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Description and evaluation of the Farmax Dairy Pro decision support model

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Decision support models have been developed to assist management in dairy systems. This paper describes Farmax Dairy Pro (a pastoral grazing model of a dairy farm) and presents an evaluation of it using two independent farmlet studies carried out in Hamilton and Palmerston North, New Zealand with spring-calving dairy cows. Farmax Dairy Pro predicted, to a high degree of accuracy, mean annual yields (per cow and per hectare) for milk, fat, protein and milksolids (MS; fat + protein) and mean annual concentrations of MS. Monthly predictions were predicted with less accuracy than whole lactation values, but still with moderate degrees of accuracy compared with other comparable models. The general trajectory over time of yield and MS concentration was predicted well for all datasets, but in some instances the model over or under predicted the degree of variation between months. The trajectory of body condition score over time was reliably simulated in early lactation but with some discrepancies in late lactation. The model was then used to determine if it was possible to achieve 1750 kg MS/cow per ha using forages grown within the milking area for the Hamilton study. Managerial changes represented in the model, which included earlier calving dates, use of a chicory crop and additional intakes of pasture in summer, predicted increases in performance of 50–190 kg MS/ha, still at least 81 kg MS/ha short of the target level of production. Farmax Dairy Pro can be used to predict animal, farm and financial performance for different management scenarios.

Keywords: dairy; simulation; decision support; pastoral

Introduction

Pastoral dairy farms rely heavily on the matching of pasture growth with feed demand. When pasture growth or stored pasture *in situ* is insufficient, supplementary feeds made or grown on the farm or bought in are used to fill feed deficits to maintain the desired level of production (Holmes et al. 2002). Formal feed planning methods, such as regular farm inspections to assess current pasture cover and growth, are used to determine whether target levels of pasture and animal performance will be achieved. If targets will not be achieved, management interventions such as feeding supplements, nitrogen applications, culling animals or reducing to once-a-day milking are implemented. However, due to the complexity of the systems, it is extremely difficult to examine the consequences of possible managerial changes on production and profit before they are actually implemented.

The need to answer these 'what if' questions has led to the development of decision support system models that assist pastoral farmers in

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making informed decisions in their farming enterprises. Dairy farm system decision support models incorporate knowledge of the farm including potential pasture growth, calving patterns, cow genetic merit, supplementary feed made or purchased, typical nitrogen application rates, input prices and product returns. These models can range from detailed Microsoft Excel® spreadsheets to Windows-based applications such as UDDER (Larcombe 1999) and the GRAZPLAN suite (Freer et al. 1997). The simulation model UDDER has been used to evaluate supplementation strategies for early and late lactation in order to increase milk yields per cow and the farm gross margin (Uribe et al. 1996) and to optimise farm management to maximise gross margin (Hart et al. 1998). The GRAZPLAN suite, now known as AUSFARM, has been used to predict dairy cattle production including pasture intakes, milk yield, growth and liveweight change (Bryant et al. 2005). Both models are available for science, consultant and farmer use. The use of agricultural decision support models by farm managers was noted to be minimal (McCown 2002), and this is still largely the case. Reasons for the lack of uptake include overly complex models that are not easy to use, insufficient evaluation of model predictions, lack of involvement of users in the design and refinement of the models, lack of demonstration of their value to business and lack of training (Cox 1996; Borenstein 1998; McCown 2002).

This paper describes and evaluates a recently developed decision support model for pastoral dairy farming systems, Farmax Dairy Pro. The steps being taken to encourage industry acceptance and greater uptake are outlined.

Materials and methods

Model description

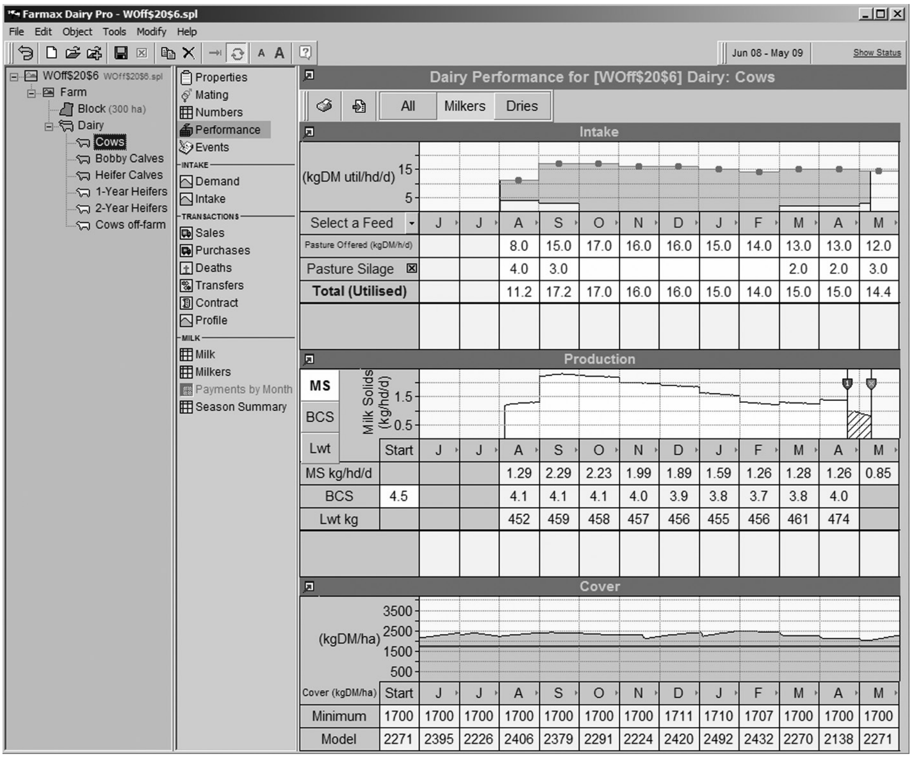
Farmax Dairy Pro (Farmax 2010) (www.farmax.co.nz) is a whole-farm decision support model that uses monthly estimates of pasture growth, farm and herd information to determine the production and economic outcomes of managerial decisions. The model is a Windows application developed using Delphi®. Farmax Dairy Pro is a combination of the pasture module of Farmax (originally called Stockpol (Marshall et al. 1991; Webby et al. 1995)), the animal components of MOOSIM (Bryant et al. 2008) with recently developed animal representations, management options, cash flow and profitability. The user interface is illustrated in Fig. 1. The model includes mechanistic and empirical representations of animal and pasture biology. The model has three modes—two short-term modes designed to consider the forthcoming season (with the ability to extend this to 24 months) and a long-term mode designed to describe the farm's average year. These modes are designed for short-term tactical decision making and longer term strategic decisions (Smith & Foran 1988).

Unique features of the model

Cow genetic merit for economic worth, milk production, mature liveweight and body condition score (BCS) are defined explicitly rather than as a series of genetic merit scalers or estimate of potential milk yield. Economic worth is specified as a breeding worth. Breeding worth is the net lifetime profit per 4.5 t of feed dry matter (DM) requirement per year compared with a base population of animals born in 1995. Genotypes by environmental interactions are incorporated where, compared with other breeds of cattle, Friesian dairy cattle have higher responses to supplementation and Jersey cattle are more tolerant of heat stress. The model calculates distributions of BCS, liveweight and calving pattern for each mob. This allows the user to cull or dry off animals preferentially on highest or lowest liveweight or BCS, or on late or early calving. The effect of changes to pasture and supplement allowances on monthly pasture cover, milksolids (MS; fat + protein) production, liveweight and BCS can all be visualised as graphs and values within the performance screen (Fig. 1).

Pasture module

In brief, model users enter historical or predicted pasture growth rates for each month (Marshall et al. (1991) give a more detailed



Select a Feed	J	J	A	S	O	N	D	J	F	M	A	M
Pasture Offered (kgDM/h/d)			8.0	15.0	17.0	16.0	16.0	15.0	14.0	13.0	13.0	12.0
Pasture Silage ☒			4.0	3.0						2.0	2.0	3.0
Total (Utilised)			11.2	17.2	17.0	16.0	16.0	15.0	14.0	15.0	15.0	14.4

	Start	J	J	A	S	O	N	D	J	F	M	A	M
MS kg/hd/d				1.29	2.29	2.23	1.99	1.89	1.59	1.26	1.28	1.26	0.85
BCS	4.5			4.1	4.1	4.1	4.0	3.9	3.8	3.7	3.8	4.0	
Lwt kg				452	459	458	457	456	455	456	461	474	

Cover (kgDM/ha)	Start	J	J	A	S	O	N	D	J	F	M	A	M
Minimum	1700	1700	1700	1700	1700	1700	1700	1711	1710	1707	1700	1700	1700
Model	2271	2395	2226	2406	2379	2291	2224	2420	2492	2432	2270	2138	2271

Fig. 1 Example of the Farmax Dairy Pro user interface.

description of the pasture module). Pasture growth rates are potential growth rates, similar to cage cut methods described by Radcliffe (1974). The program then calculates the net growth rate after calculating lost potential and decay. Lost potential occurs progressively as average pasture cover falls below and above pasture cover thresholds. This represents the lag in regrowth when there is low photosynthetic material, and the slowing of growth as pasture approaches ceiling leaf area. Decay is calculated through a method of partitioning the total pasture mass into pools of green, stem and dead material. New pasture growth enters the green pool and may be removed by livestock that consume predominantly green material. Some incidental intake is also consumed from the other two pools. The ratio of pasture cover within each pool is rebalanced daily against target ratios set for each month. If pasture cover exceeds a certain threshold during late spring, these targets increase so that a greater proportion enters the dead and stem pools. In this manner, pasture quality declines proportionally to the pasture mass in late spring. As the season progresses the target levels for dead and stem material decline. For rebalancing to achieve the target levels for each pool, dead and stem material must be removed. Through this mechanism, the decay of pasture is represented.

Animal module

For a more detailed description of the animal module, refer to Bryant et al. (2008). In brief, the energy-based animal module includes components describing maintenance requirements, lactation, body energy reserves, growth requirements and pregnancy requirements. The lactation component is the most sophisticated and includes a representation of mammary cell dynamics and reaction norm functions that adjust the potential yield of the herd or mob depending on the nutritional environment to which they are exposed. In the present version of the model, the user enters the profile of intake of pasture and supplements. The model then allocates available energy to the maintenance, lactation, body energy reserves, growth and pregnancy components using the equations outlined by Bryant et al. (2008). Milk and MS yield are adjusted for heat stress using historical weather data, with the level of adjustment related to region and breed of cow simulated. Breed thresholds for heat stress on animal performance are derived from a previous study (Bryant et al. 2007a). Hybrid vigour effects for milk, fat and protein yield, and BCS traits are included based on estimates given in Pryce & Harris (2006) and Bryant et al. (2007b).

Defining the farm

Each pastoral land unit on the farm studied is described in terms of area, initial average pasture cover and pasture quality. Monthly pasture growth can then be defined for each pastoral land unit, or model users can choose from a library of typical values for dry land or irrigated pastures in the different regions of New Zealand. Nitrogen applications and pasture growth responses to nitrogen application can then be defined. Similarly, the area in crops and the period out of the grazing area can be specified by the user. The user can select from or add to a database of crops and feeds, and define whether another crop or new pasture follows.

Defining animals on the farm

Animal groups are defined based on their age, predominant breed, initial liveweight and BCS, whether they are pregnant or lactating, mating history (mating start date, submission and expected calving profile), percentage mature weight and genetic merit. Genetic merit can be defined either as breeding worth or estimated breeding values for volume, fat and protein, liveweight and BCS. Default breeding worth and estimated breeding values are given for each cow breed. When defining BCS and liveweight, the model generates an expected distribution of BCS and liveweight for the herd. As the season progresses, the mean value and distribution of BCSs and liveweights changes depending on the feeding level of the herd. Once-a-day and dry-off dates are specified by the user. Heifer and bull calves can be sold or retained on the property. Animals can be grazed on or off the property at any stage.

Actual feed intakes of pasture and supplements are then defined for milking and dry cows. The database of different crops and supplement feed types have modifiable feed characteristics including megajoules metabolisable energy content per kilogramme of dry matter (MJME/kg DM), neutral detergent fibre (NDF) content (%), digestibility (%) and utilisation (% eaten of offered). For heifer replacements, a target liveweight profile over the course of the simulation is defined (default or entered values). Feed intake is then estimated based on the animals' requirements for maintenance, growth and pregnancy (if relevant).

Simulation feasibility

Once pasture growth rates and feed intakes have been entered, pasture cover and quality is predicted. If pasture cover is below the minimum cover to meet the desired level of animal performance, optimisation routines can be applied to ensure the farm plan is biologically feasible. Specifically, the user can choose to reduce pasture intake with an accompanied reduction in animal performance, increase supplementary feed intake, maintain the same individual animal performance and increase pasture cover by adding nitrogen, or sell animals. Alternatively, users can manually alter each of these factors or alter calving dates, milking frequency or drying-off dates to create a feasible system.

Simulation outputs

Simulation outputs at the farm level are split into categories as follows.

1. Farm—includes predicted farm cover, supply and demand of pasture.
2. Pasture—includes land use, net growth, pasture reconciliation, pasture quality.

3. Stock—includes stock reconciliation, pasture allocation, pasture and supplementary feed intake, weight reconciliation, production reconciliation.
4. Milk—includes monthly production of colostrum, milk, fat, protein and MS, monthly milk payments and a season summary.
5. Financial—includes profitability (economic farm surplus), operating expenses, capital value, monthly cashflow.

A range of reports is also produced at the level of individual pastoral land unit and animal groups.

Model evaluation

The aim of the evaluation was to test the ability of the model to predict total and monthly animal performance parameters and monthly pasture cover. In the evaluation, two independent datasets that were not part of the model development were used. The evaluation studies were performed in two different regions of New Zealand where moderate and high levels of animal performance were achieved with cows of different breeds and genetic merit.

Super Productivity (SuperP) study

This dataset comprised two years' of data (2006/2007 and 2007/2008) from a systems trial carried out at DairyNZ's Scott Farm, Hamilton, New Zealand (Table 1). The herd comprised 29 cows, grazing over 8 ha and calving in the spring. The aim of the study was to produce 1750 kg MS/ha using forages and crops grown entirely within the farm area from a herd that was in the top 1% nationally for breeding worth. Trial measurements included pasture mass (calibrated visual assessments performed weekly), pasture intake by difference between pre- and post-grazing assessed three days a week and pasture growth rate calculated weekly from the increase in herbage mass on ungrazed paddocks. Individual milk weights were determined daily and milk composition (fat, protein and lactose) was measured weekly. The averages of the daily milk weights were multiplied by the weekly measurement of milk composition to determine fat, protein and MS

Table 1 Summary data for the SuperP and Massey datasets.

	SuperP		Massey	
	2006/2007	2007/2008	1997/1998	1998/1999
Effective area (ha)	8	8	40	40
Peak cow numbers	29	29	100	100
Stocking rate (cows/ha)	3.6	3.6	2.5	2.5
Breed	F12 J4[1]	F12 J4	Friesian	Friesian
Herd breeding worth	190	190	10	10
Start liveweight (kg)	539	548	532	482
Calving start	13 Jul	13 Jul	12 Jul	12 Jul
Once-daily milking	3 Mar	25 Jan	NA[2]	NA
Dry-off date	20 Apr	25 Mar	30 Apr	17 Apr
Average total intake (% liveweight)	3.08	3.35	3.34	3.07
Composition of diet				
Pasture (%)	74	75	76	74
Maize silage (%)	20	20	10	0
Pasture silage (%)	0	1	14	26
Turnips (%)	5	4	0	0

[1] 75% Friesian, 25% Jersey.

[2] Not available.

yield. Cow liveweight and BCS were assessed every two weeks, immediately after morning milking.

Massey study

This dataset comprised data covering two years (1997/1998 and 1998/1999) from a spring-calving herd at Massey University's No 1 Dairy Farm, Palmerston North, New Zealand (Table 1). Full details of the study are described by García & Holmes (2005).

Modelling the trials

For modelling, the input data were monthly pasture growth rates (SuperP only), pasture intakes estimated from pre- and post-grazing mass, pasture quality (MJME and NDF concentrations, SuperP only), supplementary feed allowances, supplementary feed quality (SuperP only), weekly lactating cow numbers, initial cow liveweights and BCS, herd breed type and breeding worth. Output data comprised monthly milk, fat, protein and MS yield, fat and protein composition of milk, cow liveweight and BCS, and pasture cover. Due to missing data for the Massey dataset, values of 10 and 10.3 MJME/kg DM were used for pasture and maize silage, with pasture quality peaking at around 12.4 MJME/kg DM in June and July, declining to a nadir of 10.7 MJME/kg DM in January and February, and rising thereafter.

Model evaluation metrics

Model performance was evaluated using several parameters, including mean bias (MB), expressed as a percentage of the actual mean, and the coefficient of determination (R^2). Mean prediction error (MPE) as a percentage was used to measure general model efficiency, calculated from

$$\mathrm{MPE} = \left[\frac{1}{n}\sum\nolimits_{n=1}^{n}(y_i^{\mathrm{s}} - y_i^{\mathrm{a}})^2\right]^{1/2} / \bar{y}^{\mathrm{a}}$$

where n is the number of values, $\bar{y}^{\mathrm{a}}$ is the average of the actual values and y_i^{a} and y_i^{s} are the actual and simulated values (Rook et al. 1990). MPE values of less than 10%, 10–20% and >20% indicate good, moderate and poor simulation adequacy, respectively (Fuentes-Pila et al. 1996). Other parameters used were as follows. Variance ratio v measures the amount of variance in the measured and modelled datasets, with a value of one indicating the same amount of variance. Bias correction factor C_{b} indicates bias from the $y = x$ line with a value of one indicating no bias. Concordance correlation coefficient CCC is a simultaneous measure of accuracy and precision, with an ideal fit indicated by a value of one. Further details of these statistics are available in Tedeschi (2006).

Alternative scenarios for SuperP

To illustrate a practical application of the model, some alternative scenarios were applied to the SuperP study. As already stated, the aim of the study was to achieve 1750 kg MS/ha using forages and crops grown entirely within the farm area, but this target was not reached in the first two years of the study. This was largely attributable to a short lactation length (252 and 230 days in 2006/2007 and 2007/2008) and limited forage supply in summer. The short lactation length was mainly due to early dry-off dates in both seasons (a consequence of a large proportion of the farm being re-grassed in the autumn of the 2006/2007 period), and due to the extreme summer drought experienced in the 2007/2008 season. To extend lactation length and increase summer feed intakes, two scenarios that fitted within the objectives of the study were tested for each year.

Key assumptions that applied to both years for scenario 1 were as follows.

1. Planned start of calving 1 July with mean calving date of 17 July.
2. Forage chicory crop (6% of farm area) planted 10 October with grazing to commence from 10 January until the end of lactation at an average rate of 2.1 kg DM/cow per day. Assumed a total crop yield of 14 t DM/ha with an average metabolisable energy of 12 MJ/kg DM and NDF content

of 22% (Waugh et al. 1998), and 90% utilisation.

3. Herd fed to achieve the same BCS at calving as in both years of the actual study.
4. Maize silage feeding regime changed slightly by feeding more maize silage in early lactation to maintain pasture cover and less in mid to late lactation, but the total amount of maize silage fed remained the same.
5. Pasture intakes per cow to the milking herd were modified in July and August to ensure BCSs did not decrease excessively.
6. Pasture silage feeding regime for the dry cows changed slightly by feeding more as a total proportion of the diet; total amount of pasture silage fed remained the same.

Key assumptions and deviations for scenario 2 were as follows.

1. Assumptions 1 to 5 defined above.
2. 2006/2007: increased intakes of pasture from December to April.
3. 2007/2008: no pasture silage conserved in October and no pasture silage fed in late lactation.

Results

Total yield predictions

For both datasets, predictions of total milk, fat, protein and MS yields per cow and per hectare were close to simulated values (Table 2) with mean bias ranging from −1 to +6%. Simulated production was within 6 kg MS per cow of actual values for all datasets. Lower levels of production were predicted in the second year of the spring simulation datasets, in agreement with the measured data. There was a tendency for total milk yield to be over predicted, and this ranged from 48–267 kg/cow.

Monthly predictions

Yield and composition

Mean prediction errors were generally in the range 10–20% for yield traits and 3–5% for MS composition, indicating moderate and good prediction accuracy, respectively (Tables 3 and 4). The coefficient of determination (R^2) exceeded 0.65 for all yield traits. Mean bias was very low for milk and MS yield for each dataset, indicating that the modelling predicted mean values very well. In most instances, variation in yield was over predicted as indicated by v values less than one. Values for CCC were generally above 0.5 for fat, protein and milksolids yield, but were close to zero for milk and milksolids concentration. The low values for CCC were mainly attributable to bias, i.e. the $y = x$ line deviating from the 1:1 line (unity). For the SuperP dataset, the monthly patterns of yield were generally well predicted, especially the peak milk yield in September (Fig. 2). Milksolids yield was over predicted from August to October for the 1998/1999 season at Massey, but the decline in yield thereafter matched the measured data well (Fig. 3). The simulated drop-off in yield from peak milk yield was one to two months later than the measured data for SuperP. The pattern of MS concentration over the course of lactation was generally well predicted, although often under predicted at peak lactation. For most datasets (Massey 1998/1999, SuperP 2006/2007 and SuperP 2007/2008), the drop in MS concentration in January and February, which coincides with a drop in feed supply and pasture quality, was not predicted.

Liveweight and body condition score

Mean prediction errors were in the range 2–11% for liveweight and BCS traits (Tables 3 and 4). Coefficients of determination ranged from 0.61 to 0.96, with the exception of liveweight for the 1998/1999 season for Massey ($R^2 = 0.06$). For this dataset, the trajectory of liveweight over time was significantly under predicted (Fig. 3). Low values for CCC were estimated. In all instances, the model predicted the drop in BCS from calving to peak lactation well (Figs. 2 and 3). Thereafter, slight losses or maintenance in BCS were predicted while in the observed data, BCS was generally maintained or increased slightly.

Table 2 Actual and predicted milk, milksolids (fat + protein), fat and protein yields per hectare and per cow for the SuperP and Massey datasets.

	Yield (kg/ha)		Yield (kg/cow)	
	Actual	Predicted	Actual	Predicted
SuperP 2006/2007				
Milk	16487	17456	4548	4815
Milksolids	1480	1479	408	408
Fat	837	830	231	229
Protein	643	649	177	179
SuperP 2007/2008				
Milk	15896	16567	4385	4570
Milksolids	1386	1407	382	388
Fat	792	787	218	217
Protein	594	620	164	171
Massey 1997/1998				
Milk	10211	10339	4084	4136
Milksolids	815	812	326	325
Fat	463	458	185	183
Protein	352	353	141	141
Massey 1998/1999				
Milk	9855	9976	3942	3990
Milksolids	773	780	309	312
Fat	437	440	175	176
Protein	335	340	134	136

Pasture cover

Pasture cover was well predicted (MPEs of 7%) when compared with measured SuperP data. For the 2007/2008 season, a general under prediction of pasture cover was evident, as illustrated by the mean bias value of −5.7%. In general, however, the model accurately predicted the marked drop in pasture cover coinciding with the summer drought using measured pasture growth rates, pasture intake, area of land out of the grazing area, animal numbers and predicted pasture decay (Fig. 2).

Scenarios

The scenarios simulated increased production of milk, fat, protein and MS mainly in early lactation (Fig. 4). The earlier calving and chicory regimes applied to both scenarios resulted in production from calving until the end of November, as a percentage of total yields, equivalent to increasing from 59 to 64% in 2006/2007 and 66 to 71% in 2007/2008. The earlier calving regime did lower average pasture cover in both years, with average pasture cover dropping to approximately 2000 kg DM/ha in August and September; this is 50–300 kg DM/ha lower than the measured values or the values predicted using the actual study description.

Increasing intakes of pasture in summer and autumn of the 2006/2007 season (scenario 2) increased total monthly MS yields over this period. This resulted in total MS yield of 1669 kg/ha and increased BCS by 0.5 by the end of lactation (Table 5). Exclusion of silage conservation and feeding in the 2007/2008 season (scenario 2) lifted pasture cover by 130–250 kg DM/ha in spring and subsequently, but resulted in lower MS production (1457 kg MS/ha) and reduced BCS at dry-off date compared with scenario 1 where pasture silage was conserved and fed in autumn.

Table 3 Measures of model accuracy for the SuperP datasets.

	LWT (kg)	BCS	Milk (kg)	FY (kg)	PY (kg)	MS (kg)	MS% (%)	APC (kg_{DM}/ha)
2006/2007								
Mean (actual)	493	4.24	17.7	0.90	0.69	1.60	9.15	2544
Mean (simulated)	479	4.31	18.0	0.86	0.67	1.54	8.71	2485
Mean bias (%)	−2.8	1.5	1.5	−4.1	−2.9	−3.7	−4.8	−2.3
R^2	0.95	0.61	0.70	0.68	0.65	0.67	0.85	0.46
MPE (%)	3	5	23	20	23	21	5	7
v	0.81	1.15	0.71	0.77	0.67	0.73	1.23	1.04
C_b	0.00	0.10	0.01	0.71	0.77	0.45	0.03	0.00
CCC	0.00	0.18	0.01	0.58	0.62	0.37	0.02	0.00
2007/2008								
Mean (actual)	488	4.38	19.4	0.97	0.73	1.71	8.86	2018
Mean (simulated)	484	4.79	19.9	0.95	0.75	1.70	8.71	1902
Mean bias (%)	−0.7	9.3	2.2	−2.6	2.2	−0.5	−1.6	−5.7
R^2	0.80	0.77	0.86	0.82	0.83	0.83	0.79	0.88
MPE (%)	2	11	17	15	18	16	3	7
v	0.91	1.51	0.70	0.78	0.70	0.74	1.05	0.98
C_b	0.00	0.08	0.01	0.67	0.74	0.40	0.03	0.00
CCC	0.00	0.07	0.00	0.61	0.68	0.37	0.02	0.00

Notes: LWT = liveweight, BCS = body condition score, FY = fat yield, PY = protein yield, MS = milksolids (fat + protein), MS% = MS percentage, APC = average pasture cover, R^2 = coefficient of determination, MPE = mean prediction error, v = variance ratio; C_b = bias correction factor; CCC = concordance correlation coefficient.

Table 4 Measures of model accuracy for the Massey datasets.

	LWT (kg)	BCS	Milk (kg)	MS (kg)	MS% (%)
1997/1998					
Mean (actual)	457	4.47	16.1	1.34	8.09
Mean (simulated)	463	4.27	16.8	1.32	8.01
Mean bias (%)	1.2	−4.5	4.2	−1.1	−1.0
R^2	0.96	0.76	0.85	0.79	0.70
MPE (%)	2	7	15	14	3
v	1.07	0.71	0.77	0.89	0.79
C_b	0.00	0.10	0.01	0.53	0.03
CCC	0.00	0.09	0.01	0.47	0.03
1998/1999					
Mean (actual)	472	4.33	16.2	1.28	7.92
Mean (simulated)	426	4.03	16.7	1.32	8.08
Mean bias (%)	−9.8	−6.9	3.3	3.2	2.0
R^2	0.06	0.67	0.96	0.94	0.39
MPE (%)	11	9	16	14	5
v	0.76	0.56	0.68	0.79	0.65
C_b	0.00	0.11	0.01	0.54	0.03
CCC	0.00	0.09	0.01	0.52	0.02

Notes: LWT = liveweight, BCS = body condition score, MS = milksolids (fat + protein), MS% = MS percentage, R^2 = coefficient of determination, MPE = mean prediction error, v = variance ratio; C_b = bias correction factor; CCC = concordance correlation coefficient.

Discussion

An evaluation of Farmax Dairy Pro showed that it can accurately predict annual mean yields (per cow and per hectare) for milk, fat, protein and MS, and mean annual concentrations of MS for two farmlet studies with spring-calving cows. Pasture cover was also reliably predicted for the SuperP dataset. These studies varied widely in cow genetic merit for milk production and supplementary feed types. Monthly variation in yield was less reliably simulated, but still with a moderate degree of accuracy, as indicated by MPEs of less than 0.20 and R^2 values generally greater than 0.60. The CCC criteria indicated the model was best at predicting fat, protein and MS yield, but with less accuracy for liveweight, BCS and MS concentration.

It is always difficult to compare an evaluation with evaluations of other models due to the level of detail available to construct the evaluation files. Nevertheless, for milksolids production per cow per day, Beukes et al. (2008) reported MPEs ranging from 0.23 to 0.52 using the Whole Farm Model, compared with 0.14 to 0.21 in the present evaluation. The Whole Farm Model was more accurate at predicting cow condition score, with an MPE of 0.01 to 0.06 compared with 0.05 to 0.11 in the present evaluation. The comparable model UDDER (Larcombe 1999) has not been formally evaluated against an independent dataset.

Discrepancies in monthly yield and BCS could be attributed to inaccurate input data. Feed intake of pasture and supplements were estimated from pre- and post-grazing mass and supplements offered. Neither value accounts for incomplete utilisation of the feed that disappears, which can range from 60 to 100% depending on soil conditions (Nie et al. 2001). Poor utilisation in any of the measurement periods would result in an overestimate of actual feed intake and milk yield, an overestimate in BCS gain or an underestimate in BCS loss, and an underestimate of residual yield after grazing with carryover effects on pasture.

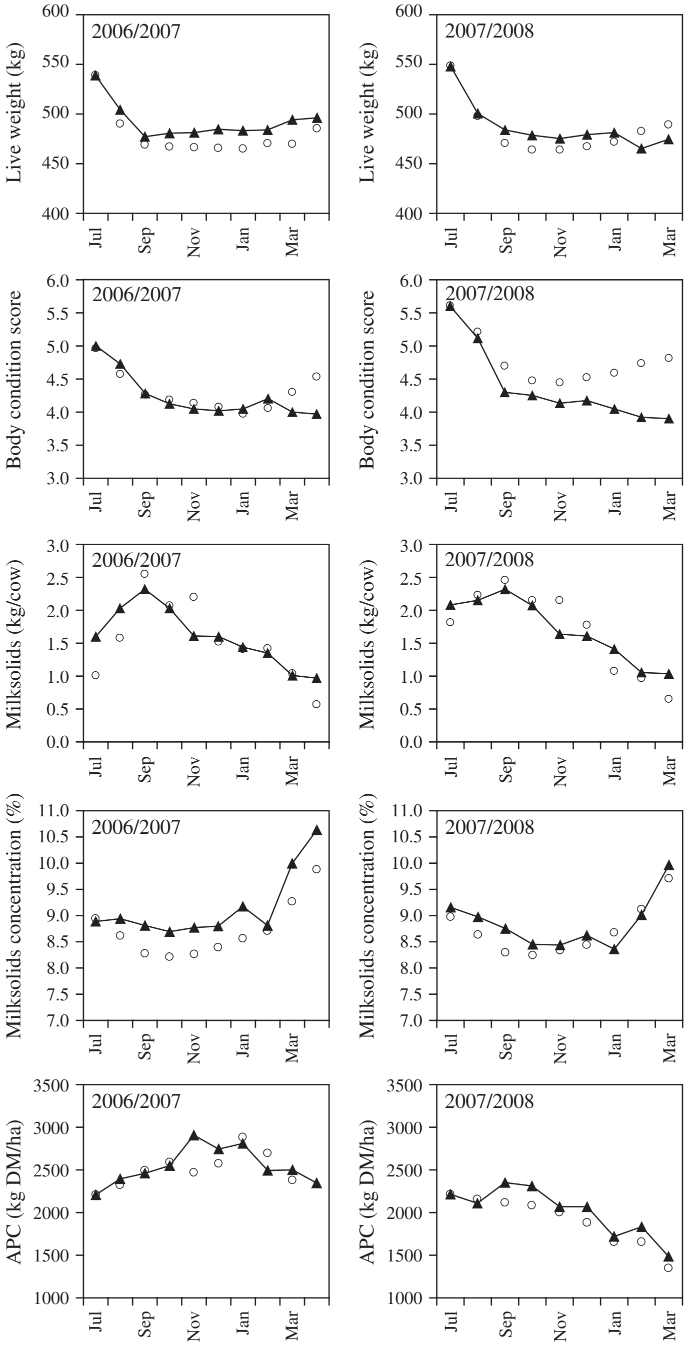


Fig. 2 Actual (–▲–) and predicted (○) monthly average liveweight, body condition score, milksolids yield, milksolids concentration and average pasture cover (APC) for SuperP in the 2006/2007 and 2007/2008 seasons.

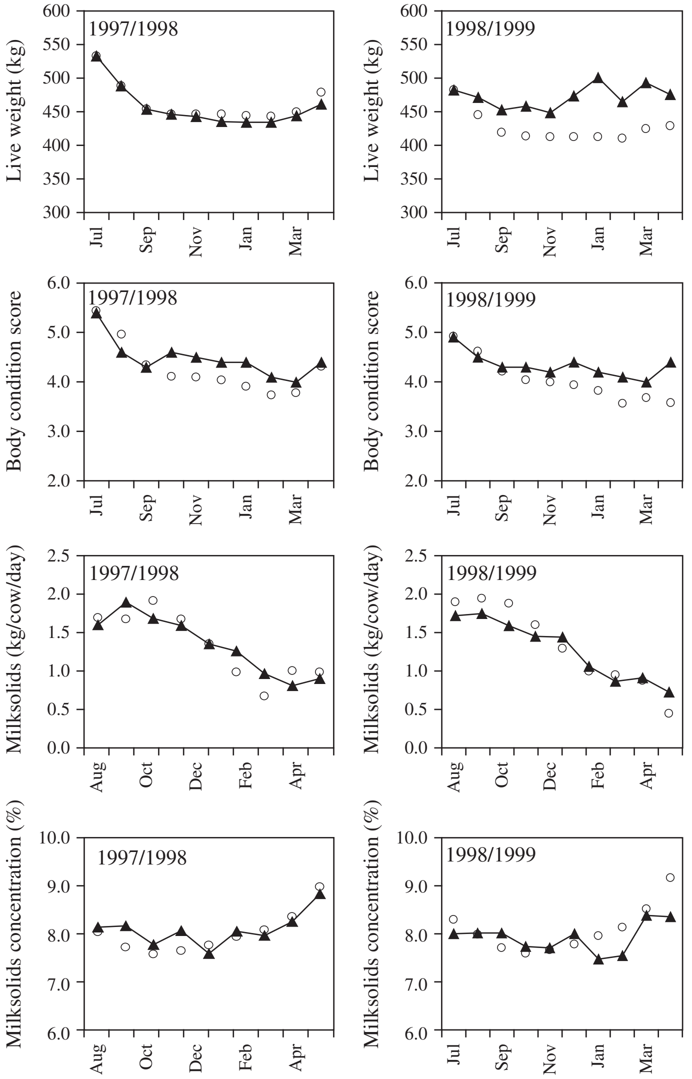


Fig. 3 Actual (–▲–) and predicted (○) monthly average liveweight, body condition score, milksolids yield and milksolids concentration for the Massey herd in the 1997/1998 and 1998/1999 season.

Inadequate mathematical representations of biology are obviously another source of error. However, a consistent source of error (i.e. bias or variance) was not observed for any of the measured traits, with the possible exception of the under prediction of MS concentration in peak lactation. This was offset by the slight over prediction of milk yield, which resulted in peak daily MS yields consistent with measured data. The mathematical representation of MS concentration was based on over 100 000 daily lactation records (Bryant et al. 2007a). Further independent datasets are needed to justify major changes to the mammary gland functions and representations of the effects of genetic merit, feeding level, BCS and age developed in the study carried out by Bryant et al. (2007c).

The findings of the scenario analysis for the SuperP farmlet revealed that an earlier calving date combined with feeding of chicory in the

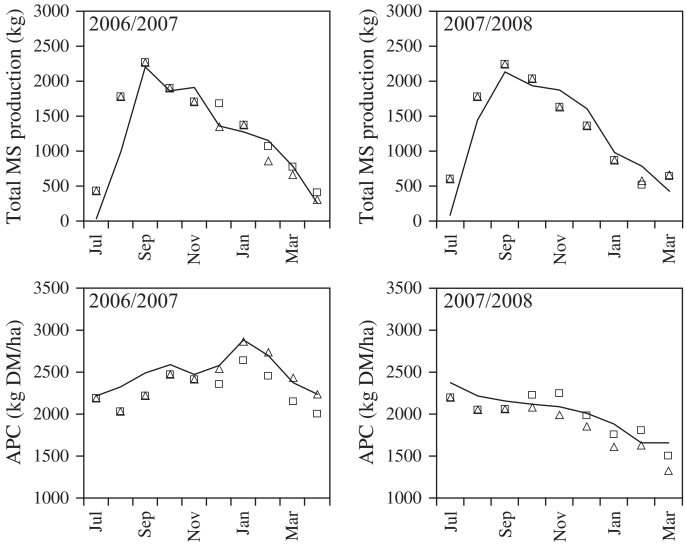


Fig. 4 Predicted (—) monthly milksolids (MS) production and average pasture cover (APC) compared with predicted values for scenario 1 (Δ) and scenario 2 (□) for SuperP in the 2006/2007 and 2007/2008 seasons.

summer could lift MS production by 50–190 kg MS/ha, but this would still be well below the target of 1750 kg MS/ha (Table 5). The earlier calving date was the main contributor to increased total yields per cow and per hectare, but this also reduced pasture cover from July to September, which is consistent with the findings of the work of Dillon et al. (1995) and the review by García & Holmes (1999). Careful pasture and animal management is needed with earlier calving systems to ensure that production and pasture cover targets can be met.

Table 5 Predicted milk, milksolids, fat and protein yield per hectare, end body condition score (BCS) and average pasture cover (APC) for the SuperP scenarios.

		Scenario	
	Predicted	1	2
SuperP 2006/2007			
Milk yield (kg/ha)	17456	18543	19606
Milksolids yield (kg/ha)	1479	1576	1669
Fat yield (kg/ha)	830	884	935
Protein yield (kg/ha)	649	692	735
End BCS	4.5	4.5	5.0
End APC (kg_{DM}/ha)	2234	2237	2000
SuperP 2007/2008			
Milk yield (kg/ha)	16567	17266	17131
Milksolids yield (kg/ha)	1407	1470	1457
Fat yield (kg/ha)	787	823	816
Protein yield (kg/ha)	620	647	642
End BCS	4.8	4.8	4.7
End APC (kg_{DM}/ha)	1654	1323	1502

Further simulation analyses (scenario 2) of the 2006/2007 season revealed that MS production of 1669 kg/ha and higher BCSs at the end of lactation could be achieved by feeding extra pasture in summer and autumn in combination with chicory. Extension of lactation length may allow the 1750 kg MS/ha target to be achieved, but autumn and winter pasture covers would be compromised.

The present research did not show a marked difference in monthly MS production or BCS in summer when comparing the feeding of chicory or turnips. Chicory is a high feed value forage known to promote fast growth rates in lambs and deer (Barry 1998) and MS responses similar to those achieved with turnips in dairy cattle (Waugh et al. 1998). In comparison with turnips, chicory is a perennial crop that can be used in a rotational grazing system, which allows establishment costs to be spread over a longer period (Waugh et al. 1998). Turnips can be grazed only once, but their contribution to total diet can be increased more easily than chicory, which is rotationally grazed. Chicory can be used more effectively than turnips to increase lactation length, as it can be grazed until May.

To facilitate greater usage of Farmax Dairy Pro, the evaluation steps and improvements outlined by Borenstein (1998) are being followed. First, face evaluation—with the main aim of achieving consistency between the designer's view and the potential user's view of the problem. Face evaluation provides a feedback mechanism for prototype refinement, reformulation and revision. Face evaluation has been achieved by allowing the testing of beta versions by farm consultants that use the other tools in the Farmax suite (i.e. Farmax Pro and Farmax Lite). Second, sub-system predictive verification and evaluation (as used in the present study and in Bryant et al. (2008)), which involves testing, verifying and/or evaluating modules as they are developed with independent datasets using a wide range of metrics to identify sources of error. Third, user assessment where independent parties (i.e. those not involved in a model's origins, development or implementation) are used to determine whether or not the model can be used in decision making. This is similar to face evaluation but will involve the use by farmers and consultants not familiar with the Farmax suite of tools. The aim of user assessment is to gain industry acceptance, and to assess the impact of computational system assumptions, simplifications, methods and generic structure. Finally, field testing in which experiments will be set up specifically to test the accuracy of model predictions will be investigated in the future.

The initial development of Farmax Dairy Pro has largely focused on the prediction and representation of feed supply, animal performance, realistic farm management and economics, and to simplify and facilitate the use and generation of informative reports. Future development, already underway, will focus on addressing the limitations of the model identified in the present paper and incorporation of a component that tracks the cover of each paddock on a farm to forecast and more accurately identify short-term feed deficits and assist with rotation planning.

Conclusion

Farmax Dairy Pro reliably predicted mean annual yields (per cow and per hectare) for milk, fat, protein and MS concentration for two farmlet studies with spring-calving cows. Pasture cover was reliably predicted for the one dataset where validation was possible. The model accurately predicted the general trajectory of yield, MS concentration and BCS, but in some instances the model over or under predicted the degree of variation between months. The model can be used to accurately predict the outcome of farm management changes on animal performance, pasture cover and total yields. Defined steps of validation have been followed to ensure that model predictions are accurate, and that the model is easy to use and adds value to a business. The aim of the evaluation procedures is to generate industry acceptance so the tool can be used to maximise farm profits by allowing easy exploration of managerial changes.

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