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Quantifying the importance of submission rate to artificial breeding on reproductive performance and profitability in dairy cattle herds

P.C. BEUKES, R.M. TIDDY[1], C.R. BURKE, G. LEVY and J.A.S. LANCASTER

Dexcel Ltd, Hamilton, New Zealand

ABSTRACT

Dexcel's Whole Farm Model (WFM) allows the user to construct a mating policy using dates for anoestrous treatment, artificial breeding (AB) and bull mating with corresponding levels of heat detection efficiency. The model then predicts the outcome of the mating programme for each individual animal using an approach based on physiological events, represented by algorithms incorporating current best knowledge. Four commercial dairy farms were initialised in WFM by describing the farm set-up and management decisions for the 2005/06 season. A range of feeding, production and reproduction indicators was used to validate the model predictions against that observed. All four farms had an observed 3-week submission rate (SR) of about 90%. An alternative scenario with SR at 80% was created for each farm by simulating reduced oestrous detection efficiency during AB. The eight scenarios were then run for 20 random simulations over three consecutive years. The trend was for SR 90% to result in more milksolids in the second and third years, improved reproductive outcomes and, despite higher AB costs, an increased ($P<0.05$) economic farm surplus of $80+/ha. This exercise demonstrated that the WFM is capable of simulating reproductive performance in dairy herds and holistically linking this performance to productivity and profit over successive seasons.

Keywords: dairy; modelling; reproduction; economics.

INTRODUCTION

Relatively high levels of reproductive performance are required in seasonal dairying where inter-calving intervals are constrained to 365 days (Macmillan, 1998). However, the links between reproductive performance, production and profitability are not easily quantified for several reasons including: complexity of farm systems; nutritional influences on fertility are only partly understood; production can be resilient to variances in reproductive performance; and reproductive performance is subject to carry-over effects where true costs or benefits are only realised over several seasons.

Modelling is the most feasible approach to linking variances in reproductive performance to production and profitability. Further, a model would serve to focus and contain knowledge and best-practices in relation to cow fertility. This would greatly assist with development and extension of consistent messages and predicted outcomes in relation to reproductive advice to farmers.

One of the key drivers of reproductive performance is the proportion of the dairy herd mated within the first 3 weeks (3-week submission rate, SR; Macmillan, 2002). The SR achieved has short-term implications for that year (*e.g.* breeding costs, in-calf rate, final empty rate, culling and replacement), but also longer-term carry-over effects in the following years by influencing calving pattern, feed budgets, production and economics.

This paper:

1) summarizes the capability of the Dexcel Whole Farm Model (WFM) to predict reproductive performance of a dairy herd over successive years;
2) validates the model output against observed data from four commercial Waikato farms and
3) demonstrates utility by predicting the impact of 80% versus 90% SR on overall farm performance over successive years.

MATERIALS AND METHODS

The WFM is a VisualAge Smalltalk (IBM) framework, linking sub-models of pasture growth (McCall & Bishop-Hurley, 2003) and cow metabolism (Baldwin, 1995) written in different programming languages, and designed to simulate the complex interactions of climate, pasture, animals and management on a dairy farm. For this exercise, WFM version 1.1.4 was used and the exercise was completed in three steps:

1) Developing the capabilities of the model to predict cycling, insemination, conception and pregnancy of individual cows,
2) Initializing four Waikato farms in the model and validating model predictions against observed and,
3) Using the four validated scenarios to model

[1]Vet Resource, Te Awamutu, New Zealand

the impacts of changing the 3-week SR from 90% to 80% by reducing the heat detection efficiency during artificial breeding (AB).

1) Developing the predictive capabilities of the model:

The WFM was upgraded to simulate reproduction using an approach reflecting the physiological events required for postpartum cows to re-establish pregnancy (Figure 1). Key milestones for individual cows are first oestrus, insemination to detected oestrus, conception and pregnancy maintenance. Each step is influenced by cow factors, management factors and randomness. The WFM predicts the outcome of the interplay of these factors for each individual animal, and summarises these outcomes to derive familiar performance indicators at herd level (*e.g.* rates of calving, anoestrum, insemination, conception and pregnancy).

a) Cow factors:

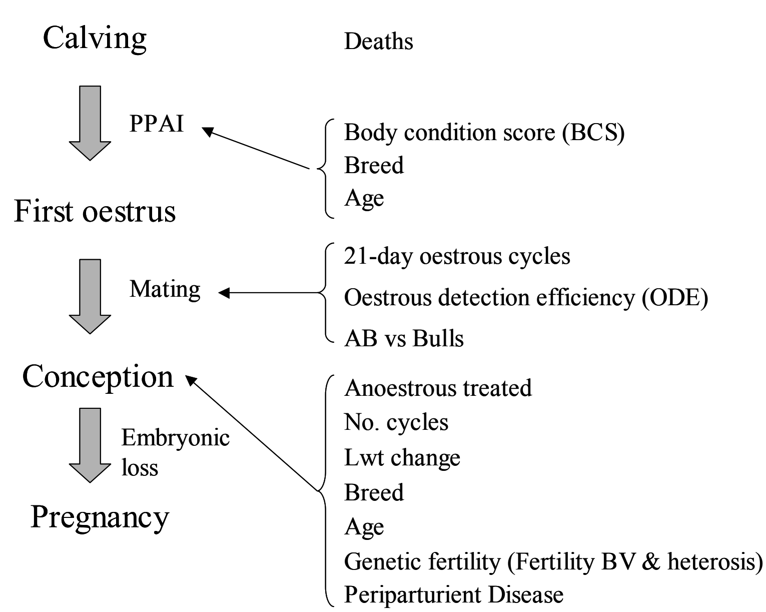
When the WFM is initialised, calving dates are either manually ascribed or randomly assigned to cows in order to reflect the herd's calving pattern. In successive years, calving date is 282 days from previous conception when the cow is retained. Replacement heifers are randomly assigned calving dates to reflect the previous calving pattern for heifers or calving dates can be specified individually.

Date of first oestrus is determined by adding the postpartum anoestrous interval (PPAI) to calving date. The PPAI for each animal is selected from a reference matrix of PPAI that varies by breed and age with further modification by body condition score at calving (Grainger *et al*., 1982; McDougall *et al*., 1995; Burke *et al*., 2005; 2006). The PPAI ascribed to an individual is chosen randomly, or semi-randomly, from normal deviations around mean PPAI values within the reference matrix, but truncated to a minimal PPAI. The mating policy in WFM includes an option to artificially abbreviate PPAI by applying anoestrous cow treatments.

Cows maintain a 21-day oestrous cycle from date of first oestrus until pregnancy is established. They are only eligible for insemination when oestrus occurs (every 21 days once cycling) and is detected during defined mating periods specified by the mating policy. Oestrous detection efficiency is a user-defined variable and can be varied through the mating period to reflect temporal differences in oestrous detection performance throughout the mating period (*e.g.* AB versus bull matings).

Conception rate (CR) is the chance of a cow conceiving to an insemination. At insemination, the CR is selected initially from a reference matrix that accounts for age, breed and number of previous oestrous events prior to insemination.

Figure 1: Physiological events modelled by the Dexcel Whole Farm Model (WFM) for re-establishment of pregnancy in the dairy cow.



The CR matrix is based on large-scale field observations (*e.g*. Xu & Burton, 2003). The final CR ascribed to individuals is modified by liveweight change three weeks prior to insemination, genetic merit for fertility, genetic heterosis (if crossbred) and a "health factor". The effect of liveweight on CR is derived from data of Buckley *et al*. (2003). Genetic effects on CR (*i.e*. Fertility BV and heterosis) are derived from Harris *et al*. (2006). The impact of calving disorders on subsequent fertility are represented by the "health factor", and based on data from McDougall *et al*. (2006). Embryonic loss is also simulated in the WFM, with the prevalence being user-defined but defaulted at 10%. Individuals that lose a pregnancy return to an oestrous cycling state and can be mated again.

b) Management factors:

On the "Management" page of the WFM user interface the user constructs a mating policy with dates for anoestrous treatments (if used), artificial breeding (AB) and bull mating with corresponding levels of oestrous detection efficiency (ODE). The user also specifies the pre-mating ODE which subsequently influences the number and accuracy of treating anoestrous cows. Additional settings include death rate at calving and dates for pregnancy tests (which affects costs and accuracy of culling decisions). Reproductive outcomes are also linked with policies around feed supply and drying-off dates since these features influence the body condition and liveweight of animals.

c) Randomness:

The WFM can generate varying outcomes with successive iterations of the model to reflect the inherent randomness of biological systems. The user can specify PPAI to be assigned in one of three ways. The random option will assign PPAI from a normal distribution, with different iterations of the same scenario producing varied results. The semi-random option reshuffles cow order so that cow outcomes may vary, but iterations of the same scenario will ultimately produce the same outcomes at herd level. The third option is for the exact mean value within the reference matrix to be assigned. The random and semi-random options are also available for assigning CR to mating events.

2) Validating WFM against commercial dairy farms

Detailed information regarding reproductive performance in four commercial Waikato dairy farms for the 05/06 mating season was made available (C.W.R. Compton, Morrinsville Animal Health Centre). Additional information including farm type, feeding levels, management and productivity was collected to initialise the WFM to best represent the particular farm being examined. The farm systems varied from

- a high-stocked system 4 farm (Hedley *et al*., 2006) with a mixture of breeds (Farm A),
- a system 2-3 farm feeding minimal silage in spring and turnips in summer to a mixture of Holstein-Friesians and Crossbreds (Farm B),
- a high-input system 5 farm with supplements being fed to large crossbreds all year round (Farm C), and
- a system 3 farm with zero-Nitrogen policy and Jersey cows being milked once-a-day for part of the year to protect their body condition (Farm D).

All farms had to be scaled down to a 100-cow herd to fit the available computing power. The scenarios were then run using actual climate data from the Ruakura climatological station (supplied by NIWA) for the 05/06 season to drive the pasture sub-model. Scenarios were run with the semi-random setting in the mating policy, resulting in variation amongst cows, but with a deterministic outcome of the policy. A number of feeding, production and reproduction-related indicators were adjusted to validate the model predictions against observed (Table 1). Each scenario was fine-tuned using cow genetic potential for milk yield, pasture production and factors for which little or no information existed, such as ODE, in an attempt to achieve predicted indicators within <10% of the observed value.

3) Modelling the impact of 80% versus 90% 3-week SR

All four farms showed predicted and observed 3-week SR of between 87% and 93% (Table 1). An alternative scenario with 3-week SR at 80% was created for each farm by reducing ODE during the AB mating period. An SR 80% is considered average performance within the dairy industry (Harris *et al*., 2006). All eight scenarios (two per farm) were then run for 20 simulations over three consecutive years by repeating the 05/06 climate-year. All simulations were run using the random option for assigning PPAI and CR (as described previously), which resulted in a stochastic outcome for each simulation. The 05/06 climate-year was repeated to remove the effect of climate variability on the outcome of the multiple-year simulations. Multiple-year simulations accounted for cow aging, herd-specific culling policy and replacements. Replacement heifers, with randomly assigned calving dates reflecting the original calving pattern of the heifer population, were introduced each season to maintain the original herd size. Inductions were not simulated. At the end of each simulation reports were generated and the required measurements extracted. Each farm was considered to be a separate trial because of the large differences between farm systems, so the data were analysed individually for each farm and each year using analysis of variance with SR as the treatment (GenStat 9, 2007).

RESULTS

Differences between on-farm observations and WFM predictions for several key performance indicators are presented in Table 1. A difference value of 100% depicts absolute predictive accuracy. Predictions for feed given, milksolids production and reproduction indicators were generally within an acceptable range from the observed. However, WFM consistently over-predicted the end cow liveweight (on 31 May). The WFM also had difficulty in accurately predicting the proportion of cows treated for anoestrous. On further investigation, it was discovered that farmers made *ad hoc* decisions regarding anoestrous treatment policy that were not accounted for by WFM. Final empty rate (%) also proved to be hard to predict accurately (Table 1).

For two farms the SR 90% treatment resulted in a significantly smaller proportion of the herd calving after 8 weeks from start of calving and within 28 days from start of mating ("late calvers") in the second year (Table 2). The SR 90% treatment resulted in significantly fewer days to 50% of the herd calved in the 2nd and 3rd years (Table 3). A decrease in ODE during AB, and therefore a decrease in the 3-week SR from 90% to 80% in the first year, resulted in a significant decrease in milksolids production (kg/ha) in the following year (2nd year of simulation) in two of the four farms (Table 4). Nominally lower milk production with SR 80% was also evident in the 3rd year although this was not a statistically significant result.

Changes in SR did not alter the economic farm surplus (EFS) in the first year (Table 5). However, the higher SR resulted in more days in milk and higher milksolids production per ha, and ultimately resulted in carry-over effects valued from $8/ha to $95/ha (the range across all four farms) in the second and third years. In two of the four farms (A and B), the EFS was significantly higher in the second year with SR 90%, and associated with significant increases in milk yields (Table 4). In these two farms WFM predicted the economic gain to range from $81/ha to $95/ha (Table 5).

Table 1: Observed (Obs), predicted (Pred) and difference (Diff%=Pred/Obs*100) of key performance indicators for four commercial Waikato farms for the 05/06 season2.

Farm	A			B			C			D		
	Obs	Pred	Diff%	Obs	Pred	Diff%	Obs	Pred	Diff%	Obs	Pred	Diff%
End farm cover (kg DM/ha)	2125	2506	118	2209	2227	101	2073	2344	113	1946	1976	102
End cow liveweight (kg)	460	531	115	450	541	120	480	522	109	440	454	103
Maize silage fed (t DM/scaled farm)				24.4	22.3	91	90.6	92.5	102	28.5	28.7	101
Palm kernel fed (t DM/scaled farm)	14.5	14.3	99				41.1	45.2	110			
Grass silage fed (t DM/scaled farm)	36.9	34.2	93	22.0	22.7	103	24	23.1	96	12.8	13.8	108
Turnips fed (t DM/scaled farm)				18.2	16.2	89						
Hay fed (t DM/scaled farm)	4	3.8	95				2.3	1.6	70	3.8	4.1	107
Silage made (t DM/scaled farm)	30.9	25.3	82	13.2	11.4	86	18.9	19.1	101	14.1	15.4	109
Milksolids (kg/cow)	317	317	100	335	346	103	455	498	109	355	388	109
Milksolids (kg/ha)	1134	1242	110	1064	1028	97	1863	1897	102	1115	1193	107
Treated non-cyclers (%)	11	22	200	31	25	81	33	28	85	21	33	157
3 wk SR (%)	90	90	100	93	91	98	90	92	102	93	87	94
4 wk SR (%)	93	95	102	95	95	100	93	94	101	95	96	101
4 wk in-calf (%)	64	65	102	64	58	91	61	62	102	62	66	106
8 wk in-calf (%)	82	85	104	81	79	98	82	82	100	82	79	96
10 wk in-calf (%)	88	90	102	84	81	96	86	88	102	87	87	100
Final empty rate (%)	11	9	82	8	11	138	9	6	67	13	12	92

Table 2: Predicted percentage of the herd calved after 8 weeks and within 28 days from start of mating ("late calvers") for four farms for three consecutive years with 3-week submission rate (SR) at 80% or 90%. Significant differences are highlighted in grey.

Farm	Year	80% SR	90% SR	sed	P-value
A	1	4.8	5	0.11	0.159
	2	11.7	10.2	0.66	0.029
	3	11.5	10	0.98	0.133
B	1	9.9	10	0.07	0.154
	2	12.9	10.2	1.3	0.049
	3	12.7	13.7	0.91	0.256
C	1	13.9	13.9	0.11	0.643
	2	13.5	13.5	1.07	0.963
	3	14.3	12.1	1.26	0.088
D	1	5	5	0	
	2	6.7	5.6	0.72	0.133
	3	5.7	4.7	0.66	0.14

Table 3: Predicted number of days to 50% of the herd calved for four farms for three consecutive years with 3-week submission rate (SR) at 80% or 90%. Significant differences are highlighted in grey.

Farm	Year	80% SR	90% SR	sed	P-value
A	1	21	21	0	
	2	19.3	15.9	0.88	0.001
	3	18.7	15.2	1.02	0.002
B	1	15.4	15.4	0.91	
	2	23	19.6	1.28	0.012
	3	22.8	20.1	1.16	0.028
C	1	22	22	0	
	2	21.7	20.3	0.67	0.044
	3	19.9	17.4	0.73	0.001
D	1	15.1	15.1	0	
	2	14.9	13.5	0.58	0.02
	3	13.8	12.9	0.61	0.126

Table 4: Predicted milksolid yield (kg/ha) for four farms over three consecutive years with 3-week submission rate (SR) at 80% or 90%. Significant differences are highlighted in grey.

Farm	Year	80% SR	90% SR	sed	P-value
A	1	1242	1243	3.8	0.947
	2	1177	1195	6.6	0.007
	3	1195	1210	9.3	0.117
B	1	1022	1022	2.5	0.861
	2	991	1012	6.4	0.003
	3	965	976	7.5	0.135
C	1	1883	1884	4.3	0.806
	2	1913	1917	8.6	0.666
	3	1883	1896	7.6	0.079
D	1	1191	1191	4.0	0.881
	2	1061	1069	5.8	0.176
	3	1015	1027	6.7	0.08

Table 5: Predicted Economic Farm Surplus (EFS, $/ha) for four farms for three consecutive years with 3-week submission rate (SR) at 80% or 90%. Significant differences are highlighted in grey.

Farm	Year	80% SR	90% SR	sed	P-value
A	1	957	955	27	0.954
	2	692	773	30	0.01
	3	692	745	47	0.263
B	1	859	858	21	0.959
	2	802	897	26	0.001
	3	814	858	32	0.18
C	1	2511	2510	21	0.96
	2	2698	2706	35	0.814
	3	2762	2813	31	0.11
D	1	1275	1270	20	0.794
	2	858	895	31	0.249
	3	666	714	34	0.167

DISCUSSION

An approach to assessing likely impacts of altering reproductive performance on dairy farms is described. The basis is the development of a model (WFM) that simulates the entire dairy farm system and holistically links multiple physical performance factors to profitabilty. The reproductive modelling component is a recent addition to WFM, and is founded on well-known physiological requirements for postpartum cows to re-establish pregnancy. The default values and incidences that drive reproductive performance at herd-level within WFM are derived from large-scale field observations. The utility of using the WFM to explore the on-farm consequences of altered reproductive performance or management policies represents a powerful tool for research and extension activities aimed at improving reproductive performance on New Zealand dairy farms.

This exercise highlighted some areas for ongoing improvement in WFM. One of these areas relates to the impact of body condition score on influencing PPAI. The consequences of PPAI being inaccurately predicted have flow-on effects in the WFM, with inaccurate rates of anoestrum, anoestrous cow treatments and conception rates in early mating. The default "BCS factor" in WFM is 8 days longer PPAI with each 1 unit decline in BCS at calving, which is an average value reported in several previously published studies (Grainger *et al*., 1982; McDougall *et al*., 1995; Burke *et al*., 2005; 2006). However, breed by age interactions on the magnitude of the "BCS factor" should also be taken into account. McDougall *et al*. (1995) found this "BCS factor" to be greater for Friesians (15 days per unit BCS) than Jerseys (4 days per unit BCS). The greater value for Friesians is probably subject to breed x age interaction. Two-year old Holstein-Friesians appear particularly sensitive to BCS at calving. Burke *et al*. (1995) found that the interval to first oestrus was increased from 62 to 85 days in Friesian heifers calving at 1.5 BCS units (50 kg Liveweight) lighter (4 versus 5.5 BCS). The "BCS factor" in this instance would amount to 15 days PPAI per unit BCS, which is consistent with other data (McDougall *et al*., 1995) showing Holstein-Friesians take longer than Jerseys to cycle after calving. The WFM can be manually adjusted to account for these interactions but a high degree of user-expertise is required.

Another area highlighted for improvement was the magnitude with which changing liveweight could influence conception rate. The intention was to incorporate an effect accounting for "rising plane" of nutrition, which is generally believed to exist although poorly defined. The calculations were derived from Irish data (Buckley *et al*., 2003). Liveweight change is used instead of BCS since the early stages of positive energy balance are evident with increasing liveweight, without an obvious increase in BCS (Buckley *et al*., 2003; Roche *et al*., 2006). It makes sense that internal reserves are replenished initially, before accumulation of peripheral adipose tissue that determines BCS. The work by Roche *et al*. (2006) based on New Zealand data has shown that the Buckley-parameters in WFM may result in the "rising plane of nutrition" effect having an overly large bearing on CR, both negatively during weight loss or positively during weight gain. Recent improvements in WFM allow the user access to the parameters controlling the "rising plane" effect and therefore control the magnitude of the effect of nutrition on CR; while the default values now reflect the New Zealand data of Roche *et al*. (2006).

Exploration of changes in SR was deemed appropriate to test the utility of the model in predicting the consequences of variable reproductive performance. Macmillan & Watson (1973) first reported the importance of 3-week SR on conception patterns in dairy herds. Since then the SR target of >90% has been advocated for herds with a seasonal calving pattern, that are fed to achieve peak daily milk yields of at least 17 L (Jersey) to 23 L (Friesian), and where most cows usually have a pre-mating oestrus (Macmillan, 1998). Macmillan (2002) identified the two main influences on SR as prevalence of anovulatory anoestrus and ODE. ODE can be described as accurate when only cows that are actually in oestrus (or have been in oestrus during the preceding 24 h) are drafted for insemination, and thorough when no oestrus cows are missed at the time of drafting for AB. Macmillan (1998) also outlined the three main types of errors in heat detection, *i.e*. errors in diagnosis (non-oestrus inseminations), errors of omission (non-detection) and errors of identification (non-oestrus insemination because of confused identity). The WFM accounts for error of omission with the user specifying ODE, but it does not currently address the issue of "non-oestrous" insemination. The WFM also assumes that all cycling cows display a detectable oestrus, whereas ovulatory events without overt oestrus can be prevalent during the early mating period in some herds. These are features that could be incorporated with ongoing refinements to the WFM.

Our results show that by reducing this error of ommision (*i.e*. increasing ODE) and thereby increasing the SR from 80% to 90%, most farms with seasonal calving herds can expect a reduction in late-calvers and a more concentrated calving in the following two years. These gains could be converted into more days in milk and higher milksolids production per ha, and ultimately result in economic carry-over effects valued from $8/ha to $95/ha (the range across the four modelled farms) in the second and third years. Contributing to this increased profit with the SR 90% treatment could be lower 10-week empty rates in the 2nd and 3rd years resulting in higher net stock income from fewer culled empty cows, despite increased AB costs from more earlier matings.

Farms C and D were different from farms A and B by not showing significantly higher milksolids production and EFS with the SR 90% treatment in the second year of the simulation. The underlying reasons would require further exploration. Possible explanations include compensatory effects during bull mating, feeding levels in the subsequent lactation limiting any benefit of a more condensed calving pattern, and, ironically perhaps, that poorer mating performance leads to more replacement heifers that calve relatively early. The possibilities highlight the complexity of the farm system, and the need for ongoing refinements to modelling reproduction in the WFM.

The trend in EFS over the three years was downwards for three farms (A, B, D) with both SR 80% and SR 90% treatments. This was correlated with a general trend of an increase in the proportion of late calvers over the three years. Despite a general reduction in the number of days to 50% of the herd calved (a more compact calving spread at the front end of calving) the tail-end of the calving spread actually lengthened over time. Farm C was the only farm where EFS consistently increased over the three years irrespective of treatment. In this case the calving spread was compacted at the front end of calving, while the proportion of late calvers was held in check. Farm D managed to do the same over the three years, but high empty rates and consequently replacement rates resulted in an altered herd structure with higher proportions of younger cows with lower milk production potential in the 2nd and 3rd years. With zero Nitrogen-input, Farm D also suffered from a gradual reduction in pasture cover and consequently pasture intakes. These changes over time reflected in substantial reduction in milksolids/cow, with WFM predicting an unsustainable system.

The trends described above highlight the challenge of modelling successive years when management policies and decisions are established at initialisation. Although WFM is constantly monitoring the outcomes there is no current facility to adjust decision rules or farm set-up while simulations are running. In practice, farmers constantly monitor and make day-to-day adjustments to maintain a stable farm system.

CONCLUSIONS

Simulating reproductive events on dairy farms is a recent function added to the Dexcel WFM. A somewhat deterministic approach based on well-documented physiology and industry prevalences is the basis of this function. The reproductive component of the model is robust, although further refinements and limitations have been identified. The utility of the WFM was demonstrated with an exercise that explored the importance of the 3-week SR in commercial dairy farms. The economic benefits of SR 90%, as compared with SR 80%, materialised as carry-over effects in the 2nd and 3rd years. The increase in profitability was estimated at $80+/ha in the cases where the SR 90% treatment resulted in significant compaction of calving spread in the early part of calving, and also a significant reduction in the proportion of late calvers.

As with all biological models, the inputs need to be accurate and the outputs require cautious interpretation. Further, a reasonable degree of subject expertise is required to maximise the value of the WFM as a tool for supporting dairy farm research and extension to assist farmers to maintain good reproductive performance.

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