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# Productivity and financial characteristics of herds that produce milkfat with different concentration of unsaturated fatty acids using a stochastic farm model

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## ABSTRACT

The objective of this study was to describe the characteristics of dairy farms with different concentrations of unsaturated fatty acids (UFA) in milkfat using a stochastic farm model. Daily phenotypic cow performance was simulated using an exponential function including terms for milk, fat, protein and live weight, and a third order orthogonal polynomial of milkfat UFA concentration. Daily and yearly feed requirements were estimated from metabolisable energy requirements for maintenance, lactation, pregnancy and growth. Two groups of farms were simulated: (1) Average UFA farms (30 farms, milkfat UFA concentration = 30.04 g/100g milkfat) and (2) High UFA farms (30 farms, milkfat UFA concentration = 35.99 g/100g milkfat). Each farm was 140 ha and had 386 cows, a replacement rate of 18% and a spring calving between 20 July and 10 September. The simulation was replicated 1,000 times. High UFA farms produced significantly ($P < 0.05$) less milkfat (338 vs 502 kg/ha) and milksolids (692 vs 927 kg/ha) than Average UFA farms. This resulted in High UFA farms having lower ($P < 0.05$) gross farm income (\$3815 vs \$5075 /ha) and cash operating surplus (\$-331 vs \$598/ha) than Average UFA farms. This highlights the need to develop a payment system that rewards concentration of UFA in milkfat.

**Keywords:** unsaturated fatty acids; milkfat; farm model

## Introduction

In recent times, niche markets have emerged for dairy products with an improved milkfat composition. Several studies have indicated that the nutritional quality of milkfat can be improved by increasing its concentration of unsaturated fatty acids (UFA) and decreasing its concentration of saturated fatty acids (SFA) (Givens 2008). This is because, in western countries, dairy products constitute the main source of dietary SFA (Givens 2009) and high intakes of SFA have been associated with coronary heart disease, the main causes of death in these countries (Zyriax & Windler 2000). Furthermore, increasing the milkfat UFA concentration can improve butter spreadability (MacGibbon et al. 2002). Thus, improving the nutritional quality of milkfat and butter spreadability can allow the New Zealand dairy industry to enter the niche markets for healthy and convenient dairy products.

Over the last 20 years, several studies have been done in New Zealand concerning milkfat composition. Milkfat UFA concentration is influenced by season, breed, strain, diet, parity, stage of lactation and nutrition (Auldist et al. 1998; Thomson & Van-der-Poel 2000; Wales et al. 2009).

On-farm, milkfat UFA concentration can be increased by manipulation of the diet and genetic selection. However, before implementing a programme to increase the milkfat UFA concentration it is necessary to determine its impact on farm production and profitability. Currently there is no published information about the impact of altering the milkfat UFA concentrations on the physical and financial characteristics of dairy farms. In the past, simulation models have been used to study the effects of altering milk composition on farm production and profitability (Lopez-Villalobos 2002). The objective of this research was to study the effect of altering the milkfat UFA concentration on farm productivity and profitability, using a stochastic farm model.

## Materials and methods

### *Model description*

A stochastic farm model that accounts for all the inputs and outputs in a typical New Zealand dairy farm was developed in SAS (SAS 2009). The model simulates the daily and annual performance of individual cows for milk yield (MY) (L/day), milkfat percentage (F%), protein percentage (P%), milkfat UFA concentration and cow live weight (LW) (kg). Key model inputs are start of calving date and calving pattern, drying-off date, replacement rate, herd structure, feed supply, milk payment, stock prices and farm expenses. Key outputs of the model are data corresponding to milk production and composition, milkfat UFA concentration, herd live weight, feed demand, farm income and farm profitability.

### *Phenotypic variance-covariance matrices*

Milk yield, F%, P% and LW per cow were expressed as a function of days in milk (DIM) using the Wilmink (1987) function (Equation 1). Daily milkfat UFA concentration was estimated as a function of

DIM, with DIM being expressed as a third order orthogonal polynomial (Equation 2).

$$\text{Trait} = a + (b \times \text{DIM}) + (c \times \exp^{(-0.05 \times \text{DIM})}) \quad \text{Equation 1}$$

where Trait refers to MY, F%, P% or LW, and a, b and c are the Wilmink parameters estimated for each trait.

$$\text{UFA} = (\alpha0 \times p0) + (\alpha1 \times p1) + (\alpha2 \times p2) + (\alpha3 \times p3) \quad \text{Equation 2}$$

where α0, α1, α2 and α3 are regression coefficients associated to the orthogonal polynomial parameters and p0, p1, p2 and p3 are transformed DIM into the orthogonal coefficients for intercept, linear, quadratic and cubic effects in the range from 1 to 270 days.

Data from test-day records of Holstein-Friesian cows (Macdonald et al. 2008) was used to estimate the Wilmink parameters for the simulation of daily MY, F%, P% and LW per cow. Regression coefficients for the orthogonal polynomials used in the simulation of daily milkfat UFA concentration per cow were estimated from test-day records of Holstein-Friesian cows from the sire proving scheme of Livestock Improvement Corporation (Silva-Villacorta et al. 2011).

Two phenotypic variance-covariance matrices were developed using the standard deviation of each Wilmink and orthogonal polynomial parameter and their corresponding correlation coefficient. A correlation coefficient of 0 was assumed between the parameters of milkfat UFA concentration and LW.

To account for the effects of animal and farm management, a vector of cow effects (c) and farm effects (f) were generated in the following way:

$$\begin{bmatrix} c_{ij1} \\ \cdot \\ \cdot \\ \cdot \\ c_{ij16} \end{bmatrix} = \begin{bmatrix} l_{c1,1} & 0 & \cdot & \cdot & 0 \\ \cdot & \cdot & & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & & \cdot & \cdot & 0 \\ l_{c16,1} & \cdot & \cdot & \cdot & l_{c16,16} \end{bmatrix} \times \begin{bmatrix} \phi_{ij1} \\ \cdot \\ \cdot \\ \cdot \\ \phi_{ij16} \end{bmatrix} \text{ and,}$$

$$\begin{bmatrix} f_{j1} \\ \cdot \\ \cdot \\ \cdot \\ f_{j16} \end{bmatrix} = \begin{bmatrix} l_{h1,1} & 0 & \cdot & \cdot & 0 \\ \cdot & \cdot & & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & & \cdot & \cdot & 0 \\ l_{h16,1} & \cdot & \cdot & \cdot & l_{h16,16} \end{bmatrix} \times \begin{bmatrix} \phi_{j1} \\ \cdot \\ \cdot \\ \cdot \\ \phi_{j16} \end{bmatrix}$$

where $c_{ij}$ is a vector of cow effects for cow i of farm j, $f_j$ is a vector of farm effects for farm j, 1 to 16 represents the Wilmink parameters for MY, F%, P% and LW, and the orthogonal polynomial regression coefficients for UFA, $l_c$ is the Cholesky decomposition of the variance-covariance matrix of cow effects (assumed to be 60% of the total phenotypic variance), $l_h$ is the Cholesky decomposition of the phenotypic variance-covariance matrix, and $\phi$ is a random number obtained from a normal distribution with mean zero and standard deviation one.

For each cow(i) in a farm(j), a vector ($p_{ij}$) describing its phenotype was generated by the sum of the vectors of parameter means ($\bar{x}$), the vector of farm effects (f) and the vector of animal effects (c).

$$\begin{bmatrix} p_{ij1} \\ \cdot \\ \cdot \\ p_{ij16} \end{bmatrix} = \begin{bmatrix} \bar{x}_1 \\ \cdot \\ \cdot \\ \bar{x}_{16} \end{bmatrix} + \begin{bmatrix} f_{j1} \\ \cdot \\ \cdot \\ f_{j16} \end{bmatrix} + \begin{bmatrix} c_{ij1} \\ \cdot \\ \cdot \\ c_{ij16} \end{bmatrix}$$

The $p_{ij}$ vector was used to simulate daily cow performance as indicated in Equations 1 and 2. Adjustments factors for MY, LW and milkfat UFA concentration were estimated from New Zealand dairy statistics (LIC 2011) and Silva-Villacorta et al. (2011) to account for the effect of parity on these traits. Milkfat yield (kg/d) and protein yield (kg/d) were estimated from milk yield and its corresponding concentration in milk.

### *Calving date and calving pattern*

The model allows for specifications of planned start of calving date, mean calving date, date for 90% of cows calved and end of calving date.

### *Replacement rate and herd structure*

The replacement rate and stable herd structure of the herd was determined using a Leslie matrix (Leslie 1945). This information is used to estimate the number of stock and average LW (kg) culled for each age group.

### *Feed demand and feed supply*

Energy requirements for maintenance, lactation, pregnancy and liveweight change per cow were estimated as indicated by Nicol & Brookes (2007) and converted to kilograms of dry matter (DM) considering the energy concentration of pasture during the year as an input of the model.

### *Farm income*

The model estimates farm income considering the daily yields of milk, milkfat and protein; milksolids payout ($/kg milkfat + $/kg protein – $/L milk), the number and live weight of stock culled, price for each stock category including bobby calves, rising one-year-old heifers, rising two-year-old heifers and cows, and other income. Farm expenses comprised marginal costs per cow and feed costs ($/kg DM).

### *Validation*

No proper validation of the model has been possible due to the lack of data corresponding to milk production, milk composition, milkfat UFA concentration and cow live weight during a full lactation on an independent farm. However, the values generated by the model for MY, FY, PY, F%, P% and LW are within the range published in the literature (LIC 2011).

### *Application*

To determine the influence of milkfat UFA concentration on farm production, the model was used to simulate two groups of farms, Average and

**Figure 1** Mean and standard error of the mean (above the graph lines) of the concentration of unsaturated fatty acids (UFA) in milkfat supplied to a processing plant by 30 modelled farms with Average or High milkfat UFA concentration. * = P value < 0.05.

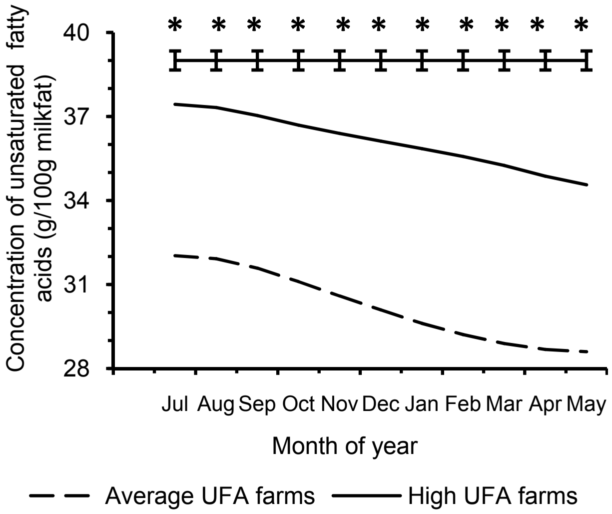
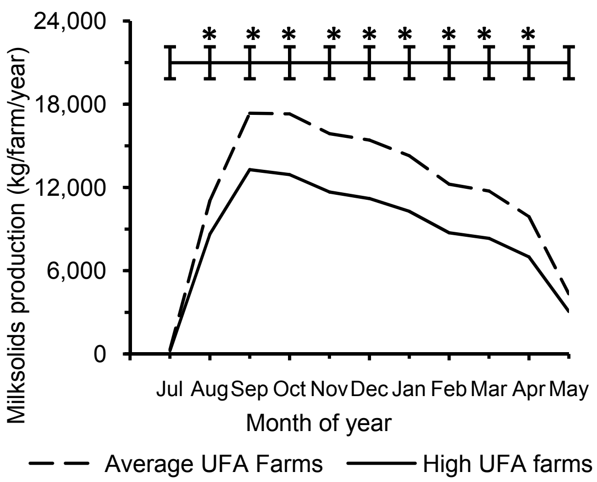



**Figure 2** Average milksolids production per month, and standard error of the mean (above the graph lines), for modelled farms with Average or High concentration of unsaturated fatty acids (UFA) in milkfat. * = P value < 0.05.




High UFA farms. Average UFA farms consisted of 30 simulated farms with average milkfat UFA concentration of 30.04 g/100g milkfat. High UFA farms consisted of 30 simulated farms with high milkfat UFA concentration of 35.99 g/100g milkfat. Each farm had 140 hectares, a herd size of 386 cows, 18% replacement rate and a spring calving between 20 July and 10 September. For each farm, it was assumed that 11 tonnes of pasture DM were consumed per hectare per year, with supplements being used to cover feed deficits. Assumptions considered in the simulation were: for milksolids payout \$7.00/kg protein, \$4.66/kg milkfat, \$-0.04/litre milk, for stock income the prices per kg of carcass were \$1.2 for bobby calves, \$2.6 for one-year-old heifers, \$2.6 for two-year-old heifers and \$2.5 for culled cows. Surplus pasture was sold as hay at \$0.14/kg DM. Assumed feed costs were \$0.10/kg pasture DM and \$0.20/kg supplement DM and sundry farm expenses, excluding feed costs, were \$1,130/cow.

### *Statistical analysis of the High and Average unsaturated fatty acid farms*

In the present study trait means were compared using bootstrapping methodology at the P < 0.05 significance level. For this, the simulation of the two groups of farms comprising 30 High UFA farms and 30 Average UFA farms, with the characteristics mentioned earlier, was repeated 1,000 times to determine a 95% confidence interval for each trait.

## Results

Throughout the dairy season from July to May the following year, High UFA farms had significantly (P < 0.05) higher milkfat UFA concentration (+17% to +22%) than Average UFA farms (Fig. 1).

Between August and the following April, High UFA farms had significantly (P < 0.05) lower milksolids production (-22% to -29%) than Average UFA farms. The difference was not significant at the beginning and end of the dairy season (Fig. 2).

High UFA farms had lower yields of milkfat and milksolids on both a per cow and per hectare basis, and lower percentages of milkfat and protein, than Average UFA farms (Table 1). As a consequence, High UFA farms had lower milk income, gross farm income and cash operating surplus than Average UFA farms (Table 2).

## Discussion

The segregation of cows within a herd, and the segregation of dairy farms, has been suggested in the past as an option to increase milkfat UFA concentration (Silva-Villacorta et al. 2011). In the present study, throughout the year the High UFA farms produced milkfat with 17% to 22% more UFA than standard milkfat (Fig. 1). This difference is equivalent to the one between the milk marketed by FrieslandCampina and standard milk in the Netherlands (FrieslandCampina 2011). However, it is possible that a greater difference in milkfat UFA concentration of approximately 30% would be necessary to have abeneficial effect on health (Givens 2008).

Previous studies have indicated that high milkfat UFA concentrations can negatively affect other milk production traits (Silva-Villacorta et al. 2011; Stoop et al. 2008). This was also observed in the present simulation study, where High UFA farms produced 22% to 29% less milksolids between August and April than Average UFA farms (Fig. 2). The difference in milksolids production per month between the two groups of simulated farms could

**Table 1** Mean and 95% confidence interval of physical characteristics of the 30 farms simulated to be Average and the 30 farms simulated to be High for concentration of unsaturated fatty acids (UFA) in milkfat. DM = Dry matter. NS = Not significant at the P < 0.05 level of significance.

| Trait | Average UFA farms | | High UFA farms | | Significance |
|---|---|---|---|---|---|
| | Mean | 95% Confidence interval | Mean | 95% Confidence interval | |
| Farm size (ha) | 140 | | 140 | | |
| Herd size (cows) | 386 | | 386 | | |
| Stocking rate (cows/ha) | 2.76 | | 2.76 | | |
| Per cow production | | | | | |
| Lactation length (days) | 275 | (274–276) | 274 | (277–270) | NS |
| Litres milk/cow/lactation | 4,338 | (4,172–4,499) | 4,428 | (3,850–5,005) | NS |
| kg milkfat/cow/lactation | 182 | (175–189) | 123 | (95–149) | < 0.05 |
| kg protein/cow/lactation | 154 | (148–160) | 129 | (101–153) | NS |
| kg milksolids/cow | 336 | (324–348) | 252 | (198–299) | < 0.05 |
| Fat % | 4.30 | (4.20–4.38) | 2.83 | (2.37–3.35) | < 0.05 |
| Protein % | 3.61 | (3.57–3.64) | 2.96 | (2.77–3.16) | < 0.05 |
| g UFA/100g of milkfat | 30.04 | (29.91–30.16) | 35.99 | (35.95–36.06) | < 0.05 |
| Live weight (kg/cow) | 497 | (487–508) | 491 | (470–530) | NS |
| kg DM demand/cow | 4,461 | (4,358–4,655) | 3,719 | (3,227–4,372) | NS |
| Per hectare production | | | | | |
| Litres milk/ha | 11,959 | (11,501–12,405) | 12,180 | (10,601–13,831) | NS |
| kg milkfat/ha | 502 | (483–520) | 338 | (263–409) | < 0.05 |
| kg protein/ha | 424 | (408–440) | 355 | (276–420) | NS |
| kg milksolids/ha | 927 | (893–959) | 692 | (540–827 ) | < 0.05 |
| t DM/ha pasture supply | 11 | | 11 | | |
| t DM/ha supplement | 1.31 | (1.06–1.57) | 0.17 | (0.00–1.11) | NS |

have been due mainly to differences in milkfat production. Cows in the High UFA farms produced significantly less milkfat, and had lower percentages of milkfat and protein, than cows in the Average UFA group (Table 1). Other studies have also reported that high milkfat UFA concentrations are associated with low milkfat production and low percentages of milkfat and protein (Marin et al. 2010; Silva-Villacorta et al. 2011).

In the present study, it is assumed that the High UFA farms were pasture-based farms that achieved high milkfat UFA concentrations by genetic selection and without manipulation of the diet. Therefore, the reduced percentages of milkfat and protein and milkfat yield in the High UFA farms could be due mostly to the negative genetic correlation between these traits and milkfat UFA concentration (Stoop et al. 2008). This is because it was assumed that both groups of farms were under similar environmental conditions.

With a milk payment system that rewards milkfat and milk protein yields, the cash operating surplus of High UFA farms was significantly reduced. This indicates the need to modify the payment system before the establishment of a programme to increase the milkfat UFA concentration.

The use of phenotypic variance-covariance matrices in the farm model developed enabled the simulation of dairy farms with production levels characteristic of New Zealand dairy farms. Since the datasets used to estimate the parameters for milk production, milk composition and live weight corresponded to Holstein-Friesian cows, data simulated by the model can only be extrapolated to individual cows or herds of the Holstein-Friesian breed. Most of the studies that focused on altering milkfat composition have been short-term and have not looked at the farm system as a whole (Thomson et al. 2002; Wales et al. 2009). Therefore, the use of simulation models can help in the investigation of the impacts of increasing the milkfat UFA concentration on-farm. However, since this model does not consider the manipulation of the diet, caution should be taken when interpreting the results of this study. Some studies have indicated that the concentration of UFA in milkfat can be increased by feeding protected supplementary oils, without negatively affecting milkfat yield per cow (Thomson et al. 2002).

The data simulated by the model indicates that farm milksolids production, especially milkfat production, is negatively affected. Under the current milk payment system this can negatively affect farm profitability. Furthermore, this will negatively affect the yield of dairy products when milk is processed at the dairy plant. However, dairy processors can benefit from the manufacture of value added products with a higher milkfat UFA concentration, such as spreadable butter. More studies are needed to evaluate the impact of increasing the milkfat UFA

**Table 2** Mean and 95% confidence interval in New Zealand dollars of financial characteristics of the 30 farm simulated to be Average and the 30 farms simulated to be High for concentration of unsaturated fatty acids (UFA in milkfat. Unit prices used were \$7.00/kg protein, \$4.66/kg milkfat, \$-0.04/litre, \$0.10/kg pasture dry matter \$0.20/kg supplement dry matter and \$0.14/kg pasture hay. P value in bold indicates significance ($P < 0.05$).

| Trait | Average UFA farms | | High UFA farms | | Significance |
|---|---|---|---|---|---|
| | Mean | 95% Confidence interval | Mean | 95% Confidence interval | |
| Per cow | | | | | |
| Milk income | 1,753 | (1,689–1,811) | 1,286 | (990–1550) | < 0.05 |
| Stock income | 72 | (71–74) | 71 | (65–79) | NS |
| Sale of pasture hay | 0 | | 30 | (0–143) | < 0.05 |
| Other income | 14 | | 14 | | |
| Gross farm income | 1,839 | (1,774–1,898) | 1,383 | (1,199–1,647) | < 0.05 |
| Marginal expenses | 1,130 | | 1,130 | | |
| Feed expenses | 493 | (473–512) | 379 | (293–478) | NS |
| Farm expenses | 1,622 | (1,601–1,640) | 1,502 | (1,250–1,607) | NS |
| Cash operating surplus | 216 | (172–257) | -119 | (-273–21) | < 0.05 |
| Per hectare | | | | | |
| Milk income | 4,837 | (4,662–5,001) | 3,550 | (2,731–4,280) | < 0.05 |
| Stock income | 200 | (196–203) | 198 | (179–216) | NS |
| Sale of pasture hay | 0 | | 83 | (0–396) | < 0.05 |
| Other income | 39 | | 39 | | |
| Gross farm income | 5,075 | (4,899–5,239) | 3,815 | (3,308–4,546) | < 0.05 |
| Marginal expenses | 3,118 | | 3,118 | | |
| Feed expenses | 1,361 | (1,308–1,412) | 1,074 | (809–1322) | NS |
| Farm expenses | 4,477 | (4,423–4,528) | 4,147 | (3,451–4,436) | NS |
| Cash operating surplus | 598 | (476–710) | -331 | (-756–58) | < 0.05 |

concentration on the whole dairy industry. A holistic approach by the dairy industry is necessary when developing strategies to increase the milkfat UFA concentration. This will help to maximise profits for dairy processors and dairy farmers while meeting new market demands. A scheme of dairy farms dedicated to the production of milk of high UFA concentration in milkfat needs the implementation of a payment system that rewards the concentration of UFA in milkfat.

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