respectively. On average, cows on the PKE-PLUS farm produced more MS per cow than cows in the PAST farm (Table 2). Due to large between-year variation (Table 3), there was no significant difference in MS production between the PKE and PKE-PLUS farms. On a per hectare basis, cows in the PKE and PKE-PLUS farms produced more MS than cows in the PAST farm (Table 2).

When compared with the PAST farm the mean MMPR for the PKE and PKE-PLUS farms was 113 and 104 g MS/kg DM imported supplementary feed, respectively. When compared with the PKE farm the MMPR for the PKE-PLUS farm was 92 g MS/kg DM. The MMRP for each year is presented in Table 4a and 4b.

The mean cost of the marginal milk for the three seasons was $5.86 for the PKE farm and $6.55 for the PKE-PLUS farm compared with the PAST farm. When the PKE-PLUS farm was compared with the PKE farm the cost of the marginal milk was $8.60. The cost of the marginal milk for 18/19, 19/20 and 20/21 is presented in Table 5a and 5b.

There was no significant difference in mean operating profit between the three farms (Table 6), whether using the milk payout prices for 18/19 ($6.35), 19/20 ($7.14), or 20/21 ($7.55) or a fixed price for all three years (*i.e.*, $5.00 or $8.00 per kg MS). However, there were numerical differences in the mean operating profit overall and for each season, with PKE numerically greater than PAST and PKE-PLUS overall and in 18/19 and 20/21, with the PKE-PLUS farm numerically greater in 19/20 (Table 7).

On average over the three seasons, the PAST farm produced 18% less methane per hectare than the PKE farm and 23% less methane per hectare than the PKE-

Table 1 The amount of supplementary feed offered (kg DM) to cows in the PAST, PKE, and PKE-PLUS farms for 18/19, 19/20 and 20/21.

Season	PAST	PKE	PKE-PLUS
2018/19	0	748	1,046
2019/20	0	978	1,410
2020/21	0	754	1,303

Table 2 Mean milk solids (kg MS) from cows in the PAST, PKE, and PKE-PLUS farms for the three seasons 18/19, 19/20 and 20/21.

Milk solids production	PAST	PKE	PKE PLUS	SED	P
kg MS per cow	342^{a}	389^{ab}	426^{b}	20.8	0.02
kg MS per hectare	916^{b}	1,209^{a}	1,328^{a}	63.6	< 0.01

Table 3 Milk solids (kg MS) from cows in the PAST, PKE, and PKE-PLUS farms for 18/19, 19/20 and 20/21.

Season	PAST	PKE	PKE-PLUS
2018/19	996	1,225	1,300
2019/20	816	1,129	1,279
2020/21	936	1,272	1,405

Table 4 The MMPR (g MS/kg DM) for a) cows in the PKE and PKE-PLUS farms compared with cows in the PAST farm; and b) cows in the PKE-PLUS compared with PKE farm for 18/19, 19/20 and 20/21.

a)	Season	PKE	PKE-PLUS
	2018/19	100	94
	2019/20	102	104
	2020/21	136	114

b)	Season	PKE-PLUS
	2018/19	81
	2019/20	112
	2020/21	82

Table 5 The cost of the marginal milk ($/kg MS) from a) cows in the PKE and PKE-PLUS farms compared with cows in the PAST; and b) cows in the PKE-PLUS farm compared with the PKE farm for 18/19, 19/20 and 20/21.

a)	Season	PKE	PKE-PLUS
	2018/19	$5.39	$6.67
	2019/20	$6.54	$6.27
	2020/21	$5.65	$6.73

b)	Season	PKE-PLUS
	2018/19	$10.57
	2019/20	$5.70
	2020/21	$9.47

PLUS farm, when calculated using OVERSEER. The mean methane emissions efficiency (g methane/kg MS) was greater for the PAST farm compared with the PKE-PLUS farm but did not differ between the PAST and the PKE farm, nor the PKE and the PKE-PLUS farm (Table 8).

The mean amount of time spent (labour hours) over and above operations common to all farms was 45, 355 and 483 hours for people in the PAST, PKE and PKE-PLUS farms, respectively. The mean amount of time the tractor was used, over and above what was common to all farms was 45, 85, 112 hours for the PAST, PKE and PKE-PLUS farms, respectively.

Discussion

The greater stocking rate and the additional supplementary feed offered to cows in the PKE and PKE-PLUS farm resulted in more MS produced (kg MS/ha) compared with the PAST farm. The prolonged drought in 2019/20 resulted in all farms having their lowest milk production that year, with the greatest reduction in MS (~15%) occurring in the PAST farm. This was due to the negative effect that adverse weather events have on milk production in systems where there is no imported supplementary feed available. This was because there was little opportunity to increase feed supply and, thus, feed deficits must be managed by reducing feed demand (*e.g.*, once-a-day milking, drying cows off, removing culls). In contrast, cows in the PKE-PLUS farm had the most consistent milk production throughout the seasons due to the ability to purchase and offer supplementary feeds during feed deficits within the FEI constraints. Although the PKE and PKE-PLUS farms produced more milk, the relative operating profit of the farms was not dependent on milk production, but rather the MMPR to supplementary feed, and the resulting cost of the marginal milk.

When supplements were incorporated into a pasture-based system there was the potential for increased total intake and greater production. However, the actual MMPR was variable and often less than expected (Bargo et al*.,* 2003; Ramsbottom et al*.,* 2015; Macdonald et al*.,* 2017). This was because several factors affected the MMPR for supplements. From a physiological perspective, the dairy cow requires 70 - 80 MJ ME to synthesise 1 kg MS (3.5% protein and 4.5% fat; NRC 2021). This means 1 kg DM should have provided enough energy to produce 140 - 150 g MS. However, this was the maximum possible physiological MMPR and assumes that all the metabolisable energy from the supplementary feed was converted into MS, which was not the case in a grazing situation. Bargo et al. (2003) reviewed component studies and concluded that cows produced 70 g MS per kg DMI offered and Macdonald et al. (2017) analysed three-year lactation performance and reported average MMPRs of 73 to 97 g MS/kg DM offered. These figures were supported by Neal et al. (2018) who reported an average MMPR of

Table 6 Mean operating profit ($/ha) from the PAST, PKE, and PKE PLUS farms for the three seasons 18/19, 19/20 and 20/21.

Milk pay-out price	PAST	PKE	PKE-PLUS	SED	P
Actual MS price each season	$2,637	$3,053	$2,939	$571.7	0.76
$5 per kg MS	$811	$616	$248	$717.4	0.74
$8 per kg MS	$3559	$4242	$4232	$824.3	0.66

Table 7 Operating profit ($/ha) from the PAST, PKE, and PKE-PLUS farms for 18/19, 19/20 and 20/21.

Season	Milk price ($/kg MS)	PAST	PKE	PKE-PLUS
2018/19	$6.35	$3,002	$3,301	$2,991
2019/20	$7.14	$1,877	$2,119	$2,336
2020/21	$7.55	$3,031	$3,743	$3,488

Table 8 Mean methane emissions per hectare and per kg MS from cows in the PAST, PKE, and PKE PLUS farms for the three seasons 18/19, 19/20 and 20/21.

Methane emissions	PAST	PKE	PKE PLUS	SED	P
kg methane/ha	316^{b}	386^{a}	412^{a}	20.9	<0.01
g methane/kg MS	0.35^{a}	0.32^{ab}	0.31^{b}	0.011	0.04

80 g MS/kg DM from the last 12 years of NZ Industry data (DairyBase).

The MMPR included both an immediate and a deferred response to the changes in the system (*e.g*., increased stocking rate and supplementary feed offered) and these were influenced by several factors, including supplementary feed utilisation, pasture substitution and energy partitioning. Supplementary feed utilisation depends on the type of supplementary feed offered and method of feeding out. For example, the cow can utilise approximately 95% of a concentrate or pellet offered through an in-shed feeding facility but may only utilise 60% of silage that is fed out in the paddock in poor weather conditions, as utilisation influences how much of the supplementary feed is consumed by the cow.

Energy partitioning plays a role in MMPR, whereby some cows (thinner, lower producers) convert a larger proportion of the energy to body reserves instead of milk production. A negative relationship has been reported between the amount of supplementary feed offered and the portion that is converted to milk production, such that the amount of energy going to milk production decreases as the amount of supplementary feed offered increases (Stockdale, 2000; Roche and White, 2012).

The factor that potentially has the greatest effect on MMPR was pasture substitution. This represented the reduction in pasture intake when supplementary feeds were offered in grazing situations. On average, cows graze for approximately 12 mins less for every 1 kg DM of supplementary feed introduced into the system (Stockdale 2000). The effect of pasture substitution on the MMPR depended on how it was managed in the system. With poor management, post-grazing pasture residuals may be greater than target, resulting in lost energy, as high-energy, high-quality pasture is left uneaten in the paddock, where it can lose quality and energy before the next grazing. Conversely, if pasture substitution is managed well, such that pasture targets are met (*e.g*., post-grazing residuals, rotation length, pre-cover mass), pasture can be spared and/or more can be grown which can be eaten later. This would then contribute to the deferred portion of the MMPR.

In the current three-year farm systems trial, the MMPR for the PKE (113 g MS per kg DM) and PKE-PLUS farm (104 g MS per kg DM), compared with the PAST farm was greater than predicted, based on previous literature (Bargo et al*.,* 2003; Ramsbottom et al*.,* 2015; Macdonald et al*.,* 2017; Neal et al., 2018). The greater MMPR in the PKE compared with the PKE-PLUS farm was most probably due to less pasture substitution and/or better management of the pasture substitution, as indicated by the greater amount of pasture grown in the PKE compared with the PKE-PLUS farm. This was consistent with the fact that, as the amount of supplementary feed eaten increased the level of substitution rose, primarily due to satiety signals (*e.g*., ghrelin and insulin) informing the cow she is not as hungry and therefore she was not prepared to spend additional energy consuming more pasture (Roche et al*.,* 2008; Sheahan et al*.,* 2013). This effect was highlighted when the MMPR for the PKE PLUS was compared to the PKE farm. When cows in the PKE farm were offered 836 kg DM supplementary feed, the MMPR was 113 g MS/kg DM offered; however, when an additional 417 kg DM supplementary feed was offered to cows in the PKE-PLUS farm, the MMPR was only 92 g MS/kg DM offered, resulting in a total MMPR of 104 g MS/kg DM offered.

The MMPR is a driver of the cost of the marginal milk, which affects operating profit. The cost of the marginal milk produced over and above the PAST farm was \$5.86 per kg MS in the PKE farm, compared with \$6.55 per kg MS in the PKE-PLUS farm. The marginal cost is also driven by the cost of purchasing the supplementary feed plus the cost associated with the greater stocking rate and feeding the supplementary feed (e.g., greater labour and tractor hours). Previous literature stated that, for every \$1.00 spent on supplementary feed, more than \$1.50 is added to farm working expenses (Ramsbottom et al*.,* 2015; Neal et al., 2018). This is due to increased time associated with feeding out supplementary feed and milking cows, such as machinery and labour. In the present trial, for every dollar spent on PKE or PKE plus other supplementary feeds, an additional \$0.86 or \$0.66 was added to farm expenses, respectively. This means the PKE delivered on farm for 33c per kg DM, actually cost the farm 61c per kg DM when additional labour, machinery and other costs were considered. Additionally, dried distiller grain costing 60c per kg DM delivered added \$1.00 per kg DM to the cost to the farm business.

Thus, even with greater than average MMPRs generated on the PKE and PKE-PLUS farms, the milk pay-out price needed to be greater than \$5.86 for the PKE farm and \$6.55 for the PKE-PLUS farm to return more profit when compared to the PAST farm. When comparing the PKE-PLUS farm with the PKE farm, the milk pay-out price needed to be \$8.60 for the former to be more profitable across the seasons. These figures were consistent with those reported by Ma et al. (2018), who calculated that the marginal cost of milk produced by moderate farms and high input farms, compared with low input farms, in NZ was \$7.66 and \$7.50, respectively.

In addition to economics, personnel and environmental footprint are important considerations when evaluating feed management and farm systems. Attracting and retaining people in the dairy industry is challenging (DairyNZ et al*.,* 2017; Nettle 2018), with total hours worked being one of the key factors for people leaving the industry. More intensive production systems, with greater stocking rates and a greater proportion of supplementary feed in the system are associated with greater hours worked. This was reflected at NARF with greater additional labour hours in the PKE-PLUS farm. In addition, total feed eaten is a key driver of enteric methane production (Waghorn and Woodward 2006; Pinares-Patiño et al., 2009) and this was reflected by the positive relationship between methane emissions and supplementary feed offered in the three farm systems, with the PKE and PKE-PLUS farms producing more methane per hectare than the PAST farm over the three years. Although Ledgard et al. (2017) reported little difference in emissions intensity (g methane per kg MS) between systems with low, medium and high feed inputs, despite an increase in emissions per hectare with higher imported feed use, methane emissions intensity was slightly improved for the PKE and PKE-PLUS farms, compared with the PAST farm. This highlights a problem for the NZ dairy industry when attempting to use farm system changes to reduce total methane emissions to meet legislated targets while maintaining other emissions efficiency (Mazzetto et al., 2021).

In summary, economic, environmental and people factors should be considered when evaluating a farm system. All farm systems can be profitable; however, the sole focus on production per cow or per hectare is misleading and does not account for the marginal cost of the additional milk produced, the additional time required or methane emissions. Systems that use no imported supplementary feed are more at risk from adverse weather events that reduce pasture growth, whereas production systems which import supplementary feed are more affected by externalities, such as milk and feed prices. With looming environmental challenges and the need to attract and retain good employees, farmers should monitor their supplementary feed budgets with these factors in mind. Dropping expensive supplementary feed from the system and/or identifying when supplementary feed is appropriate and how it is managed (costs and feeding) to maximise the MMRP and minimise the cost of the marginal milk will help ensure gains in milk revenue are not eroded by costs of production when using supplementary feeds in a grazing system.

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