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Culled early or culled late: economic decisions and risks to welfare in dairy cows

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Abstract

Involuntary culling (IC) is where a cow is disposed of due to injury, poor health or infertility. The main reasons for IC are infertility, mastitis and lameness. These reasons have differing age profiles in when they affect cows, cost variable amounts to treat and have an effect on the value of the cow at market. They also reduce cow welfare in different ways. These factors influence the economically optimum cow replacement decision, which must balance the risks of future loss from the current cow against its future prospects and the net costs of a replacement. So the farmer's economic decision as to when to cull a cow may not occur at the same time as when the cow could, and sometimes should, be culled to maximise her welfare. To explore this dilemma, we developed a Dynamic Programme (DP) model to assess the optimum replacement policies for each of 180 possible cow states (12 parities and 15 milk-yield levels) under a simplified set of alternative husbandry systems and remedial practices. The DP was used to explore the relationships between financial outcomes, investment in improving welfare, lifespan and IC in dairy systems. There is a trade-off between dairy cattle lifespan and risk of suffering over which farmers have some control by the replacement and investment decisions they make. Our results show that improving cow welfare by reducing mastitis, lameness or infertility over the long term increases the mean longevity of the herd and also reduces the potential of long-term suffering resulting from chronic conditions. Additionally, it has the effect of increasing replacement opportunities and the annuities for each cow (£ per cow per year) mainly by increasing milk yield and reducing costly on-farm culls, creating a win-win situation for both farmer and cow.

Keywords: *animal welfare, culling, dairy cows, Dynamic Programme, economic values, longevity*

Introduction

Dairy cows are culled (defined as a cow being euthanised on-farm or being sold for slaughter into the human food-chain or disposal of the carcase) at the end of their working life due to low milk yield, if there is an untreatable health or welfare problem, or if the cow is unable to become pregnant during lactation. The relationships between the factors leading to culling, whether or not the farmer has been able to actively make the decision to cull the cow and the timing of where within the cow's potential lifespan that culling occurs, affects the overall cost to the farmer. These factors also affect the welfare of the cow. There have been a number of recent reviews on culling (eg Forbes *et al* 1999), the reasons for culling (eg Logue *et al* 2000), and decision-support tools for farmers on optimising financial outcomes for the farmer by the timing of culling (eg Kennedy & Stott 1993). This study aimed to build on that research by examining trade-offs between the humane end-points for the cow and the optimum culling decision from the farmer's financial point of view.

There are two main reasons why culling occurs (Fetrow *et al* 2006). Animals that the farmer chooses to cull for his/her own reasons (the animal makes way for one with higher potential) are culled 'voluntarily' (voluntary culling: VC). VCs are usually sold for slaughter into the human food chain. Some farmers will also include the cows they have sold 'in-milk' as VCs (ie the cows sold to another farm mid-lactation carrying on as a productive animal at their new farm — usually due to a lower yield than required on the first farm) but these are not strictly covered by the term 'cull' and are not counted as such in our modelling process. 'Involuntary culling' (IC) is where a farmer must dispose of a cow before he/she would otherwise choose to because of injury, poor health or infertility in the cow. IC cows may be milked part-way or throughout the lactation and sold direct to slaughter for human consumption or other use depending on the carcase grade (Shemeis *et al* 1994). IC also includes those cows that die on-farm due to accident, injury or are euthanised.

Total culling rates include both VC and IC. Recent studies have estimated the UK total culling rate to be 22–25% per year (Whitaker *et al* 2000; Bell *et al* 2010; Orpin & Esslemont 2010). This is lower than the USA rate of approximately 35% (Hadley *et al* 2006; De Vries *et al* 2010) and comparable to other countries in the EU with similar intensities of farming (eg The Netherlands: 27 to 34%; Barkema *et al* 1994 and Ireland: 27%; Evans *et al* 2006).

If a farm is to maintain its herd size, the number culled must not exceed the numbers of replacements available. The percentage of UK total culling which is VC is often below 10% (8.8%: Bell *et al* 2010; 2.9%: Orpin & Esslemont 2010; ~3%: Brickell & Wathes 2011; 5.7%: Whitaker *et al* 2000). Because the majority of culling is unplanned or unexpected (and so is IC), this means that in order to maintain herd size, lower yielding cows can remain on-farm for longer than economically ideal. It may also lead to cows that would have been culled for health issues remaining on-farm as long as they get pregnant. The most common reason for IC is 'infertility' (Beaudeau *et al* 1993; Bascom & Young 1998) accounting for between 15–40% of cows culled. Mastitis is the second most common reason, at approximately 5 to 20% of cows culled (Bar *et al* 2008). Other health complaints including lameness (Booth *et al* 2004) and uterine infection (Bell & Roberts 2007) account for another 5 to 15% of cows culled. There is evidence of a relationship between higher yielding cows and IC (Hadley *et al* 2006), but higher yielding cows are given more time to get back into calf than lower yielding cows (Mackey *et al* 2007).

Cows tend to increase their yields until their fifth parity, declining in yield thereafter. As cows age, veterinary-input costs increase associated with the increased likelihood of disease (Smith *et al* 2010). If cows remain healthy during the first five parities, it becomes economically desirable to cull them after the sixth or seventh parity to pre-empt the extra veterinary costs occurring in older age (Stott 1994). However, most cows are culled long before their sixth parity due, in many cases, to conditions associated with poor welfare. This gives some concern for both economic (ie not selling in milk what the animal cost to raise: Veerkamp *et al* 1995) and welfare reasons (ie cows not surviving more than four lactations due to poor health: FAWC 2009). Kossaibati and Esslemont (1997) found that 41% of cows did not survive to their fourth parity. On larger US herds, 83% of cows were culled before their fourth parity (De Vries *et al* 2010).

Orpin and Esslemont (2010) calculated losses for the different IC types and found that farms with the same culling rate may vary considerably in costs of culling, as the reason or timing of culling explains the majority of the variation in cost. Determining the cost to the cow is a little more speculative. The welfare 'cost' to the cow of IC would vary with the underlying cause of IC and the length of time the cow had compromised welfare before the cull was carried out (eg Bar *et al* 2008).

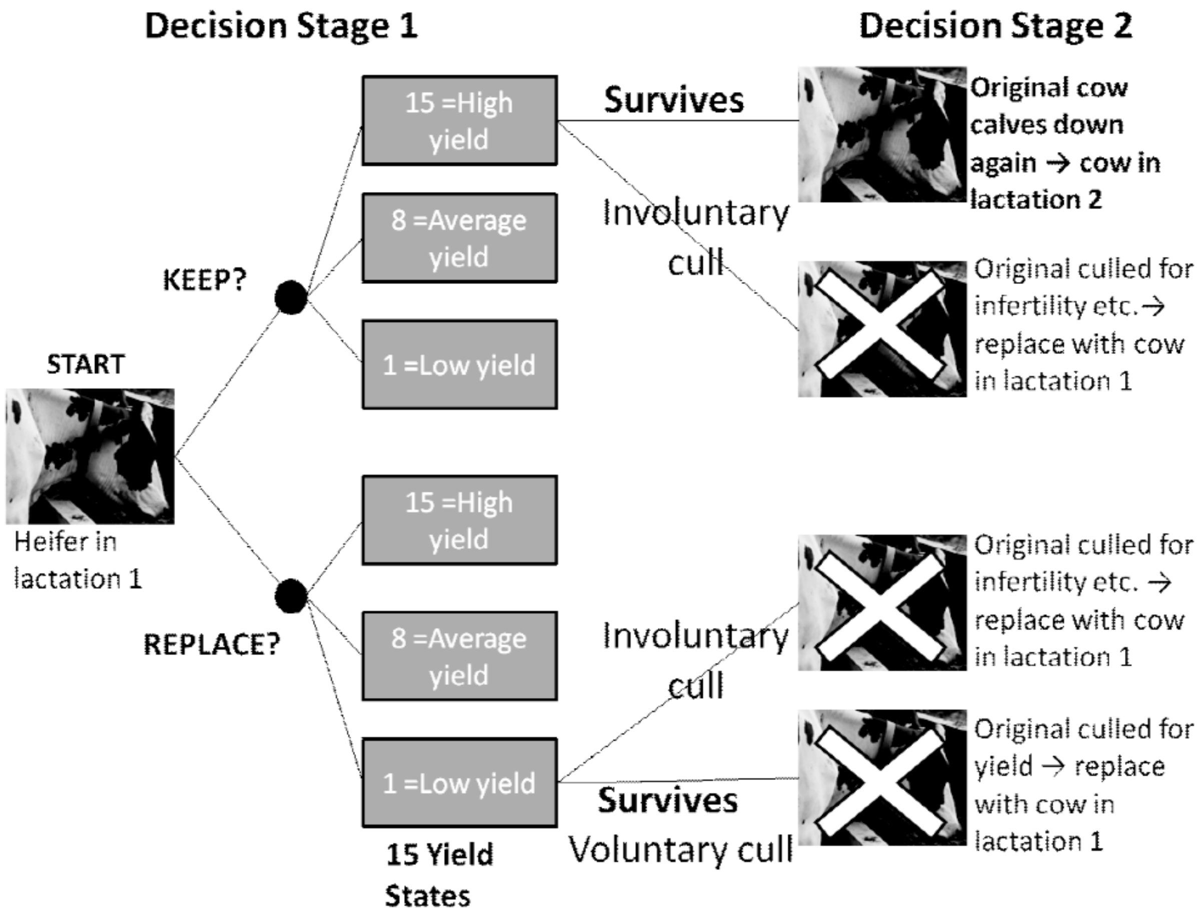
Dynamic Programming (DP) has been used to analyse dairy cow replacement decisions (Kennedy 1986). The DP acts as the financially perfect farmer by making 20 years of financially optimum 'keep and replace' decisions (not optimum for welfare or any other parameters). Recent models have examined important management decisions such as the optimal replacement of mastitic cows (Stott & Kennedy 1993) and the relative value of different mastitis control procedures (Yalcin & Stott 2000). To-date, the technique has not been used to model the relative costs of the main causes of IC. Therefore, the aim of this study was to model, for two different but not extreme input systems, the effects of altering the incidence of the three main causes of culling: infertility, mastitis and lameness, on involuntary culling, economics and cow welfare.

Materials and methods

The DP method used was based on an updated version of the model described by Stott (1994). The expected net present value (ENPV) was the chosen method of financial outcome considered. The objective was to maximise the ENPV of returns from a current heifer (newly calved in year 0) and all of its successors over 20 year-long stages. The returns were discounted for each year so that extending the time-period beyond 20 years had little effect on the outcome. To make the outcome as clear as possible, the ENPV was expressed as an annuity in £ per cow. The objectives were achieved by selecting the appropriate sequence of replacement decisions (ie 'keep heifer/cow' or 'replace with a new heifer') at the start of each stage. As the optimal decision at any stage depends on the decisions to be made at each future stage, the majority of sub-optimal decision sequences must be eliminated. The DP technique removes this problem as the optimal decision in the final stage must form part of the optimal decision sequence, so the routes to all other outcomes are ignored. This process continues backwards across all the decisions to the first decision, allowing the optimal decision path for any given initial stage to be found by following forwards as shown in Figure 1. Kennedy (1986) gives full details of the procedure and this model can be downloaded online (http://www.kennedyltu.net/research/) (Kennedy 2011).

The DP was undertaken for two 'typical' 100-cow herds, one from a 'high-input' system (where the diet of the cows had a high concentrate/roughage ratio and cows would only have access to grazing for a short period with a high level of veterinary input), the other from a 'low-input' system (where cows were assumed to be grazing during the summer, the concentrate feed/roughage ratio was lower with a low level of veterinary input). Further details on the inputs used to build the 'typical' herds can be found in Langford *et al* (2011). National Milk Records (NMR) and Holstein UK (HUK) database outputs for the period 1998 to 2010 were used to gather information on British dairy herd 305-day yields for the DP model. These data were from England, Wales and Scotland. Data from Holstein and Holstein-Friesian cows were used. All complete lactations below 280 days were removed from the data, as were lactations above 450 days to reduce the skewing of the data distribution. As in previous studies using a similar method (eg Logue *et al* 2000), the bottom 10% by yield of all herds (eg including very small-scale farmers and niche producers) were rejected as their data would skew the distribution. The remaining data were split into the two input systems using an estimation method based on milk yield as described by

Figure 1



Part of the Dynamic Programme decision tree, representing the first and second decision made by the programme for one potential heifer. The animal could be giving one of 15 different yield levels or 'states' affecting the first keep or replace decision. What happens to the animal during lactation will affect the second keep or replace decision. The cow could be culled involuntarily during lactation, survive and be culled voluntarily (eg due to yield), or survive and carry on to the second parity.

Haskell *et al* (2007). The classification of the low-input system included data from the 20–40 percentiles of the national data on milk yield. The high-input system included data from the 60–90 percentiles of the national yield data. In each input system, 305-day yields were used to calculate mean milk yields for each of 12 parities.

The DP's objectives depend on the expected net margins generated from the current heifer and its optimum sequence of successors at each stage over the 20 annual stages. These net margins were the margins of milk and calf sales over the feed costs. IC (due to death, disease and infertility which will be adjusted in each culling scenario below) and other 'fixed' costs (which included veterinary costs not associated with the culling scenarios) were added for each input system. As the future milk production and levels of IC are unknown at the time of the keep/replace decision, the range of possibilities was reflected by 180 milk-yield 'states' for each input system which each consisted of 15 milk-yield levels (ranging from low to high around the mean at milk level 8) at each of 12 parities (parity 1 to 12).

Table 1 Mean 305-day milk yield (kg) for two model herd systems (low input and high input) by parity number sampled from UK national records between 1998 and 2010.

Parity number	Mean milk yield (kg)	
	Low input	High input
1	5,704	8,039
2	6,640	9,360
3	7,080	9,862
4	7,174	9,971
5	7,086	9,861
6	6,856	9,623
7	6,625	9,343
8	6,370	9,026
9	5,953	8,587
10	5,511	8,054
11	5,214	7,768
12	4,913	7,645

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Table 2 Probability of involuntary culling (IC) and value of a cull cow (VC and IC) in both low- and high-input systems.

Parity number	Probability of IC*		Value of a cull cow (£)†			
	Low input	High input	VC Low input	VC High input	IC Low input	IC High input
1	0.110	0.147	450	450	58	–79
2	0.164	0.196	475	475	62	–52
3	0.208	0.289	478	478	63	–67
4	0.245	0.345	480	480	64	–65
5	0.352	0.454	483	483	61	–70
6	0.410	0.428	487	487	60	–76
7	0.424	0.401	487	487	59	–84
8	0.423	0.402	487	487	55	–82
9	0.420	0.437	487	487	55	–97
10	0.417	0.412	487	487	40	–101
11	0.392	0.362	487	487	24	–94
12	0.365	0.355	487	487	14	–118

* Updated figures from Forbes *et al* (1999) and Stott *et al* (2005) to include Bell *et al* (2010), Orpin and Esslemont (2010) and Brickell and Wathes (2011). † VC values based on market information from Dairy Co (2010) and SAC (2010) and Orpin and Esslemont (2010). IC values include the costs of treatment and milk-yield losses for each major cause of culling at the baseline level for each input system. It was assumed that 2.5% of IC would be culled on-farm (with associated milk-yield losses and other costs) and the remaining culls would be sold for slaughter (a cull as defined in this paper) rather than sold on to another farm as a productive animal (in-milk). The assumption for the baseline models was that 50% of sale culls have been finished for sale and reach carcase grade 2 (£1.03 per kg) and 50% would not be finished before sale reaching a carcase grade of 3 (£0.96 per kg) (Dairy Co monthly cull cow prices for 2010). Further detail given in Langford *et al* (2011).

The 180 milk-yield states represented (approximately) the normal distribution of yield for each input system. Given the means (Table 1) and the variances (Stott 1994) of these distributions, it was possible to assign values (eg the amount of money the farmer would get for a VC) to each milk-yield state and its associated probabilities of VC and IC. For every milk-yield state, the amount of money that the milk from an animal at that particular milk-yield state would bring during one lactation period of 305 days after paying for her feed (margin over feed MOF) was calculated on the basis of a least-cost diet (ie the lowest cost of concentrated feed, conserved roughage and grazing needed to feed an animal at that milk-yield state during lactation) formulated for a heifer and a 2nd, 3rd and 6th lactation cow calving in November and having a calving interval of 365 days. The milk price was assumed to be £0.243 per kg for both systems from the mean rolling 12-month UK milk price in October 2010 (Dairy Co 2010). The assumptions of housing length and diet type for each stage of lactation were adjusted for each input system and based on figures commercially available for 2010. Each least-cost diet was formulated using the Scottish Agricultural College's 'Feedbyte' programme (Schofield *et al* 1999) as described in detail by Langford *et al* (2011). These parameters had been previously used in other studies using the same DP model (eg Kennedy & Stott 1993; Yalcin & Stott 2000), but were updated using the most relevant figures available to the authors.

The cost (market value of the culled cows, taking into account the grade of carcase achieved, less the cost of removal of cows culled on-farm, the cost of veterinary treatment of disease or casualty culls and the loss in potential milk for cows culled during lactation) and probability of involuntary culling varied with parity and input system were calculated as follows. A recent study by Orpin and Esslemont (2010), where detailed breakdowns of culling costs were made from 843 British dairy herds, was used to help determine the prices for replacements and calves along with the market data available from Dairy Co for cull cows at market in 2010 (Tables 2 and 3). Additionally, the data on culling probabilities were updated from those given in Forbes *et al* (1999) and Stott *et al* (2005) to include recent research from Bell *et al* (2010), Orpin and Esslemont (2010) and Brickell and Wathes (2011) and extra data gathered from the 'Langhill herd' (SAC [2011], described in detail in Langford *et al* [2011]) (Table 2). The expected net margin, ie the probability weighted mean margin from all 180 milk-yield states, could then be calculated as the margin of milk and calf sales over feed costs and IC costs and all other 'fixed' costs for each input system.

The UK mean levels of lameness, mastitis and infertility were applied to both farming systems to inform the model of the probability of IC in these herds. For lameness, the overall annual rate was assumed to be 55 cases per 100 cows for high input systems, 45 cases per 100 cows on

Table 3 'Fixed' financial assumptions used in the dynamic programming model for each input system.

Assumption	Value	Units
Discount rate	5	%
Milk price	0.243	£ per kg
Calf sale value	50	£
Replacement heifer price	1,400	£
Low input 'fixed' and non-variable costs	750	£ per cow
High input 'fixed' and non-variable costs	950	£ per cow

low-input systems, (from Barker *et al* 2010). On-farm, lameness rates differ by parity, but to-date there has been little research published that includes these details beyond the first three parities. In order to inform our models, unpublished breakdowns of data from the recent SAC study (see Rutherford *et al* 2009) was used to establish differences in lameness rates by lactation in the two input systems.

There was less evidence of a difference between farming input system on the incidence of mastitis so the same overall rate was applied to both (ie 40 cases per 100 cows for both farm systems: Bradley & Green 2001). It is well known that the risk of mastitis increases with parity (Green *et al* 2007), however there are little recent UK data on mastitis incidence per parity beyond the first two parities. A recent Swedish study reported a 31% incidence of clinical mastitis in heifers and a 44% incidence in parity 3 and above (Hultgren & Svensson 2009) and the odds ratios produced by Green *et al* (2007) were used to update the model.

The risk of involuntary culling due to infertility (31% of total culling: Orpin & Esslemont 2010) was taken into account. The detailed descriptions of the first two parities by Brickell and Wathes (2011) were used, as were the data from Bell *et al* (2010) up to lactation 4. However, as infertility is a multifactorial 'condition' it is difficult to pinpoint exactly the effect it has on increased risk of culling for each parity and a similar profile of risk of IC due to infertility was applied to all parities in the model.

In the model, if the decision is to 'keep' the animal and the heifer/cow is not subject to any IC, then the probability of transition to any state in the next parity will be influenced by the state in the current and any previous parities. This fact will affect the expected net revenue and hence the current DP objective. The extent of this effect will depend on the repeatability of milk yield (Kennedy & Stott 1993) which is detailed in Yalcin and Stott (2000).

Adjustments for IC scenarios

Infertility (and its underlying causes), mastitis, and lameness were all assumed to affect milk yield, leading to a difference in margin over feed. The diseases and infertility also were assumed to affect the probability of involuntary culling, and the value of an involuntarily culled cow at market. For each herd, the DP model was re-run six times to observe the effect of having above or below mean infertility, mastitis and lameness on the ENPV. In each case, a weighted mean value, based on the proportion of affected and unaffected cows thought to be present in each parity of each herd system under each scenario was calculated (Table 4).

Results

The baseline 'runs' of the model, where culling was based on milk yield and system type only, had outputs which closely mirrored the current conditions found on UK dairy farms as shown by a number of case studies carried out in the same year (Langford *et al* 2011). The baselines outputs showed that scope for VC (ie the number of cows and therefore the choice of cows to cull by VC) was low in both systems (Table 5). However, this was most pronounced on the high-input system, where high yields were achieved with an associated lowering in mean age of the cows within the system and a high percentage of culls being IC. Low-input farms have slightly more scope for VC and a higher mean age.

The results of the 20-year re-runs of the DP for each infertility scenario can be seen in Table 6. Reducing infertility from the baseline had a small effect on the total culling rate, the annuity and the mean age of the herd in the low-input systems. Although reducing infertility also had little effect on herd age in the high-input system, the IC rate was improved by 3.4%. The difference in IC found between the low infertility scenario and the baseline in the high-input system is twice that found between the low infertility scenario and baseline in the low-input system. Figure 2 shows the optimum milk-yield level replacement decisions for each parity under the different infertility scenarios. In the low-input system (Figure 2[a]), optimum replacement decisions for the baseline and low infertility scenarios were similar, differing by one milk-yield level in the parities 8, 10 and 11. The high infertility scenario reduced the optimum VC compared to the low infertility scenario for the majority of parities, except parity 2, and 7. The high-input system (Figure 2[b]) shows a difference in VC options between infertility scenarios, especially in the older parities. The low

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Table 4 The adjustments in model factors and assumptions made from the baseline models for re-runs of the DP model to include low and high levels of infertility, mastitis and lameness for both input systems.

Scenario	Culling details	Factors	Low-input system	High-input system	Assumptions made
Low infertility	20% of culls (eg in a 100-cow herd with a culling rate of 25% 5 cows would be culled for infertility)	Yield	0 L per cow	0 L per cow	Good hygiene at calving, few assisted calving minimising uterine infection (Bell & Roberts 2007)
		Margin over feed	£0.00 per cow	£0.00 per cow	
		Value of IC	–£16.81	–£21.00	
		Probability of IC	–0.03	–0.06	
		Veterinary costs	+£30.0 per case*	+£30.0 per case*	
		Additional costs	+£10.00 per cow†	+£10.00 per cow†	
High infertility	65% of culls (eg in a 100-cow herd with a culling rate of 25% 16 cows would be culled for infertility)	Yield	0 L per cow	0 L per cow	Slight increase in on-farm culling due to uterine infection, but most culls going to market for sale
		Margin over feed	–£0.50 per cow‡	–£0.73 per cow‡	
		Value of IC	+£18.75	+£89.46	
		Probability of IC	+0.05	+0.04	
		Veterinary costs	+£30 per cow§	+£30 per cow§	
Low mastitis	20 cases per100 cows per year. No more than 2 cows per 100 culled for udder health (lower quartile: Orpin & Esslemont 2010)	Yield	+79.3l per cow	+76.7l per cow	Clinical mastitis treated with antibiotics. Dry-cow treatment, post-milking disinfection and forced standing post-milking (Yalcin & Stott 2000).
		Margin over feed	+£19.28 per cow	+18.63 per cow	
		Value of IC	+£16.81	+£66.29	
		Probability of IC	–0.04	–0.07	
		Additional costs	+£30 per cow	+£30 per cow	
High mastitis	80 cases per100cows per year. 6.5% of cows culled for udder health (upper quartile: Orpin & Esslemont 2010)	Yield	–144.3 L per cow	–147.0 L per cow	Not maintaining hygiene or prevention measures. Increased culling due to mastitis related infertility
		Margin over feed	–£35.07 per cow	–£35.07 per cow	
		Value of IC	–£61.81**	–£104.57**	
		Probability of IC	+0.06	+0.05	
		Additional costs	£20 per severe case††	£20 per severe case††	
Low lameness	22 cases per100 cows per year. No more than 1 cow per100 culled for foot problems (lower quartile: Orpin & Esslemont 2010)	Yield	+14 L per cow	+35l per cow	Early treatment and prevention regime including locomotion scoring, regular foot baths and trimming (Leach *et al* 2010)
		Margin over feed	+£3.45 per cow	+£8.50 per cow	
		Value of IC	+£102.70	+£161.75	
		Probability of IC	–0.05	–0.06	
		Additional costs	+£15 per cow‡‡	+15 per cow‡‡	
High lameness	88 cases per 100 cows per year. 7% cows culled for foot problems (upper quartile: Orpin & Esslemont 2010)	Yield	–69 L per cow	–62 L per cow	Cows treated when severely lame only and no active preventative measures taken
		Margin over feed	–£16.77 per cow	–£15.77 per cow	
		Value of IC	–£109.84	–£101.25	
		Probability of IC	+0.07	+0.04	
		Veterinary costs	+£20 per severe case§§	+£20 per severe case§§	

* For artificial synchronisation etc for cows with poor fertility. † For parlour milk progesterone kits. ‡ MOF increased due to longer lactations when farmers are trying to get good cows pregnant. § AI services, fertility treatments and veterinary costs increased for the herd. § Increased veterinary costs and increased bedding and post-teat dip. ** Decrease value of cull as more cows at market mid-lactation rather than after dry-off. †† Increased costs for veterinary call-out to severe cases of clinical mastitis. ‡‡ Additional costs of regular foot-bathing and trimming. §§ Additional veterinary call-out fees for severe cases of lameness.

Table 5 Comparison of low- and high-input system herds after a 20-year run of the DP model before the introduction of culling scenarios for disease and infertility (baseline conditions).

Variable	Low-input systems	High-input systems
Yield (L per cow per year)	6,657	9,236
Mean age (parities)	3.2	2.9
Involuntary cull rate	21.7%	26.2%
Voluntary cull rate	2.0%	1.2%
Annuity (£ per cow per year)	£196	£549

Table 6 The effect of low and high rates of infertility on each herd system after a 20-year run of the DP model.

Farm scenario	IC%		VC%		Total%		Annuity (£)		Expected milk yield (L)		Mean age of herd (parities)	
	L	H	L	H	L	H	L	H	L	H	L	H
Baseline	21.7	26.2	2.0	1.2	23.7	27.3	196	549	6,657	9,236	3.2	2.9
Low infertility	20.0	22.8	2.5	2.1	22.5	24.9	214	597	6,675	9,294	3.3	3.1
High infertility	24.4	28.1	1.1	0.7	25.5	28.8	166	541	6,610	9,204	3.0	2.8
Difference baseline to low	–1.7	–3.4	+0.5	+0.9	–1.2	–2.4	+£18	+£48	+18	+58	+0.1	+0.2
Difference high to baseline	+2.7	+2.0	–0.9	–0.5	+1.8	+1.5	–£30	–£7	–47	–32	–0.2	–0.1
Difference high to low	–4.4	–5.3	+1.4	+1.4	–3.0	–3.9	+£48	+£55	+65	+90	+0.3	+0.3

L= low input; H = high input.

infertility scenario allowing a higher VC rate than the higher infertility scenario in parities 1 and 3 to 11 and baseline condition in lactations 1, 3 and 7 to 11.

Improving mastitis had a bigger effect than reducing infertility on the majority of the elements of the model (Table 7), particularly in the low-input system. When the low-input system reduced levels of mastitis the ENPV expressed as an annuity was £247 per cow, suggesting that improving cow 'udder health' increases the net margin from milk production by £51 per cow per year. The corresponding difference in the high-input system was £90 per cow per year. The differences in mean age between the high and low mastitis scenarios were similar across both systems.

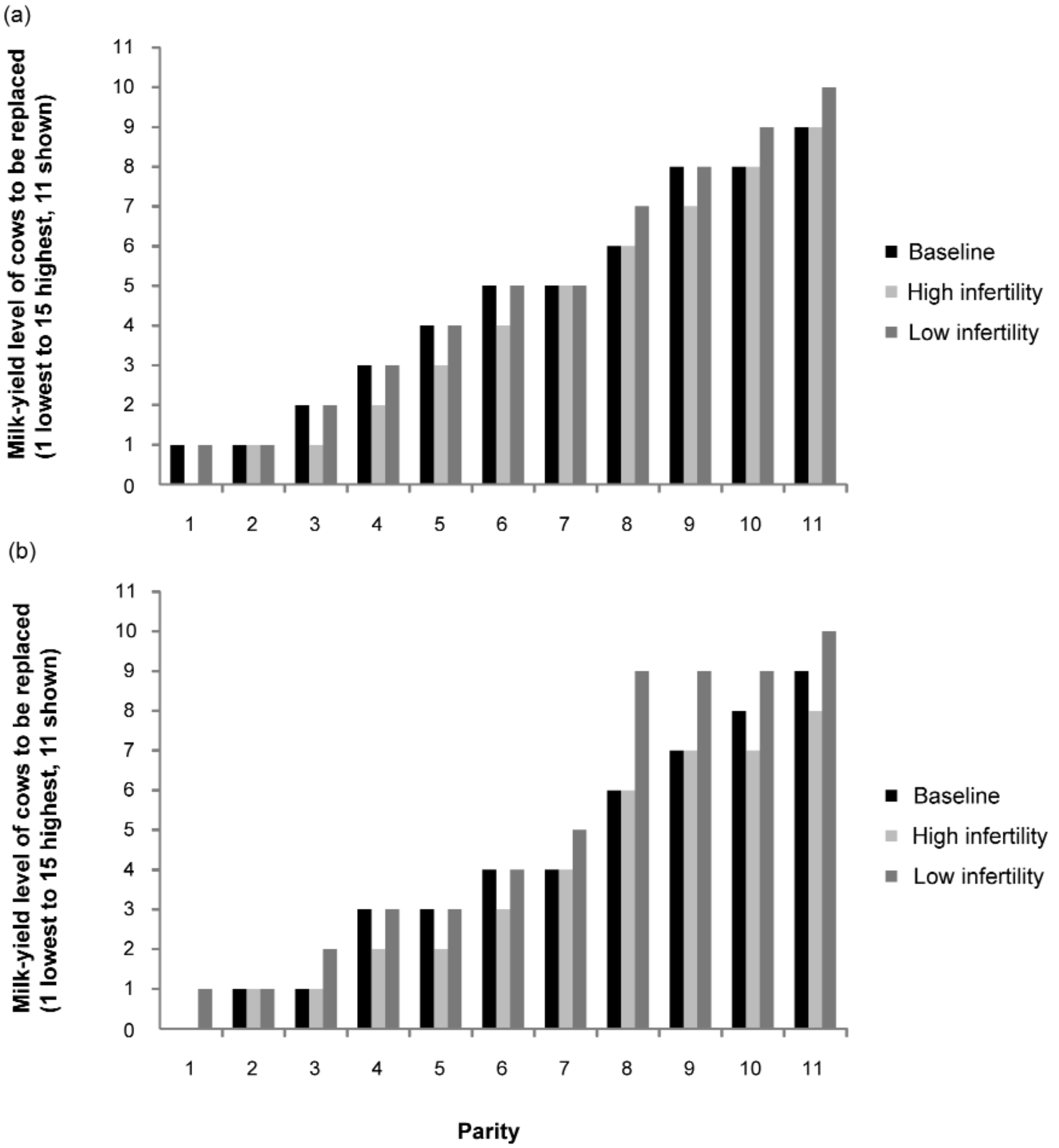
There was a smaller effect on the optimum-culling programme for mastitis scenarios than infertility (Figure 3). In the low-input system (Figure 3[a]), three of the lactations had greater VC possible for the low-mastitis scenario than the baseline (lactations 8, 10 and 11). In the high-input system (Figure 3[b]), the low-mastitis scenario allows for a greater VC level than the baseline in the first lactation, otherwise the two scenarios are identical. In lactations 7 and 8, there was a higher level of VC justified in the high-mastitis scenario.

The lameness scenarios (Table 8) in the low-input system had the biggest effect on culling and longevity of all the scenarios presented. The difference between the IC rate in the high-lameness and the low-lameness scenarios was 6%, allowed for an extra 1.2% VC and resulted in a 0.5 parity increase in age of the herd. In the high-input system, the culling rates and mean herd age were also improved, but not as substantially as mastitis.

In Figure 4, there is an increase in the financially optimum VC opportunities in the low-input system (Figure 4[a]) with the reduced lameness scenario compared to the baseline in parities 2, 8, 10 and 11 and compared to the high-lameness scenario in parities 1, 2 and 8 to 11. Whereas, in the high-input system (Figure 4[b]), the lower lameness scenario is only different from the baseline in parity 1 and 6 and different from the high lameness scenario in parities 1, 6, 10 and 11.

Improvements in milk yield were seen after the long-term reductions in the levels of clinical mastitis from the baseline, followed by reducing lameness levels and improving fertility had the smallest effect on milk yields (Figure 5[a]). After 20 years of reducing mastitis or lameness from the baseline levels, annuities (£ per cow per

Figure 2



Optimum-replacement decisions identified by the Dynamic Programme for (a) low-input systems and (b) high-input systems for the two contrasting infertility-rate scenarios and the 'mean' baseline condition. The replacement decisions are shown in terms of the relative milk-yield states of the cows to be replaced (by voluntary culling) in each lactation.

year) were similar (Figure 5[b]) within input systems. The effect of improving fertility on annuities was smaller than improving the other health outcomes.

Discussion

The DP acts as the financially perfect farmer by making 20 years of financially optimum 'keep and replace' decisions (not optimum for welfare or anything else) leading to culling low-yielding animals when IC rates allow. This series of decisions then results in a certain mean age, culling rate, mean yield and annuity (£ per cow per year) if the DP's strategy is followed. The IC rates are based on the age-dependent probabilities of mastitis, lameness, infertility and other conditions at the UK means for both system types. It is important to reiterate that the inputs to the model (eg the UK mean yields for each parity in the two input systems) are not the same as the outputs after 20 years of financially ideal 'keep and replace' decisions. It can be seen from the baselines that the two herd-input systems differ most markedly in the yield and annuities after the 20-year runs of the DP. The mean net income per cow on UK dairy farms in 2009 was £340 (SAC 2010); and this figure fits midway between our baseline annuities from the two different input systems derived using the DP model. This

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Table 7 The effect of low and high rates of mastitis on each herd system after 20-year runs of the DP model.

Farm scenario	IC%		VC%		Total%		Annuity (£)		Expected milk yield (L)		Mean age of herd (parities)	
	L	H	L	H	L	H	L	H	L	H	L	H
Baseline	21.7	26.2	2.0	1.2	23.7	27.3	196	549	6,657	9,236	3.2	2.9
Low mastitis	19.6	22.6	2.6	1.8	22.2	24.4	247	640	6,759	9,360	3.4	3.2
High mastitis	24.6	27.7	1.5	1.1	26.1	28.8	105	457	6,479	9,069	3.0	2.7
Difference baseline to low	–2.1	–3.5	+0.5	+0.6	–1.6	–2.9	+£51	+£90	+102	+124	+0.2	+0.3
Difference high to baseline	+2.9	+1.5	–0.6	–0.1	+2.4	+1.5	–£92	–£92	–178	–167	–0.2	–0.2
Difference high to low	–5.0	–5.0	+1.2	+0.7	–3.9	–4.3	+£143	+£183	+280	+291	+0.4	+0.5

L = low input; H = high input.

Table 8 The effect of low and high rates of lameness on each herd system after 20-year runs of the DP model.

Farm scenario	IC%		VC%		Total%		Annuity (£)		Expected milk yield (L)		Mean age of herd (parities)	
	L	H	L	H	L	H	L	H	L	H	L	H
Baseline	21.7	26.2	2.0	1.2	23.7	27.3	196	549	6,657	9,236	3.2	2.9
Low lameness	19.0	23.7	2.7	1.4	21.7	25.1	253	637	6,704	9,306	3.4	3.1
High lameness	25.1	28.5	1.5	0.9	26.6	29.4	103	465	6,550	9,137	2.9	2.7
Difference baseline to low	–2.7	–2.5	+0.7	+0.3	–2.0	–2.2	+£57	+£87	+47	+70	+0.2	+0.2
Difference high to baseline	+3.3	+2.3	–0.6	–0.2	+2.8	+2.1	–£94	–£84	–107	–99	–0.3	–0.2
Difference high to low	–6.0	–4.8	+1.2	+0.5	–4.8	–4.3	+£151	+£172	+154	+169	+0.5	+0.4

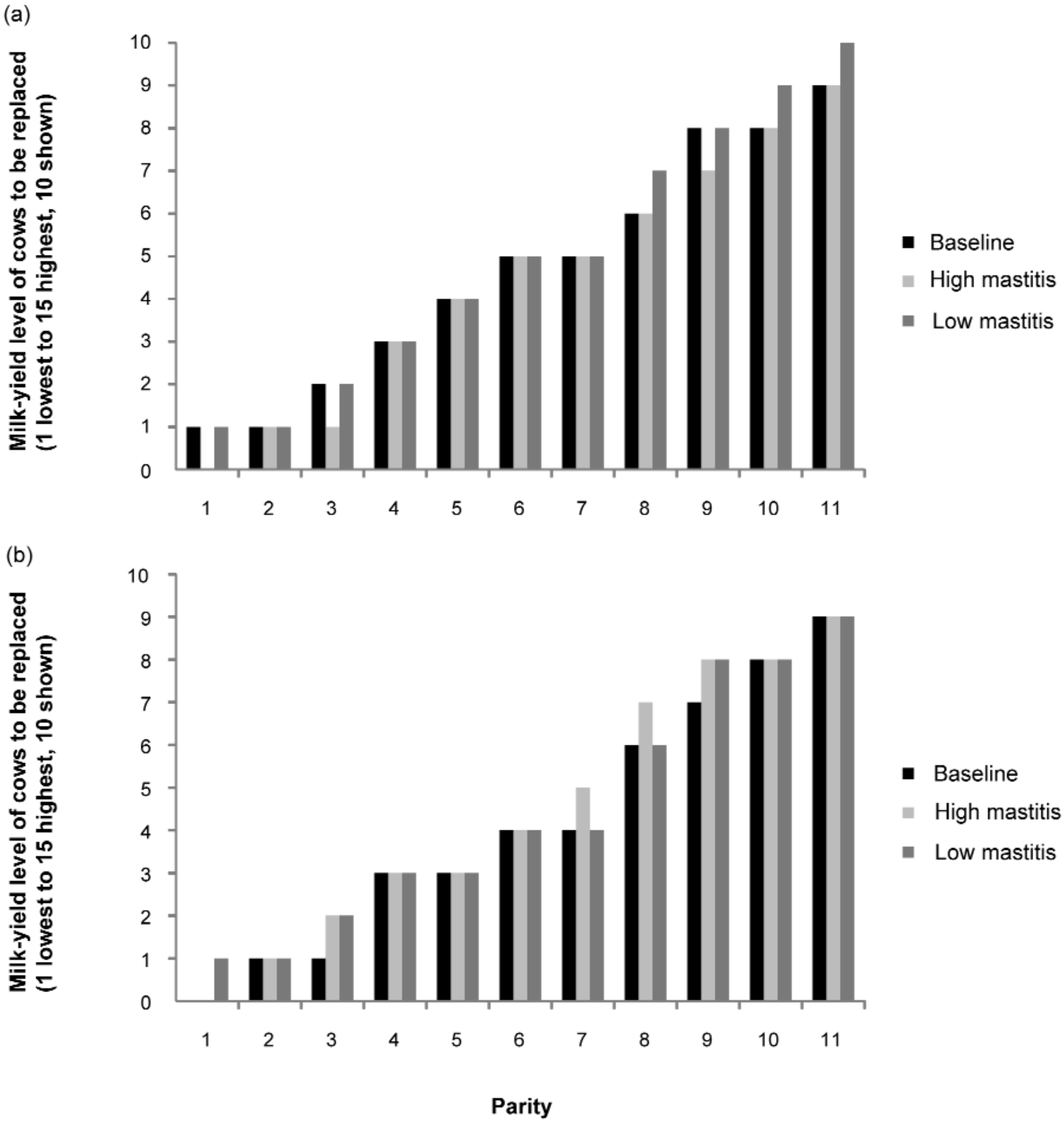
(L = low input; H = high input.

suggests that the results derived from the model are consistent with current dairy farming experience.

Investment has to be made by farmers to reduce the rates of the three main causes of culling. Farmers can be reluctant to spend extra on areas that do not show a quick return (and with good reason when they are getting low prices for their milk from the buyers), such as increased frequency of footbathing for lameness (Leach *et al* 2010), increased time spent watching for heat for infertility (Garforth *et al* 2006) or increased frequency of bedding change to reduce mastitis. However, we show here that when investments are added and costs increased in the model input to make improvements in one of the three main causes of IC, the long-term outcomes are favourable and outweigh the investment. These outcomes show similar differences between systems to the baselines, in that the increases in yield and annuities are largest after improvement in the high-input system than the low-input system and this is due mainly to the differences in yield in the cows in these input systems, and also the greater benefit in reducing 'poor-value' culls to the high-input farmer. The opposite is also shown, in that if conditions are allowed to worsen due to under investment, this affects the high-input system more than the low-input system.

One of the great advantages of the DP modelling process is that it allows us to tease out the costs and benefits of changing the rates of specific conditions within a farming system, a process that could not be carried out or properly understood on either commercial or experimental farms due to interconnected disease, infertility and management factors. As it is an 'optimising model' it makes the best result of the changes, whilst minimising the economic

Figure 3



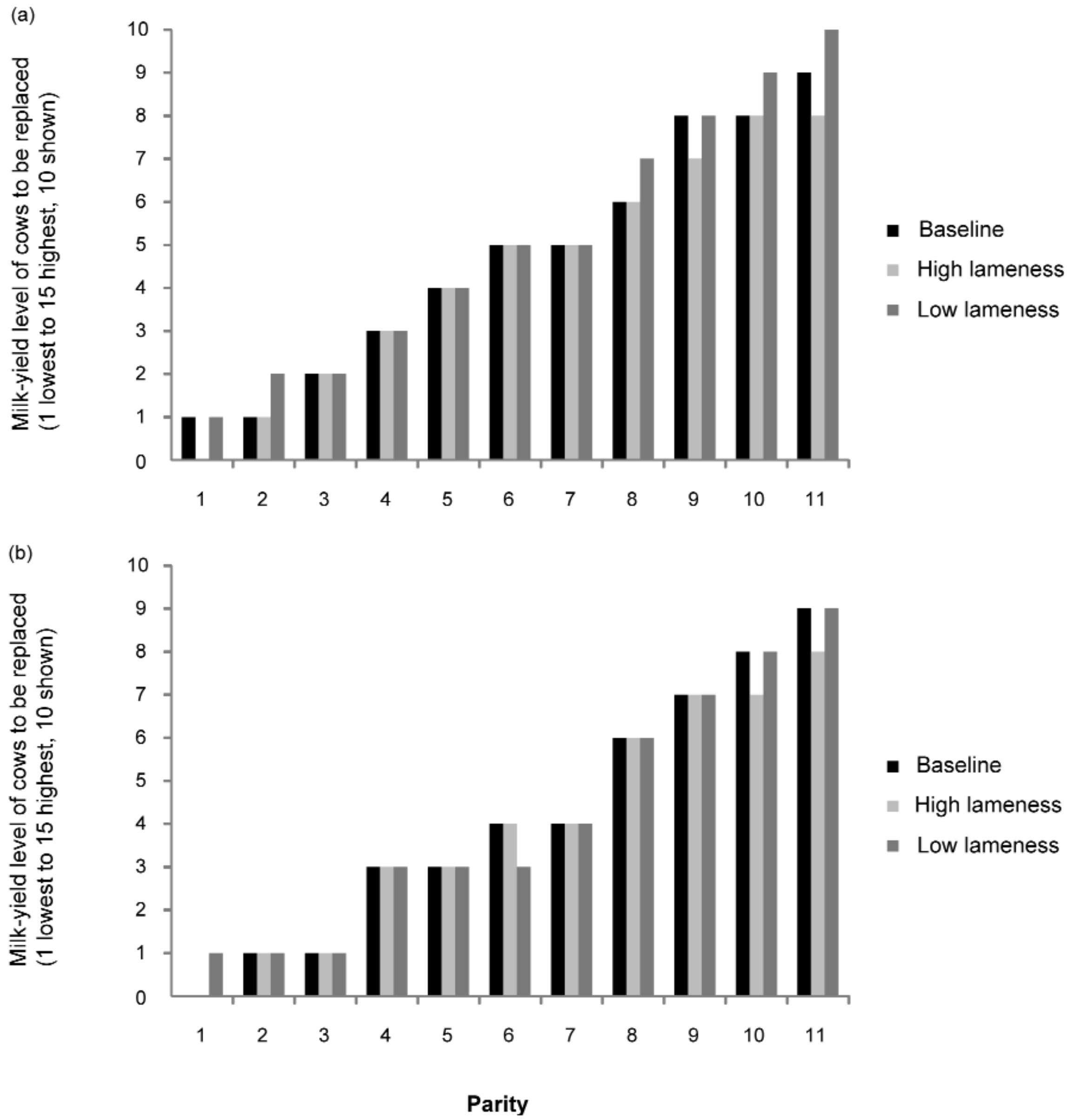
Optimum-replacement decisions identified by the dynamic programme for (a) low-input systems and (b) high-input systems for the two contrasting mastitis rate scenarios and the 'mean' baseline condition. The replacement decisions are shown in terms of the relative milk-yield states of the cows to be replaced (by voluntary culling) in each lactation.

damages. We can see from these results that although on 'real' farms infertility rates have a substantial effect on involuntary culling rates in the UK and around the world, that when taken in isolation from the disease-related drivers of infertility as the DP model does, the financial costs to the farmer are not that great because the cow can still be milked for the whole of her lactation and get a good return at market.

By far the biggest improvements in milk yield in our models were seen after the long-term reductions in the levels of clinical mastitis, with improvements of 102 and 124 L per cow seen in low- and high-input systems, respectively. Improving hygiene and preventative measures had a very low cost per cow, but had a large effect on yield as both actual yields improved from healthier animals and less milk was discarded due to treatment and withdrawal times. Our models showed that reducing lameness levels from the baseline (Figure 5[a]) had an approximately 50% lower effect on yield than mastitis, and the effect of improving fertility was lower still.

In contrast, after reducing mastitis and lameness from the baseline levels, annuities (£ per cow per year) were very similar (Figure 5[b]). In the low-input system, farmers should

Figure 4

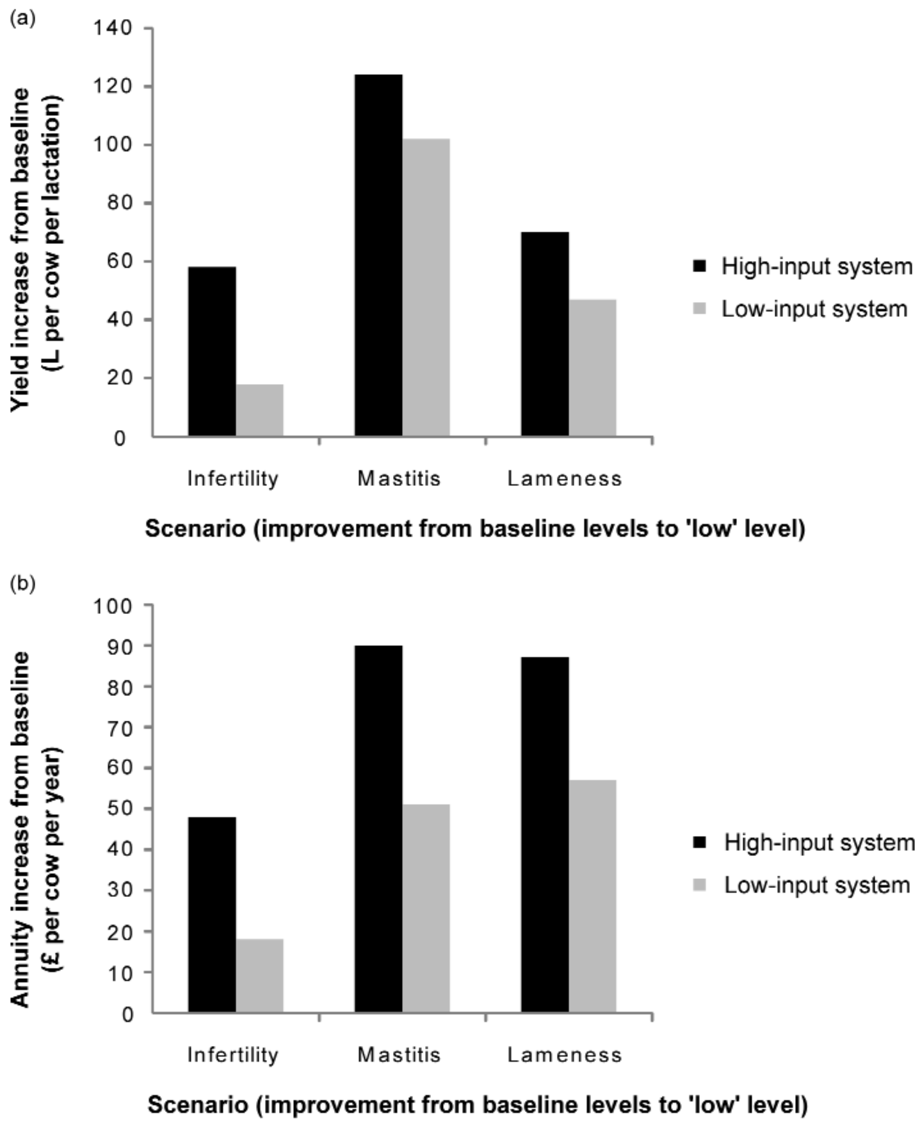


Optimum-replacement decisions identified by the dynamic programme for (a) low-input systems and (b) high-input systems for the two contrasting lameness rate scenarios and the 'mean' baseline condition. The replacement decisions are shown in terms of the relative milk-yield states of the cows to be replaced (by voluntary culling) in each lactation.

expect to see a benefit of approximately £50 per cow per year from improving either mastitis or lameness to the levels suggested, in the high-input system the annuity figure increases to £90. This is the extra expected annuity (ie net margin) over and above the baseline amount per cow per year — and as near as we can express for expected future profits for improving lameness and/or mastitis. So, although reducing lameness did not increase the expected yield as much as reducing mastitis, having lower lameness on-farm still increased cashflow considerably. This is due in part to the expense of on-farm culling. The lowered lameness scenarios have the benefit of lower on-farm culling saving the added cost to the farmer of around £3,000 depending on the timing of the event during a lactation (Orpin & Esslemont 2010). There is a positive correlation between farms with high lameness rates and higher rates of on-farm mortality, accidents and injuries leading to on-farm culls (Rabiosson *et al* 2011).

Not only do the financial outcomes and yields improve after the reductions in mastitis, lameness and infertility, but also the choices that the farmer is able to make in terms of culling to improve their herd. Improving reducing mastitis, lameness or infertility from the baseline levels increased the

Figure 5



The (a) additional expected milk yield (L per cow per lactation) and b) additional expected discounted cash flow expressed as an addition in annuity (£ per cow per year) for each input system when moving from the baseline condition to the low 'infertility', 'mastitis' and 'lameness' scenarios, respectively.

VC percentage by between 0.3–0.9%. VC opportunities were reduced by between 0.1–0.9% with worsening in levels of the conditions. These differences may only seem to be slight, but for herd number to remain static, farmers can only make the VC decisions with the animals left over after any IC. If the IC rate is high, this leaves very little 'room for improvement' of the herd. This would mean that yields might remain static or decrease as lower yielding animals may remain in the herd by being pregnant. Additionally, as the farmer is not able to choose which animals to replace they may be restrained in the ability to replace animals that might be more susceptible to health problems for animals with a better health potential using modern breeding indices (Wall *et al* 2003). Therefore, any increase in the percentage of VC available, without altering the herd size, can help a farmer making active decisions about their farm.

There is a potential for conflict in this trade-off between farm profits and cow welfare. What if we were to look at culling decisions from a cow's point of view? When, during her life, a cow might 'choose' to be culled to maximise her welfare could differ from the best time to cull the cow as an economic decision for the farmer. In reality, of course, an animal does not choose when to be culled, and we could imagine that if they could be asked, a cow may never choose death over life when instead prompt veterinary treatment could be given and the possibilities of positive life experiences remain. So, instead, perhaps, we have to ask the

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alternative question of when would the farmer cull the cow if he/she were interested in maximising the cows' welfare but were unable to change other aspects of husbandry? A cull early in lactation, especially for a young animal, is the most expensive financially for the farmer, but might this type of cull be preferable to a cow than some of the other culling scenarios common on-farm? A cow is only culled on-farm (not resulting in any sale) under extreme circumstances, eg severe mastitis that does not respond well to treatment. As an on-farm cull is expensive for farmers (and not forgetting that farmers care about their animals and do not want them to suffer), animals in these severe conditions would receive prompt veterinary treatment, and the euthanasia itself would be humane (and less stressful than going to market). Notwithstanding the cows' potential, especially if she is only in her first or second parity, to have a good life in the future if it were able to 'pull through' from such a poor welfare incident (see Yeates 2010), it is possible that culling at this point would be preferable to other prolonged conditions leading to culling. We know that many dairy cows that go to market at the end of lactation are in a poor body condition (as shown by the mean prices dairy cows fetch at market and their carcase grading) and this poor body condition can be associated with chronic lameness and other conditions which may have been inadequately treated (Machado *et al* 2010). These cows are often nominally culled for 'infertility' as the farmer is unable to get the cow back into calf (Dobson *et al* 2008; and as detailed in Langford *et al* 2011). From the cows' perspective, the pain of lameness and the prolonged length of time the condition occurs could be worse than the on-farm cull scenario presented above.

We should conclude overall that from the financial position, it is best to avoid on-farm culls and from the welfare position it is best to avoid the chronic suffering potential of the low-value end of lactation 'infertility and other causes' cull. Fortunately, we have shown that with added investment and care to reduce the three main causes of culling, farmers will end up, in the long-term, reducing both of these culling types especially for cows in their first few lactations. The longer a healthy cow remains in the herd after her 4th parity, the more likely she is to be culled for poor yield or to make way for a younger animal with more potential (ie voluntarily culled), which our model and associated discussion would predict to be the best result for both farmer and cow.

Animal welfare implications

Improving the welfare of lactating dairy cows by reducing mastitis, lameness and infertility, increases: the mean longevity of the herd; the choices that the farmer can make in terms of herd improvement by increasing VC potential; the milk yield from the cows by reducing losses — due directly to disease and indirectly due to culling during lactation; and also the annuities for each cow (£ per cow per year) mainly by increasing milk yield and reducing costly on-farm culls. This is undoubtedly a win-win situation for both farmer and cow. The 'five-point plan' which outlines the association between improving hygiene, preventative measures and early treatment of mastitis and the potential financial gains is a message that has been successfully taken up by dairy farmers (Blowey 1986). This is unsurprising as the results presented above show mastitis has the biggest direct effect on future yield of the herd and therefore an obvious financial cost. Yet, here, we have shown for the first time that in the long-term, improving conditions to reduce lameness has a near identical effect to that of reducing mastitis on culling rates, herd longevity and most strikingly, on the financial outcomes for the farm (only a £6 per cow per year difference between the two conditions over a 20-year period). There is enough evidence now available to put resources into communicating about the 'true' costs of lameness and benefits in reducing lameness rates among dairy farms and to promote a similar strategy to the 'five-point plan' in mastitis for lameness to improve the welfare of the dairy cow.

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