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Associations between genetic merit for milk production and animal parameters and the fertility performance of dairy cows

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Relationships between genetic merit for milk production and animal parameters and various parameters of reproductive performance were examined using multilevel binary response analysis in a study of 19 dairy herds for three successive years, representing approximately 2500 cows per year. The proportion of cows intended for rebreeding that were back in-calf again within 100 days of calving (ICR-100) and the proportion of cows that reappeared again with 365 (RR-365) and 400 days (RR-400) of a previous calving were considered in addition to the traditional measures of reproductive performance. Each 100-kg increase in genetic merit for milk yield was associated with an increased interval to first service (IFS) and calving index (CI) of 1.4 ($P < 0.001$) and 1.8 days ($P < 0.001$), respectively, a 0.5% increase ($P < 0.05$) in calving rate to first insemination (CR-1) and 0.8% increase in RR-400. Each £10 increase in £PIN (the economically weighted yield selection index used in the UK that takes account of butterfat and protein yields) was associated with an increased IFS and CI of 1.5 ($P < 0.001$) and 3.0 days ($P < 0.001$), respectively. Cows with increased genetic merit for milk yield and £PIN were more likely to re-calve (RR-overall; $P < 0.001$). Each 1000-kg increase in 305-day milk yield was associated with an increased IFS and CI of 3.2 ($P < 0.001$) and 7.8 days ($P < 0.001$), respectively, and a 13.6 ($P < 0.001$), 22.4 ($P < 0.001$), 19.9 ($P < 0.001$) and 19.0% ($P < 0.001$) decrease in CR-1, ICR-100, RR-365 and RR-400, respectively. A 10-kg increase in maximum yield was associated with a 6.6-day increase in CI ($P < 0.001$) and a 14.9 ($P < 0.001$), 18.3 ($P < 0.001$), 9.6 ($P < 0.05$) and 14.2% ($P < 0.001$) decrease in CR-1, ICR-100, RR-365 and RR-400, respectively. Fertility performance was also associated with season of calving, lactation number and dystocia score. Level of production had a larger effect on fertility performance than genetic merit for milk production suggesting that infertility at an individual cow level is more likely to be associated with increased production and an inability to meet the nutritional requirements of the cow.

Keywords: dairy cows, fertility, genetic merit, production

Introduction

Poor reproductive performance is a major problem on many dairy farms throughout the United Kingdom (UK) and has been identified in two farm surveys in Northern Ireland (1997 and 2003) as the single most important problem in dairy herd management (AgriSearch Farm Surveys, personal communication). The decline in reproductive performance of the dairy herd has been widely reported with various studies around the world citing conception rates to first insemination of approximately 40% (Butler, 1998; Royal *et al.*, 2000; Mayne *et al.*, 2002), though this figure tends to be higher in grass-based production systems (Buckley *et al.*, 2003; Grosshans *et al.*, 1997). At herd level, decreased individual cow fertility, with more services per conception, has been reported in cows producing more than the herd average (Wicks and Leaver, 2004) but Darwash *et al.* (1997) found no such phenotypic effects of yield on fertility. Hoekstra *et al.* (1994) reported negative phenotypic and genetic correlations between milk production and fertility traits. In addition to the decline in traditional measures of fertility, Royal *et al.* (2002) have reported genetic correlations between yield and endocrine parameters such as commencement of luteal activity. While some studies attribute the decline in reproductive performance to the direct genetic effect of increased genetic merit for milk production (Buckley *et al.*, 2000; Kadarmideen *et al.*, 2000, Pryce and Veerkamp, 2001; Royal *et al.*, 2002) and specifically the increasing proportion of Holstein genes (Buckley *et al.*, 2000 and 2003), others

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cite the indirect effects resulting from higher milk production (Berry *et al.*, 2003) or negative energy balance in early lactation as the major cause of the decline (Butler, 2001). In addition to the direct financial cost, estimated at over £500 million per annum in the UK (Lamming *et al.*, 1998), infertility can result in increased management complexity with spread calving patterns and therefore extended breeding seasons with prolonged heat observation and infertility intervention for problem and late calving cows. In Northern Ireland, there is a diverse range of milk production systems ranging from compact spring-calving systems to all-year-round calving systems, but the majority of herds are autumn/winter calving and in these herds infertility causes increased management complexity through the inability to achieve a compact calving pattern (Mayne *et al.*, 2002).

Calving index (the average interval between successive calvings for a group of cows, ignoring cows who fail to conceive) has traditionally been used as the primary measure for assessment of fertility performance in dairy herds as it combines the various contributory factors into one index. Recent results from a fertility study in Northern Ireland have reported a mean calving index of 407 days with a range between herds from 359 to 448 days (Mayne *et al.*, 2002). While information on calving index is readily available from milk records, data analysis is problematical since it only relates to cows that conceive and calve again (Olori *et al.*, 2002; Veerkamp *et al.*, 2002). In the study of Mayne *et al.* (2002), 28% of cows were removed or sold of which almost 27% were sold for infertility. Removal rates varied from 17 to 49% between herds, making the comparison of fertility performance using calving index extremely difficult. Fertility performance has also been assessed using conception rate, but this varies according to the method of calculation (non-return rate, pregnancy rate or calving rate).

Kirkland *et al.* (2003) used an alternative approach for assessing fertility performance in suckler herds. They assessed the proportion of cows that subsequently produced a further calf (re-appeared) within 390 and 450 days of a previous calving with results of 52% and 71%, respectively. The InCalf Project in Australia adopted an alternative approach to take account of variable culling rates for the assessment of fertility performance in dairy herds (Morton, 2000 and 2001). They have developed in-calf rate, an index that assesses the proportion of cows intended for rebreeding post calving that have conceived, or are back in-calf, by the end of a specific period, either 6 weeks from the start of breeding (in seasonal calving herds) or within 100 days of calving (in all-year-round calving herds). Hence, cows destined for culling or sale are not included in the calculation, so this method of assessing fertility performance gives an early indication of the proportion of cows due to calve again within approximately 380 days of the previous calving.

Reproductive performance is influenced by a large number of factors, including management practices (such as prolonged calving patterns, increased herd size, heat detection rate and insemination technique) and nutritional factors (such as energy balance in early lactation), but the decline in dairy cow fertility is also associated with a period of increased genetic capacity for milk production, attained through substitution of the British Friesian by the North American Holstein. Whilst there is evidence of a negative genetic correlation between milk production and fertility performance (Dematawewa and Berger, 1998; Pryce *et al.*, 2002; Berry *et al.*, 2003), there is a lack of consensus in the literature regarding the effects of increasing production and genetic merit for production on dairy cow fertility at farm level. Hence, the aim of the current study was to examine the relationships between genetic merit and milk production on the fertility performance of dairy cows in a range of dairy herds, representative of production systems in Northern Ireland. In addition to examining the associations between genetic merit and milk production on calving interval and conception rate, alternative analytical techniques for assessing fertility will also be considered.

Material and methods

Selection of participating herds

In autumn 1998, a 3-year monitoring study was initiated involving 19 herds of Holstein/Friesian cows across Northern Ireland, representing a total population of approximately 2500 cows. Herds were identified by local DARD advisers as having a good track record of data recording, a willingness and enthusiasm to participate in the study and being geographically spread throughout Northern Ireland. Twenty herds were selected as representative of those throughout the region and included a wide range of herd size, concentrate input, feeding methods, genetic merit and level of milk production, details of which are provided in Mayne *et al.* (2002). One of these herds was later omitted from the study due to farmer illness and not replaced. Between herds, both season and compactness of calving varied considerably, ranging from compact autumn and spring calving herds through to prolonged winter calving and all-year round calving herds.

Collation of data

Collaboration between farmers, local veterinarians, Institute technical staff, milk recording agencies and pedigree breed societies allowed the collation of a comprehensive range of data on herd management, genetic merit, productive and reproductive performance. Fertility data were recorded by the individual farmers including details of all calvings, heats, services and removal of cows from the herd, as described previously (Mayne *et al.*, 2002). Each record included a unique cow number and event date, where appropriate. Calving records included details on lactation number, calving difficulty score and calf type. Calving difficulty score was defined using a scoring system from 0 to 5, where 0 = unobserved and unassisted, 1 = observed and unassisted, 2 = assisted without calving aid, 3 = assisted with calving aid, 4 = vet assisted and 5 = caesarean. Calf type was defined as heifer, bull, twin heifers, mixed twins or twin bulls. Data were collated on a series of spreadsheets that were used to regularly update a central masterfile containing fertility, pedigree and production data using SPSS software (Statistical Packages for the Social Sciences, 2002). This facilitated validation of the data pertaining to years 1, 2 and 3 of the study which included the records of cows which calved in the year from 1 August 1998, 1 August 1999 and 1 August 2000, respectively, and which subsequently calved or were removed from the herds. Data continued to be collated for a year after completion of year 3 and cows that had neither calved again nor been removed were followed up after this time.

Cows were milk-recorded monthly by milk-recording technicians from two milk recording agencies, United Dairy Farmers (UDF) or HerdTech. Data provided included individual cow test-day milk yields (kg) with butterfat (BF) and protein (P) composition (g/kg), 305-day milk, butterfat and protein yields (kg) with butterfat and protein composition (g/kg), and complete lactation milk, butterfat and protein yields (kg) with butterfat and protein composition (g/kg). For individual lactations, test-day records were used to establish peak yield (kg/day) and interval from calving to peak yield (days), protein nadir (g/kg) and interval from calving to protein nadir. Test-day records were also used to calculate 100-day milk, butterfat and protein yields (kg) for each lactation, and butterfat and protein concentrations (g/kg). Milk energy output was calculated from milk yield at 100 days, 305 days and over the complete lactation using the formula:

$$\text{milk energy output (MJ)} = \text{yield (kg)} \times [0.0376\,(\text{BF g/kg}) + 0.0209\,(\text{P g/kg}) + 0.948]$$

Tyrrell and Reid (1965).

Data were also provided by the milk-recording agencies on the pedigree details of individual cows involved in the study and these were validated through the co-operation of herd-owners and Holstein UK (HUK). A database was established for all cows that included the name of both sire and maternal grandsire and individual cow predicted transmitting abilities (PTAs) for milk, butterfat and protein yield, butterfat and protein concentration, and £PIN (expressed on a PIN_{2000} base), collated from the August 2002 proof run. Since PTAs take account of both herd effects and a cow's previous production, and these were not available for all cows, an alternative approach for examination of genetic merit effects was used instead, viz. pedigree index (PDX). The PDX for milk, butterfat and protein yield, and butterfat and protein concentration was calculated using sire and maternal grandsire PTAs from HUK's August 2002 proof run using the formula:

$$\text{cow PDX} = (0.5 \times \text{sire PTA}) + (0.25 \times \text{maternal grandsire PTA}).$$

This formula assumed that maternal grand dams had zero PTA for each trait. Where no maternal grandsire was identified, a cow's PDX was estimated to be half the sire PTA, assuming that both maternal grandsire and maternal grand dam had zero PTA for each trait. Pedigree index (£PIN), the economic genetic index used in the UK for milk production traits that allows ranking according to genetic merit was calculated using the formula:

$$\text{£PIN} = (-0.03 \times \text{milk PTA}) + (1.2 \times \text{fat PTA}) + (3.0 \times \text{protein PTA}).$$

Collation of fertility data and definitions

Interval to first service (IFS) was defined as the interval from calving to first recorded service. Calving rate to first service (CR-1) was defined as the proportion of cows that conceived and subsequently produced a calf to the first insemination, including also cows that had a positive pregnancy diagnosis prior to removal from the herd in the event of either sale or death. Conception rate to second insemination (CR-2) and first or second insemination (CR-1/2) was calculated on the same basis. Minimum and maximum calving indices were based on gestation lengths of 260 and 299 days respectively equating to a gestation length of approximately 280 ± 20 days. For gestation lengths <260 days the animal was assumed to have aborted and a calving index was not calculated unless a viable calf was produced. For gestation lengths >299 days it was assumed that the animal conceived to a subsequent non-recorded service, nominally 282 days prior to subsequent calving. While calving index (CI) has traditionally been used to assess herd reproductive performance, variable removal rates between herds (Mayne *et al*., 2002) and between years within a herd (unpublished data from present study) made direct comparisons of herd fertility difficult. Therefore alternative techniques of assessing herd fertility performance were used, viz, re-appearance rate (RR) and in-calf rate (ICR).

In this study, each calving record was followed by either a subsequent calving (normal or abortion) or removal of the cow from the herd. Re-appearance rate was defined as the proportion of cows with a subsequent calving within 365 days (RR-365) or 400 days (RR-400) of the previous calving. The overall re-appearance rate (RR-overall) was the proportion of calvings that were eventually followed by a subsequent calving and was essentially the inverse of removal rate. The in-calf rate was assessed using the method of Morton (2001) which examines the proportion of cows in year-round calving herds intended for rebreeding that are back in-calf within 100 days of calving

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(ICR-100). This method was selected due to the predominance of prolonged calving patterns in Northern Ireland dairy herds. For statistical analysis, cows intended for rebreeding were retrospectively classified as having at least one service or culled for infertility, signifying an intention to rebreed. In-calf status at 100 days was determined by the date of last service, based on either subsequent calving or pregnancy diagnosis prior to removal from the herd.

Data analysis

Prior to analysis of the dataset, a 99% confidence interval was established for all linear parameters based on the mean ± 3 standard deviations to filter off extremes of data over which there was some doubt. This included the reproductive parameters (IFS and CI), productive parameters (those concerned with minimum milk protein concentration, maximum yield, 100-day production, 305-day production and total lactation production) and genetic merit parameters (those based on PDX). Records with reproductive parameters outside the 99% confidence interval range were omitted from the dataset, while only complete groups of productive and genetic merit parameters (listed in parentheses above) that fell inside the 99% confidence interval range were submitted for data analysis.

Analysis of the data was conducted using the GenStat statistical programming software (GenStat, 2000), employing a three level random intercepts multilevel model, where year was nested within cow, which in turn was nested within herd. Continuous response variables were analysed using the REML command, while binary variables were analysed using the GLMM procedure. A univariate analysis was carried out relating the full range of reproductive variables, viz. IFS, CI, RR-365, RR-400, RR-overall, ICR-100, removal rate, CR-1, CR-2 and CR-1/2 to both genetic merit and production variables. For continuous response variables the results were reported in the form of a slope and standard error, while for the binary variables they were reported using odds ratios and 95% confidence intervals. The significance level of each relationship was calculated using a Wald test. Where explanatory variables were continuous, the results were reported for a meaningful increase on the scale of the particular variable in question. The relative effect of genetic or production variables on both the continuous and binary measures of fertility was examined by observing the effect of a standard deviation increase in each genetic merit or production variable where significant associations occurred. In addition, a similar separate analysis was employed to examine the effect of season of calving, lactation number, calving difficulty and calf type on three key reproductive variables, viz. CR-1, ICR-100 and RR-400. Records were categorised into a number of groups, and one of these groups was designated as the reference category for odds ratio analysis (OR = 1.0) where an OR >1.0 indicates increased likelihood and an OR <1.0 indicates decreased likelihood.

Results

A total of 7747 calving records from 4217 different cows were recorded across the 19 herds in the period from 1 August 1998 to 31 July 2001, with 2476, 2559 and 2712 cows calving in years 1, 2 and 3 of the study, respectively. This allowed the establishment of a comprehensive database on a wide range of fertility, milk production and genetic merit parameters. The mean $\pm$ s.d. IFS and CI across the entire dataset were 85.2 ± 39.3 and 405.9 ± 71.0 days, respectively, and the mean CR-1 was 40.3%, but there was large inter-herd variation for all reproductive parameters (IFS, herd range = 69.9–126.0 days; CI, herd range = 372.0–446.8 days; CR-1, herd range = 16.6–61.1%). The average RR-365, RR-400 and RR-overall were 24.0% (herd range = 4.2–44.9%), 44.5% (herd range = 21.8–64.9%) and 72.8% (herd range = 62.0–80.3%), respectively. The average ICR-100, based on cows intended for rebreeding was 46.0% (herd range = 16.4–70.8%). The range in fertility, milk production and genetic merit parameters seen in the filtered dataset used for the more detailed statistical analysis is presented in Table 1.

The association of changing genetic merit on the calculated PDX for a range of reproduction parameters are presented in Table 2, where the association of a £10 increase in £PIN, 100 kg increase in milk yield and 0.1% increase in fat or protein concentration is presented. The main associations were that increasing £PIN and PDX for milk yield caused increases ($P < 0.001$) in IFS, CI and RR-overall and a decrease in removal rate ($P < 0.001$). Increasing genetic merit for milk yield was associated with an increase in RR-400 ($P < 0.05$), CR-1 ($P < 0.05$) and CR-1/2 ($P < 0.05$). Increasing genetic merit for fat composition was associated with significant decreases in RR-400 ($P < 0.001$), RR-overall ($P < 0.001$) and calving rate ($P < 0.05$ or less), and a increase in removal rate ($P < 0.001$). Increased genetic merit for protein composition was associated with a decrease in IFS ($P < 0.05$), CR-1 ($P < 0.05$) and RR-overall ($P < 0.001$).

The association between milk production parameters, as reflected by 100-day and 305-day production, on a range of reproduction parameters is presented in Tables 3 and 4, respectively. A 1000 kg increase in 100-day milk yield or 1000 MJ increase in milk energy output was associated with a 4.49 ($P < 0.001$) or 1.38 days ($P < 0.01$) increase in calving index, respectively, while the same increase in 305-day yield and milk energy output increased calving index by 7.79 ($P < 0.001$) and 2.64 ($P < 0.001$) days, respectively. The other main associations of increases in 100-day yield and milk energy output were significant ($P < 0.05$ or greater) reductions in CR-1, CR-1/2, ICR-100, RR-400 and removal rate, while increases in 305-day yield and milk energy output also decreased RR-365 ($P < 0.001$) but had no association with removal rate.

A 1-g/kg increase in both 100- and 305-day protein concentrations was associated with an increase in RR-400 ($P < 0.01$). Increased 100-day protein concentration was also associated with decreases in IFS and CI ($P < 0.001$),

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Table 1 *Number of calving records (n) and the basic statistics for a range of parameters in the data set used for statistical analysis*

	n	Mean	Min.	Max.	s.d.
(a) Fertility parameters					
Interval to first AI service (days)	6536	85.3	19.0	264.0	36.7
Interval to first service: all service types (days)	5301	84.4	19.0	264.0	35.4
Calving index (days)	5422	403.8	314.0	699.0	65.4
365-day re-appearance rate (%)	7631	23.9	–	–	0.49
400-day re-appearance rate (%)	7631	44.6	–	–	0.57
Overall re-appearance rate (%)	7631	72.7	–	–	0.51
100-day in-calf rate (%)	6662	46.0	–	–	0.61
Removal rate (%)	7631	26.4	–	–	0.50
Conception rate to 1st AI (%)	5250	40.6	–	–	0.68
Conception rate to 2nd AI (%)	2409	39.0	–	–	0.99
Conception rate to 1st or 2nd AI (%)	5340	57.5	–	–	0.68
Conception rate to AI - all services (%)	5363	39.0	–	–	0.50
Conception rate: all service types (%)	6472	43.9	–	–	0.44
(b) Production parameters					
100-day production					
Milk yield (kg per cow)	6150	3258	1560	5550	759
Fat yield (kg per cow)	6150	121.9	55.4	220.3	30.5
Protein yield (kg per cow)	6150	101.1	49.6	165.7	22.4
Fat concentration (g/kg)	6150	37.6	24.3	53.2	4.8
Protein concentration (g/kg)	6150	31.2	25.3	37.6	2.1
Milk energy output (MJ per cow)	6150	9785	4672	16 454	2240
305-day production					
Days in milk	5597	297	250	305	13.4
Milk yield (kg per cow)	5597	7966	3862	14 207	1909
Fat yield (kg per cow)	5597	300.4	144.0	532.3	72.1
Protein yield (kg per cow)	5597	257.3	128.3	433.4	57.5
Fat concentration (g/kg)	5597	37.9	27.2	50.5	4.2
Protein concentration (g/kg)	5597	32.5	27.8	38.0	1.9
Milk energy output (MJ per cow)	5597	24 222	12 064	41 526	5556
Lactation production					
Days in milk	5585	330	250	690	56.6
Milk yield (kg per cow)	5585	8505	3863	18 187	2424
Fat yield (kg per cow)	5585	322.7	144.0	686.7	92.8
Protein yield (kg per cow)	5585	276.5	128.3	574.2	76.1
Fat concentration (g/kg)	5585	38.1	27.6	50.6	4.2
Protein concentration (g/kg)	5585	32.6	28.1	38.1	1.9
Milk energy output (MJ per cow)	5585	25 975	12 064	54 438	7227
Lactation curve parameters					
Nadir protein conc. (g/kg)	5548	29.7	24.9	35.9	2.0
Max. daily yield (kg per cow)	5847	36.0	17.4	61.8	8.5
(c) Genetic merit parameters					
Pedigree index					
Milk yield (kg)	6447	173.9	−323.5	570	175
Fat yield (kg)	6447	3.75	−10.4	15.65	4.73
Protein yield (kg)	6447	5.00	−10.55	16.05	4.89
Fat concentration (%)	6447	−0.0455	−0.255	0.1425	0.0802
Protein concentration (%)	6447	−0.0092	−0.0975	0.09	0.0317
PIN (£)	6447	14.41	−33.5	49	14.8
PLI (£)	6447	15.38	−33.5	48	14.3
Predicted transmitting ability					
PTA milk yield (kg)	6165	107.5	−486	690	225.9
PTA fat yield (kg)	6165	1.38	−18.9	21.6	7.13
PTA protein yield (kg)	6165	2.66	−15.4	20.3	6.40
PTA fat concentration (%)	6165	−0.0435	−0.35	0.25	0.107
PTA protein concentration (%)	6165	−0.0126	−0.14	0.11	0.044
PIN (£)	6165	6.42	−55	61	20.6
PLI (£)	6165	7.58	−55	65	20.5
RLB	6165	48.5	0	66	16.5

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Table 2 *Effect of changing pedigree index on a range of fertility parameters, where the effect of a pre-determined change in each pedigree parameter (that could be reasonably achieved in practice at farm level) was assessed against its effect on a range of continuous and binary fertility parameters*

	n	Mean $y^†$	Mean $x^‡$	Slope	s.e.	*t*	Odds ratio	95% c.i.	Prob.	+£10
(a) £10 increase in PDXPIN										
IFS: all (days)	5532	86.4	14.5	1.59	0.356	4.47	–	–	***	1.59
IFS: AI (days)	4501	85.6	14.7	1.49	0.376	3.95	–	–	***	1.49
CI (days)	4661	406.0	15.0	3.02	0.727	4.16	–	–	***	3.02
RR-365 (%)	6354	–	14.38	–	–	–	1.008	0.967–1.051	NS	
RR-400 (%)	6354	–	14.38	–	–	–	1.023	0.987–1.061	NS	
RR-Overall (%)	6354	–	14.38	–	–	–	1.155	1.109–1.202	***	10.90
ICR-100 (%)	5642	–	14.47	–	–	–	0.963	0.926–1.001	<0.10	
Removal rate (%)	6354	–	14.38	–	–	–	0.855	0.821–0.891	***	−17.90
CR-1 (%)	4475	–	14.67	–	–	–	1.018	0.972–1.065	NS	
CR-2 (%)	2061	–	14.59	–	–	–	0.999	0.938–1.064	NS	
CR-1/2 (%)	4558	–	14.67	–	–	–	1.025	0.980–1.073	NS	

	n	Mean $y^†$	Mean $x^‡$	Slope	s.e.	*t*	Odds ratio	95% c.i.	Prob.	+100 kg
(b) 100 kg increase in PDXMILK										
IFS: all (days)	5532	86.4	175.3	1.45	0.314	4.61	–	–	***	1.45
IFS: AI (days)	4501	85.6	177.6	1.42	0.331	4.30	–	–	***	1.42
CI (days)	4661	406.0	181.2	1.77	0.638	2.77	–	–	***	1.77
RR-365 (%)	6354	–	173.6	–	–	–	1.020	0.983–1.059	NS	
RR-400 (%)	6354	–	173.6	–	–	–	1.042	1.008–1.076	*	0.80
RR-Overall (%)	6354	–	173.6	–	–	–	1.158	1.118–1.199	***	11.80
ICR-100 (%)	5642	–	174.2	–	–	–	0.976	0.943–1.011	NS	
Removal rate (%)	6354	–	173.6	–	–	–	0.852	0.822–0.883	***	−17.80
CR-1 (%)	4475	–	177.3	–	–	–	1.046	1.005–1.089	*	0.50
CR-2 (%)	2061	–	169.7	–	–	–	1.023	0.967–1.083	NS	
CR-1/2 (%)	4558	–	177.1	–	–	–	1.054	1.013–1.096	*	1.30

	n	Mean $y^†$	Mean $x^‡$	Slope	s.e.	*t*	Odds ratio	95% c.i.	Prob.	+0.1%
(c) 0.1% increase in PDXFAT%										
IFS: all (days)	5532	86.4	−0.0461	−1.15	0.680	−1.69	–	–	NS	
IFS: AI (days)	4501	85.6	−0.0469	−1.10	0.712	−1.55	–	–	NS	
CI (days)	4661	406.0	−0.0480	0.83	1.366	0.61	–	–	NS	
RR-365 (%)	6354	–	−0.04541	–	–	–	0.953	0.878–1.033	NS	
RR-400 (%)	6354	–	−0.04541	–	–	–	0.890	0.830–0.955	***	−17.00
RR-Overall (%)	6354	–	−0.04541	–	–	–	0.789	0.730–0.852	***	−27.00
ICR-100 (%)	5642	–	−0.04551	–	–	–	1.006	0.933–1.084	NS	
Removal rate (%)	6354	–	−0.04541	–	–	–	1.292	1.195–1.397	***	19.50
CR-1 (%)	4475	–	−0.04685	–	–	–	0.903	0.829–0.983	*	−17.10
CR-2 (%)	2061	–	−0.04155	–	–	–	0.877	0.776–0.991	*	−22.40
CR-1/2 (%)	4558	–	−0.04677	–	–	–	0.873	0.802–0.951	**	−19.80

	n	Mean $y^†$	Mean $x^‡$	Slope	s.e.	*t*	Odds ratio	95% c.i.	Prob.	+0.1%
(d) 0.1% increase in PDXPROT%										
IFS: all (days)	5532	86.4	−0.0092	−3.51	1.712	−2.05	–	–	*	−3.51
IFS: AI (days)	4501	85.6	−0.0094	−4.52	1.813	−2.49	–	–	*	−4.52
CI (days)	4661	406.0	−0.0095	0.99	3.422	0.29	–	–	NS	
RR-365 (%)	6354	–	−0.009192	–	–	–	0.908	0.743–1.110	NS	
RR-400 (%)	6354	–	−0.009192	–	–	–	0.880	0.737–1.049	NS	
RR-Overall (%)	6354	–	−0.009192	–	–	–	0.720	0.592–0.875	***	−40.80
ICR-100 (%)	5642	–	−0.009104	–	–	–	1.026	0.851–1.236	NS	
Removal rate (%)	6354	–	−0.009192	–	–	–	1.456	1.195–1.773	***	19.50
CR-1 (%)	4475	–	−0.009392	–	–	–	0.791	0.637–0.982	*	−36.30
CR-2 (%)	2061	–	−0.007624	–	–	–	0.826	0.601–1.135	NS	
CR-1/2 (%)	4558	–	−0.00936	–	–	–	0.765	0.615–0.950	*	−38.50

† Dependent (fertility) variable mean from random effects multi-level model for continuous variables with a response curve.
‡ Independent (genetic merit) variable mean from random effects multi-level model for binary variables where odds ratio analysis was conducted.

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Table 3 *Effect of changing 100-day milk production on a range of fertility parameters, where the effect of a pre-determined change in each 100-day yield parameter (that could be reasonably achieved in practice at farm level) was assessed against its effect on a range of continuous and binary fertility parameters*

	n	Mean $y^{\dagger}$	Mean $x^{\ddagger}$	Slope	s.e.	*t*	Odds ratio	95% c.i.	Prob.	+1000 kg
(a) 1000 kg increase in 100-day yield										
IFS: all (days)	5683	85.6	3256	0.084	0.695	0.12	–	–	NS	
IFS: AI (days)	4626	84.8	3272	0.088	0.724	0.12	–	–	NS	
CI (days)	4744	404.2	3257	4.49	1.392	3.23	–	–	***	4.49
RR-365 (%)	6052	–	3258	–	–	–	0.963	0.880–1.055	NS	
RR-400 (%)	6052	–	3258	–	–	–	0.906	0.837–0.981	*	−9.40
RR-Overall (%)	6052	–	3258	–	–	–	1.068	0.974–1.172	NS	
ICR-100 (%)	5752	–	3256	–	–	–	0.867	0.799–0.941	**	−13.30
Removal rate (%)	6052	–	3258	–	–	–	0.908	0.827–0.997	*	−9.20
CR-1 (%)	4603	–	3271	–	–	–	0.843	0.769–0.924	***	−15.70
CR-2 (%)	2115	–	3299	–	–	–	0.889	0.781–1.012	<0.10	
CR-1/2 (%)	4684	–	3273	–	–	–	0.839	0.765–0.919	***	−16.10
	n	Mean $y^{\dagger}$	Mean $x^{\ddagger}$	Slope	s.e.	*t*	Odds ratio	95% c.i.	Prob.	+0.1%
(b) 1 g/kg increase in 100-day protein concentration										
IFS: all (days)	5683	85.6	31.21	−1.042	0.252	−4.13	–	–	***	−1.04
IFS: AI (days)	4626	84.8	31.23	−1.047	0.266	−3.94	–	–	***	−1.05
CI (days)	4744	404.2	31.22	−2.518	0.506	−4.98	–	–	***	−2.52
RR-365 (%)	6052	–	31.18	–	–	–	1.032	1.000–1.066	*	3.20
RR-400 (%)	6052	–	31.18	–	–	–	1.073	1.044–1.104	***	7.30
RR-Overall (%)	6052	–	31.18	–	–	–	1.022	0.989–1.057	NS	
ICR-100 (%)	5752	–	31.21	–	–	–	1.052	1.022–1.083	***	5.20
Removal rate (%)	6052	–	31.18	–	–	–	0.983	0.950–1.017	NS	
CR-1 (%)	4603	–	31.24	–	–	–	1.022	0.988–1.056	NS	
CR-2 (%)	2115	–	31.27	–	–	–	1.019	0.972–1.068	NS	
CR-1/2 (%)	4684	–	31.24	–	–	–	1.018	0.984–1.052	NS	
	n	Mean $y^{\dagger}$	Mean $x^{\ddagger}$	Slope	s.e.	*t*	Odds ratio	95% c.i.	Prob.	+1000 MJ
(c) 1000 MJ increase in 100-day milk energy output										
IFS: all (days)	5683	85.6	9783	0.047	0.232	0.20	–	–	NS	
IFS: AI (days)	4626	84.8	9848	0.003	0.241	0.01	–	–	NS	
CI (days)	4744	404.2	9788	1.383	0.465	2.98	–	–	**	1.38
RR-365 (%)	6052	–	9784	–	–	–	0.986	0.956–1.016	NS	
RR-400 (%)	6052	–	9784	–	–	–	0.972	0.947–0.999	*	−2.80
RR-Overall (%)	6052	–	9784	–	–	–	1.027	0.996–1.059	<0.10	
ICR-100 (%)	5752	–	9784	–	–	–	0.955	0.929–0.981	***	−4.50
Removal rate (%)	6052	–	9784	–	–	–	0.969	0.939–1.000	*	−3.10
CR-1 (%)	4603	–	9846	–	–	–	0.950	0.922–0.980	***	−5.00
CR-2 (%)	2115	–	9928	–	–	–	0.955	0.914–0.998	*	−4.50
CR-1/2 (%)	4684	–	9853	–	–	–	0.946	0.918–0.976	***	−5.40

† Dependent (fertility) variable mean from random effects multi-level model for continuous variables with a response curve.
‡ Independent (production) variable mean from random effects multi-level model for binary variables where odds ratio analysis was conducted. Associations are significant where the value of 1.000 falls within the 95% confidence interval (c.i.).

and an increase in RR-365 ($P < 0.05$) and ICR-100 ($P < 0.001$). Increased mean milk fat concentration over 100 days had no significant association with any fertility parameters while an increase in mean milk fat concentration over 305 days was associated with increased removal rates ($P < 0.05$).

The association between nadir protein concentrations and maximum daily yields on the range of fertility parameters is presented in Table 5. Each 1-g/kg increase in milk protein nadir was associated with an increase in both RR-400 and ICR-100, which increased by 6.3 ($P < 0.001$) and 6.6% ($P < 0.001$), respectively. Each 10-kg increase in peak daily yield was associated with an increase in both IFS (1.59 days; $P < 0.05$) and CI (6.58 days; $P < 0.001$) and a 14.9% decrease in CR-1. Each 10-kg increase in yield was also associated with a decrease in RR-365 (9.6%; $P < 0.05$), RR-400 (14.2%; $P < 0.001$) and ICR-100 (18.3%; $P < 0.001$).

The relative effect of the various uni-variate comparisons of either genetic merit or production variables on the continuous measures of fertility are presented as the value of *t* in Tables 2–5. The value of *t* on IFS by AI was 3.95

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Table 4 *Effect of changing 305-day milk production on a range of fertility parameters, where the effect of a pre-determined change in each 305-day yield parameter (that could be reasonably achieved in practice at farm level) was assessed against its effect on a range of continuous and binary fertility parameters*

	n	Mean $y^{\dagger}$	Mean $x^{\ddagger}$	Slope	s.e.	*t*	Odds ratio	95% CI	Prob.	+1000 kg
(a) 1000 kg increase in 305-day yield										
IFS: all (days)	5371	87.1	7949	3.132	0.320	9.80	–	–	***	3.13
IFS: AI (days)	4395	85.9	8038	3.215	0.330	9.74	–	–	***	3.22
CI (days)	4737	406.1	7945	7.789	0.610	12.78	–	–	***	7.79
RR-365 (%)	5512	–	7958	–	–	–	0.801	0.768–0.836	***	−19.90
RR-400 (%)	5512	–	7958	–	–	–	0.810	0.780–0.840	***	−19.00
RR-Overall (%)	5512	–	7958	–	–	–	1.008	0.958–1.061	NS	
ICR-100 (%)	5408	–	7949	–	–	–	0.776	0.746–0.807	***	−22.40
Removal rate (%)	5512	–	7958	–	–	–	0.974	0.925–1.025	NS	
CR-1 (%)	4377	–	8033	–	–	–	0.864	0.828–0.901	***	−13.60
CR-2 (%)	2024	–	8179	–	–	–	0.929	0.878–0.983	*	−7.10
CR-1/2 (%)	4458	–	8043	–	–	–	0.880	0.844–0.917	***	−12.00
	n	Mean $y^{\dagger}$	Mean $x^{\ddagger}$	Slope	s.e.	*t*	Odds ratio	95% CI	Prob.	+0.1%
(b) 1 g/kg increase in 305-day butterfat concentration										
IFS: all (days)	5371	87.1	37.93	0.048	0.126	0.38	–	–	NS	
IFS: AI (days)	4395	85.9	37.94	0.017	0.133	0.13	–	–	NS	
CI (days)	4737	406.1	37.90	−0.165	0.246	−0.67	–	–	NS	
RR-365 (%)	5512	–	37.93	–	–	–	1.003	0.988–1.019	NS	
RR-400 (%)	5512	–	37.93	–	–	–	1.000	0.986–1.014	NS	
RR-Overall (%)	5512	–	37.93	–	–	–	0.982	0.963–1.002	<0.10	
ICR-100 (%)	5408	–	37.93	–	–	–	1.007	0.992–1.021	NS	
Removal rate (%)	5512	–	37.93	–	–	–	1.026	1.005–1.048	*	2.60
CR-1 (%)	4377	–	37.95	–	–	–	1.016	1.000–1.032	<0.10	
CR-2 (%)	2024	–	37.89	–	–	–	0.984	0.961–1.008	NS	
CR-1/2 (%)	4458	–	37.96	–	–	–	1.007	0.991–1.024	NS	
	n	Mean $y^{\dagger}$	Mean $x^{\ddagger}$	Slope	s.e.	*t*	Odds ratio	95% C.I.	Prob.	+1000 MJ
(c) 1000 MJ increase in 305-day milk energy output										
IFS: all (days)	5371	87.1	24 172	1.087	0.108	10.08	–	–	***	1.09
IFS: AI (days)	4395	85.9	24 441	1.106	0.111	9.93	–	–	***	1.11
CI (days)	4737	406.1	24 151	2.640	0.206	12.81	–	–	***	2.64
RR-365 (%)	5512	–	24 199	–	–	–	0.927	0.914–0.941	***	−7.30
RR-400 (%)	5512	–	24 199	–	–	–	0.930	0.919–0.942	***	−7.00
RR-Overall (%)	5512	–	24 199	–	–	–	0.999	0.982–1.016	NS	
ICR-100 (%)	5408	–	24 174	–	–	–	0.918	0.906–0.930	***	−8.20
Removal rate (%)	5512	–	24 199	–	–	–	0.997	0.979–1.014	NS	
CR-1 (%)	4377	–	24 431	–	–	–	0.953	0.940–0.967	***	−4.70
CR-2 (%)	2024	–	24 867	–	–	–	0.972	0.953–0.991	**	−2.80
CR-1/2 (%)	4458	–	24 460	–	–	–	0.957	0.944–0.971	***	−4.30

† Dependent (fertility) variable mean from random effects multi-level model for continuous variables with a response curve.
‡ Independent (production) variable mean from random effects multi-level model for binary variables where odds ratio analysis was conducted. Associations are significant where the value of 1.000 falls within the 95% confidence interval.

($P < 0.001$), 0.12 ($P > 0.10$) and 9.74 ($P < 0.001$) days for PDX milk, 100-day milk yield and 305-day milk yield, respectively, while the value of t for CI was 4.16 ($P < 0.001$), 3.23 ($P < 0.001$) and 12.78 ($P < 0.001$), respectively. The effect of standard deviation increase in genetic or production variables on both the continuous and binary measures of fertility indicated that 305-day production and milk energy output had a greater effect on the fertility parameters, with the exception of RR-overall where only genetic merit had significant effects (Table 6).

The associations between season of calving, lactation number, calving difficulty score and calf type on CR-1, ICR-100 and RR-400 are presented in Table 7. When compared to the 3-month period from August to October, the odds of conceiving to first insemination (CR-1) were significantly lower for cows calving in the months of February to April, while the odds of becoming pregnant within 100 days of calving (ICR-100) were significantly higher for cows calving in November to January, February to April and May to July than for cows calving

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Table 5 *Effect of nadir milk protein concentration and maximum daily yield on a range of fertility parameters, where the effect of a pre-determined change in nadir milk protein concentration or peak milk yield (that could be reasonably achieved in practice at farm level) was assessed against its effect on a range of continuous and binary fertility parameters*

	n	Mean *y*†	Mean *x*‡	Slope	s.e.	*t*	Odds ratio	95% CI	Prob.	+0.1%
(a) 1 g/kg increase in nadir milk protein concentration										
IFS: all (days)	5098	86.1	29.74	−1.179	0.275	−4.29	–	–	***	−1.18
IFS: AI (days)	4142	85.2	29.76	−1.423	0.290	−4.91	–	–	***	−1.42
CI (days)	4235	405.0	29.74	−2.383	0.541	−4.41	–	–	***	−2.38
RR-365 (%)	5461	–	29.72	–	–	–	1.032	0.998–1.069	<0.10	
RR-400 (%)	5461	–	29.72	–	–	–	1.063	1.031–1.095	***	6.30
RR-Overall (%)	5461	–	29.72	–	–	–	1.007	0.972–1.043	NS	
ICR-100 (%)	5160	–	29.74	–	–	–	1.066	1.033–1.100	***	6.60
Removal rate (%)	5461	–	29.72	–	–	–	0.994	0.959–1.030	NS	
CR-1 (%)	4119	–	29.76	–	–	–	1.008	0.973–1.045	NS	
CR-2 (%)	1909	–	29.82	–	–	–	1.006	0.957–1.059	NS	
CR-1/2 (%)	4191	–	29.76	–	–	–	1.005	0.970–1.041	NS	
	n	Mean *y*†	Mean *x*‡	Slope	s.e.	t	Odds ratio	95% CI	Prob.	+10 kg
(b) 10-kg increase in maximum daily yield										
IFS: all (days)	5385	84.9	35.98	1.590	0.662	1.40	–	–	*	1.59
IFS: AI (days)	4332	84.1	36.24	1.279	0.699	1.83	–	–	<0.10	
CI (days)	4466	403.3	36.00	6.578	1.332	4.94	–	–	***	6.58
RR-365 (%)	5757	–	36.02	–	–	–	0.904	0.829–0.986	*	−9.60
RR-400 (%)	5757	–	36.02	–	–	–	0.858	0.796–0.925	***	−14.20
RR-Overall (%)	5757	–	36.02	–	–	–	1.073	0.985–1.170	NS	
ICR-100 (%)	5450	–	35.98	–	–	–	0.817	0.756–0.884	***	−18.30
Removal rate (%)	5757	–	36.02	–	–	–	0.898	0.824–0.980	*	−10.20
CR-1 (%)	4308	–	36.22	–	–	–	0.851	0.780–0.930	***	−14.90
CR-2 (%)	1978	–	36.55	–	–	–	0.897	0.793–1.013	<0.10	
CR-1/2 (%)	4389	–	36.24	–	–	–	0.853	0.782–0.931	***	−14.70

† Dependent (fertility) variable mean from random effects multi-level model for continuous variables with a response curve.
‡ Independent (production) variable mean from random effects multi-level model for binary variables where odds ratio analysis was conducted. Associations are significant where the value of 1.000 falls within the 95% confidence interval.

in August to October. Similarly, cows calving in November to January and February to April had higher odds of calving again with 400 days (RR-400) than cows calving in August to October, while cows calving in May to July had lower odds.

Cows in their first or second lactation had significantly higher odds of conceiving to first insemination than those in their third lactation or more. The findings were similar for both becoming pregnant within 100 days of calving and calving again within 400 days, although the odds of cows in their second lactation becoming pregnant again within 100 days of calving were not significantly different ($P < 0.10$) from third lactation cows.

The odds of cows with a calving difficulty score of 4–5 calving again with 400 days were significantly lower than cows with a calving difficulty score of 0. In cows intended for re-breeding, cows with calving difficulty scores of 4 or 5 had a similar ICR-100 to those with a calving difficulty score of 0, although there were some significant differences for other scores. Cows that had twins were significantly less likely to calve again within 400 days than cows that had a single heifer calf. They also had a tendency ($P < 0.10$) towards reduced calving rates to first insemination but this was generally not reflected in a significantly reduced ICR-100 in cows intended for rebreeding.

Discussion

This study was designed to assess the reproductive performance of a range of dairy herds in terms of both genetic merit and milk production, reflecting the diverse range of dairy production systems present throughout Northern Ireland. Fertility performance was generally poor with an average CI of 405.9 days and CR-1 of 40.3%. Both these results were consistent with results from the 1st year of the study (Mayne *et al.*, 2002) where the average CI and CR-1 were 407.2 days and 37.1%, respectively, and the herd ranges were 359 to 442 days and 21 to 66%, respectively. The average CI interval reported by United Milk Records for approximately 1000 herds in Northern Ireland (personal communication) for a similar period was 399 days (herd range 365 to 445 days), similar to the 397 days reported nationally by National Milk Records (Esslemont *et al.*, 2001). The mean calving interval was also consistent

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Table 6 *Comparative effect of genetic merit and production parameters on fertility*

	s.d.	Unit	Units/s.d.	IFS (days)		CI (days)		CR-1 (%)		ICR-100 (%)		RR-365 (%)		RR-400 (%)		RR-overall (%)	
				Per unit	Per s.d.	Per unit	Per s.d.	Per unit	Per s.d.	Per unit	Per s.d.	Per unit	Per s.d.	Per unit	Per s.d.	Per unit	Per s.d.
Pedigree index																	
Milk yield (kg)	175	100	1.75	1.4	2.5	1.8	3.1	0.5	0.9	–	–	–	–	0.8	1.4	11.8	20.7
Fat concentration (%)	0.0802	0.1	0.802	–	–	–	–	−17.1	−13.7	–	–	–	–	−17.0	−13.6	−27.0	−21.7
Protein concentration (%)	0.0317	0.1	0.317	−4.5	−1.4	–	–	−36.3	−11.5	19.5	6.2	–	–	–	–	−40.8	−12.9
PIN (£)	14.8	10	1.48	1.5	2.2	3.0	4.5	–	–	–	–	–	–	–	–	10.9	16.1
100-day production																	
Milk yield (kg per cow)	759	1000	0.759	–	–	4.5	3.4	−15.7	−11.9	−13.3	−10.1	–	–	−9.4	−7.1	–	–
Fat concentration (g/kg)	4.8	1	4.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Protein concentration (g/kg)	2.1	1	2.1	−1.1	−2.2	−2.5	−5.3	–	–	5.2	10.9	3.2	6.7	7.3	15.3	–	–
Milk energy output (MJ per cow)	2240	1000	2.24	–	–	1.4	3.1	−5	−11.2	−4.5	−10.1	–	–	−2.8	−6.3	–	–
305-day production																	
Milk yield (kg per cow)	1909	1000	1.909	3.2	6.2	7.8	14.9	−13.6	−26.0	−22.4	−42.8	−19.9	−38.0	−19.0	−36.3	–	–
Fat concentration (g/kg)	4.2	1	4.2	–	–	–	–	–	–	–	–	–	–	–	–		
Protein concentration (g/kg)	1.9	1	1.9	–	–	–	–	–	–	–	–	–	–	5.1	9.7	–	–
Milk energy output (MJ per cow)	5556	1000	5.556	1.1	6.2	2.6	14.7	−4.7	−26.1	−8.2	−45.6	−7.3	−40.6	−7.3	−38.9	–	–
Lactation curve parameters:																	
Nadir protein conc. (g/kg)	2.0	1	2	−1.4	−2.8	−2.4	−4.8	–	–	6.6	13.2	–	–	6.3	12.6	–	–
Max. daily yield (kg per cow)	8.5	10	0.85	–	–	6.6	5.6	−14.9	−12.7	−18.3	−15.6	−9.6	−8.2	−14.2	−12.1	–	–

Table 7 *Association between a range of factors on some key fertility parameters*

	Conception rate to first service (CR-1)				100-day in-calf rate (ICR-100)				400-day reappearance rate (RR-400)			
	n obs. in analysis	Odds ratio	95% CI	Prob.	n obs. in analysis	Odds ratio	95% CI	Prob.	n obs. In analysis	Odds ratio	95% CI	Prob.
Calving period												
Aug-Oct	1440	1.000	1.000		1607	1.000	1.000		1844	1.000	1.000	
Nov-Jan	1846	0.929	0.802– 1.075	NS	2209	1.307	1.140– 1.499	***	2493	1.143	1.007– 1.298	*
Feb-Apr	1706	0.841	0.712– 0.994	*	2358	1.752	1.519– 2.022	***	2661	1.279	1.121– 1.459	***
May-Jul	258	0.871	0.653– 1.163	NS	488	1.544	1.239– 1.924	***	633	0.741	0.605– 0.907	**
Lactation number												
3 +	2357	1.000	1.000		3092	1.000	1.000		3577	1.000	1.000	
2	1228	1.257	1.085– 1.456	**	1548	1.131	0.997– 1.284	<0.10	1713	1.425	1.263– 1.608	***
1	1665	1.452	1.270–1.661	***	2022	1.179	1.049– 1.325	**	2341	1.346	1.206– 1.503	***
Calving difficulty												
0	779	1.000	1.000		969	1.000	1.000		1161	1.000	1.000	
1	1144	0.735	0.586– 0.922	**	1391	1.003	0.820– 1.226	NS	1561	0.999	0.828– 1.206	NS
2	1568	0.942	0.763– 1.163	NS	2105	1.247	1.029– 1.512	*	2352	1.050	0.879– 1.256	NS
3	774	0.957	0.765– 1.197	NS	954	1.197	0.975– 1.470	<0.10	1110	1.034	0.856– 1.249	NS
4	754	0.723	0.570– 0.917	**	928	0.936	0.755– 1.160	NS	1081	0.805	0.660– 0.983	*
5	39	0.566	0.269– 1.195	NS	52	0.638	0.349– 1.168	NS	66	0.465	0.261– 0.830	*
Calf type												
Heifer	2311	1.000	1.000		2925	1.000	1.000		3304	1.000	1.000	
Bull	2454	0.973	0.863– 1.097	NS	3086	0.953	0.858– 1.058	NS	3547	0.923	0.837– 1.019	NS
Unknown	349	1.113	0.865–1.433	NS	472	0.716	0.577– 0.888	**	567	0.773	0.633– 0.944	*
Twin heifers	29	0.422	0.174–1.026	<0.10	37	1.011	0.513– 1.993	NS	46	0.326	0.158– 0.672	**
Twin mixed	62	0.409	0.216– 0.776	**	84	0.503	0.309– 0.819	**	102	0.348	0.215– 0.564	***
Twin bulls	29	0.421	0.166– 1.068	<0.10	38	0.767	0.395– 1.488	NS	41	0.504	0.256– 0.992	*
Twins unknown	16	0.307	0.085– 1.114	<0.10	20	0.578	0.215– 1.556	NS	24	0.322	0.117– 0.885	*

with that extrapolated from the average interval to conception (134 and 107 days for two successive years) in a fertility study of seven herds reported by Wicks and Leaver (2004).

Slippage and extension of the calving pattern is a common feature of many dairy herds in Northern Ireland. This is demonstrated by the fact that only 24.0% of cows in this study re-appeared within 365 days of a previous calving, and only 44.5% re-appeared within 400 days. A major cause of this poor performance was the prolonged interval to first service of 85.2 days on average, and the poor calving rate to first service of 40.3% which meant that only 46.0% of cows intended for re-breeding were back in-calf within 100 days of calving, although this varied considerably between herds (herd range: 16.4 to 70.8%). While the mean 100-day in calf rate is less than the 53% reported by Morton (2001) for year-round calving herds in Australia, he reported a similar range of 19 to 73% between herds. Both 100-day in-calf rate and re-appearance rate offer alternatives to calving index as a means of assessing reproductive performance in dairy herds as they avoid the problems associated with cows not calving again and can be used to actively target improved herd fertility performance.

The average calving rate to first insemination in this study (40.3%) is similar to the findings of Royal *et al.* (2000) who reported a calving rate to first insemination of 39.7%, and similar to that of Butler *et al.* (1995) who reported a conception rate to first insemination of 40.9%. However, these results are lower than that of Grosshans *et al.* (1997) who reported calving rates to first service of 48.5 and 50.0% for first and second lactation cows. They were also lower than that of Buckley *et al.* (2003) who reported a conception rate of 49% using rectal palpation at least 56 days after the end of the breeding season and that of Wicks and Leaver (2004) who reported average pregnancy rates of 56 and 63% in 2 years of study. The study of Grosshans *et al.* (1997) was conducted in the pasture-based system of New Zealand where there is inherently better cow fertility due to the seasonal nature of the production system. This together with the lower production and shorter lactation of New Zealand cows may be the reason for their more favourable results. Similarly, the study of Buckley *et al.* (2003) was also conducted on seasonal spring-calving herds, but conception rates based on rectal palpation are likely to give a more favourable result than results based on a subsequent calving used in the present study, i.e. the ultimate assessment of fertility based on pregnancy diagnosis.

Genetic merit and fertility performance

Various reports have suggested that the declining level of fertility in dairy cows may be associated with increased genetic merit for milk production and an increased percentage of Holstein genes (Hoekstra *et al.*, 1994; Royal *et al.*, 2000; Harris and Kolver, 2001). Selection of dairy cattle for higher milk yield potential has generally been accompanied by poorer reproductive performance, where genetic correlations between production and fertility parameters are generally negative (Pryce *et al.*, 1998; Buckley *et al.*, 2000; Kadarmideen *et al.*, 2000; Olori *et al.*, 2002). Consequently, fertility traits have now been incorporated into breed selection indices in the Republic of Ireland and UK (Veerkamp *et al.*, 2002; Wall *et al.*, 2003; Santarossa *et al.*, 2004) making it possible to make genetic improvements to both milk yield and fertility simultaneously, albeit at a slower rate than selecting for each on its own.

In the present study, the main effects of increasing genetic merit, either through increases in £PIN or in the pedigree index for milk, were observed as significant increases in IFS and CI, but also as a significant increase in overall re-appearance rate or decrease in removal rate. The increased IFS and CI may have been in part due to the longer interval to commencement of luteal activity in these cows, previously reported by McCoy *et al.* (2006) but is also likely to have been due to management reasons in higher genetic merit herds, where cows have an extended voluntary waiting period of 3 months or more before service (unpublished data from present study). Cows of superior genetic merit are also less likely to display heat at first ovulation (Westwood *et al.*, 2002) with effects on interval to first service. The increase in overall re-appearance rate and decreased removal rate observed for cows with a higher £PIN and genetic merit for milk production in this study may be in part due to the predominance of herds with prolonged winter calving and extended periods of breeding in this study, typical of that currently present in Northern Ireland. The prolonged breeding period, often exceeding six months allows repeat breeding cows, often with higher genetic merit for milk production, to be preferentially retained and served a number of times, despite their lower levels of fertility performance. This is in contrast to seasonal calving systems where such cows are more likely to be removed from the herd. Cows with higher genetic merit for milk fat and protein concentration had a lower overall re-appearance rate and were more likely to be removed from the herd, possibly due to the greater importance of milk yield.

There are conflicting reports on the effect of increasing genetic merit for milk production on conception rate. Hoekstra *et al.* (1994) found that an increased proportion of Holstein genes and hence higher genetic merit for milk production had a detrimental effect on conception rate, as assessed by non-returns. In the present study, there was no significant effect of £PIN on calving rate, but each 100 kg increase in genetic merit for milk production was associated with a 0.5% increase in calving rate to first insemination and this contributed to a 0.8% increase in 400-day re-appearance rate. These findings are consistent with Buckley *et al.* (2003) who found that the proportion of Holstein genes had no effect on pregnancy rate to first service, but also found that higher milk production was associated with improved conception rates to first service.

In the present study, the positive association between genetic merit and calving rate may have been due to a number of factors including the delayed interval to first insemination.

Production and fertility performance

While there is much information on the genetic relationships between milk production and fertility (Dematawewa and Berger, 1998; Pryce *et al.*, 1998; Kadarmideen *et al.*, 2000; Berry *et al.*, 2003), there is a lack of consensus in the literature as to whether the decline in dairy cow fertility is caused by increasing genetic merit for milk production or indeed increased production itself. In this study, every fertility parameter measured was significantly and adversely affected by a 1000-kg increase in 305-day milk production (or 1000 MJ increase in milk energy output), with the exception of RR-overall and removal rate, indicating the preferential retention of high yielding cows in the herd, despite their poorer fertility performance. An increased interval to first service and a decreased calving rate to first service in higher yielding cows contributed to the prolonged calving index in higher yielding cows, with 22% fewer cows being in-calf within 100 days of calving and 19% fewer re-appearing within 400 days of a previous calving event for each 1000-kg increase in 305-day yield.

In a study of two lines of Holstein cows, a high production and a medium production line, Hageman *et al.* (1991) estimated that each 1000-kg increase in 305-day milk yield increased the number of days open, and hence CI by 7.0 and 12.5 days in first and second lactation cows, respectively. Veerkamp *et al.* (2002) predicted from genetic parameters that under selection for milk yield alone, each 1000-kg increase in yield is associated with a 5- to 10-day prolongation of calving index. Using similar arithmetic procedures for predicting the genetic relationship between production and fertility traits from various studies (Dematawewa and Berger, 1998, Pryce *et al.*, 1998, Olori *et al.*, 2002, Berry *et al.*, 2003, Pryce *et al.*, 2002 and Kadarmideen, 2004), each 1000-kg increase in 305-day milk production was associated with up to a 5-day increase in interval to first service, a 6- to 14-day increase in calving index and a 3 to 6% decrease in calving rate to first insemination. The findings of the present study, where each 1000-kg increase in 305-day milk yield was associated with a 3.2-day increase in interval to first insemination and a 7.8-day increase in calving index, are consistent with the predictions based on the genetic relationships found in the papers listed above. However, the detrimental effect of a 1000-kg increase in 305-day yield on calving rate to first insemination observed in this study (decrease of 13.6%) was greater than predicted from the findings of Pryce *et al.* (1998), Berry *et al.* (2003) and Kadarmideen (2004) where decreases of 6, 4 and 3%, respectively, would have been expected. The findings from the present study are in contrast to those of Buckley *et al.* (2003) where higher yielding cows had higher odds of conceiving to first service. However, in that study, all herds were spring-calving and there was a smaller range in 305-day production. Their statistical analysis also included adjustments for the proportion of Holstein genes and breeding value for milk yield, both of which reduced the odds of cows becoming pregnant to first service at higher levels.

Negative energy balance in the first 3 to 4 weeks *post partum* is highly correlated with interval to first ovulation (Butler, 2001). In the present study, parameters relating to early lactation milk production, viz. peak yield, nadir protein concentration and 100-day milk production also had effects on the various measures of fertility performance. Hoekstra *et al.* (1994) reported negative genetic associations between production and fertility, particularly protein yield, and Fulkerson *et al.* (2001) showed that cows with the lowest milk protein content suffered the most severe and prolonged negative energy balance. Butler (2001) cited that timing of the nadir is particularly important, with cows in greater negative energy balance being less likely to exhibit regular oestrous cycles and have poorer fertility performance. Negative energy balance is associated with low oestradiol concentrations in the periovulatory period (Mackey *et al.*, 1999), leading to less overt expression of oestrus (Spicer *et al.*, 1990; Lyimo *et al.*, 2000) and greater difficulty in heat detection. In the present study, a 1-g/kg decrease in nadir milk protein was associated with poorer reproductive performance as observed by an increased interval to first service and calving index, and a decreased 100-day in-calf rate and 400-day re-appearance rate. The relationship between milk energy content and subsequent fertility in this study is supported by the association between fertility and 100-day milk production where there was also a negative association with calving rate to first insemination.

Higher peak yields were associated with decreased calving rates to first service, equivalent to a 14.9% decrease in CR-1 for each 10-kg increase in peak yield or 15.7% decrease for each 1000-kg increase in 100-day milk production, and these had associated effects on ICR-100, RR-365 and RR-400. This is consistent with previous reports where higher levels of milk production in early lactation were associated with a reduced likelihood of successful pregnancy by day 150 due to a delay in and reduced expression of oestrus at first ovulation (Westwood *et al.*, 2002). The reduced calving rates at higher levels of production were likely to be a consequence of increased negative energy balance leading to metabolic stress and possibly suboptimal uterine conditions for embryo development (Butler, 2001).

Relative effects of genetic merit and production on fertility performance

Buckley *et al.* (2003) found no effect of genetic merit for milk production on pregnancy rate to first service, and only cows with very high genetic merit had decreased submission rates and pregnancy rates within 21 and 42 days of breeding start, respectively. While results from the

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current study indicated that fertility performance was negatively affected by both genetic merit and level of production, production had the greater negative effect, especially when considered over 305 days (Table 6). These findings indicate that infertility at an individual cow level is predominantly due to environmental effects (including nutrition), a view supported by the findings of Veerkamp and Emmans (1995) who cited that indirect selection for feed intake milk yield through selection for milk yield alone, as in the UK through the PIN index, can only provide 40 to 48% of the extra energy requirement for increased milk yield in early lactation. However, Buckley *et al.* (2000) reported no negative effects of genetic merit on reproductive performance in a spring-calving grass-based production system. This, together with unpublished data from the present study pertaining to individual herds suggest that it is possible to get good reproductive performance from high genetic merit dairy cows providing overall fertility management and nutrition is optimised.

Effects of calving season and calving difficulty on fertility performance

There were a number of significant seasonal effects on various fertility parameters, some of which can be explained by the diverse range of calving patterns observed in the 19 participating herds. Compared to cows calving from August to October, cows calving from February to April had a significantly lower CR-1. This is consistent with the findings of Buckley *et al.* (2003) who also reported a decreased calving rate to first service in late calving cows, although cows in that study calved from January to May, unlike the present study where the majority of herds calved throughout the winter. In this study, February to April calving cows had a significantly lower CR-1, but had a significantly higher ICR-100. These findings reflect the large influence of spring calving herds where cows were often inseminated in the early post-partum period, resulting in poor calving rates (Mayne *et al.*, 2002), but were also given the opportunity for more chances to conceive within 100 days of calving. The lower CR-1 and higher ICR-100 for February to April calving cows may also have been due, in part, to the shorter interval to first insemination experienced by late calving cows in prolonged winter-calving herds in an attempt to calve them earlier the following year. However, in these herds, where cows calved from May to July, there was a significantly lower RR-400 suggesting that they fell outside the ideal calving season so a smaller proportion of these were intended for re-breeding.

It is widely accepted that dystocia is a major factor affecting the subsequent reproductive performance of dairy cows (Fonseca *et al.*, 1983; Morton, 2000). In the present study, the effects of dystocia on CR-1 and ICR-100 were inconsistent, but there was a significantly reduced chance of cows with higher levels of dystocia re-appearing again within 400 days. This may have been due to an increased likelihood of retained foetal membranes and associated metritis which can delay uterine involution, disrupt post-partum hormonal profiles and ultimately lead to a delay in return to cyclicity (McCoy *et al.*, 2006). It is possible that a higher incidence of reproductive problems in older cows (unpublished results from present study) may have contributed to their lower odds of conceiving to first service compared to first or second lactation cows, with associated effects on ICR-100 and RR-400.

Conclusions

The results of this study showed that the fertility performance of dairy cows on-farm is negatively associated with both genetic merit and level of production, and various other factors including season of calving, lactation number and dystocia. Level of production has the greatest negative effect, especially when considered over a 305-day lactation, indicating that infertility at an individual cow level in this study is predominantly due to an inability to meet the nutritional requirements of high genetic merit dairy cows, as evidenced by lower nadir milk protein concentrations. These results also suggest that it is possible to get good reproductive performance from high genetic merit dairy cows providing high levels of fertility management and appropriate nutrition are achieved.

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