Economic Value of Female Fertility and its Relationship with Profit in Spanish Dairy Cattle

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ABSTRACT

A data file of 225,085 inseminations and 120,713 lactations from 63,160 Holstein cows was analyzed to obtain female fertility economic value according to number of inseminations per service period (INS). Fertility cost (FCOST) was included in a bioeconomic model, taking into account number of doses of semen, hormonal treatments, fertility culling cost, and delayed milk and calf sales. A profit equation was elaborated to estimate fertility cost and profit according to INS. Fertility in Spanish dairy cattle has worsened >10% over the last 14 yr. Days open have increased by about 15 d, and INS has increased from 1.7 to 2.0. A quadratic relationship was found between FCOST and INS. Similar profitability was estimated for cows who needed one or 2 INS, but when >3 INS were needed, profit decreased by >\$205 (US dollars)/yr per cow. Cows that needed more INS had higher milk yield per lactation, but also had a higher culling risk and lower productive life and lifetime production, therefore, lower profit. Calving interval (CI) and INS economic values were, respectively, −\$4.90 and −\$67.32 (US dollars)/yr per cow and per one unit of change. The economic values of productive traits were \$4.04, \$1.02, and \$1.19 (US dollars)/yr per cow and per one unit of change for kg protein, kg fat, and days in milk, respectively. A mature body weight economic value of −\$0.67 (US dollars)/yr per cow and per kg was estimated. The relative importance of fertility traits with respect to protein was 64% for CI and 24% for INS, although the CI economic value is highly influenced by phenotypic standard deviation considered.

(Key words: artificial insemination, fertility cost, profit)

Abbreviation key: AFC = age at first calving, CI = calving interval, DFS = days to first insemination, DO = days open, DP = dry period (days), FCOST = fertility cost, INS = number of inseminations per service period,

KGM = actual (nonadjusted) milk yield, KGM305 = 305-d adjusted milk yield, NR = nonreturn rate at 56 (NR56) or 90 (NR90) d, RSK = estimated fertility culling risk, SF = success of first insemination.

INTRODUCTION

Selection based on productive traits has a negative influence on reproductive ability, because reproduction is negatively correlated with milk yield (Veerkamp et al., 2001). Jones et al. (1994) reported that selection based on milk yield produces more income in dairy populations but also greater costs. Fertility in dairy cattle has an important effect on herd economics in terms of reducing input costs (Groen et al., 1998). Dekkers (1991) reported that an improvement in fertility increases profit, not only by reducing culling cost but also by increasing incomes from milk sale and shorter calving intervals (CI). Recently, in many countries, female fertility has been included in breeding goals to place emphasis on genetic aspects of reducing fertility costs (FCOST) in dairy cattle (Kadarmideen and Simm, 2002). Genetic evaluations across countries for fertility will be available in the near future (Wall et al., 2003b).

The economic importance of female fertility traits should be considered to specify a selection index (Sölkner and Fuerst, 2002). Reproductive aspects have been recently included in profit equations in some reports, but not all costs involved in fertility have been included. The cost of poor fertility arises from additional inseminations, veterinary and hormonal costs, and a modification of current and subsequent lactations (Boichard, 1990). Nonoptimal fertility also leads to cull cows toward the end of lactation (Roxström and Strandberg, 2002), which is the second most important cause of culling in dairy cattle (Kossabati and Esslemont, 1995). Groen et al. (1997) also considered the socio-economical importance of fertility and its effect on animal welfare. Some procedures allow prediction of the economic importance of fertility traits in a population by estimating a cost equation and including it in a profit function under a specific circumstance (Groen, 1989a,b; Bekman and Van Arendonk, 1993; Pieters et al., 1997).

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There is no consensus as to which fertility traits must be included in selection indexes. Historically, several traits were considered as measurements of fertility, normally based on 1) milk recording schemes or 2) insemination data records.

Traits from milk recording schemes related to calving date include CI and days open (**DO**). Those traits are not a direct measurement of fertility because of a dairy producer's potential decision to delay the first AI, or voluntarily increase DIM, or both (Wall et al., 2003a). Age at first calving (**AFC**) has been used as a fertility trait in heifers.

Traits from insemination records are days to first insemination (**DFS**), interval from first to last insemination, number of inseminations per service period (**INS**), nonreturn rate (**NR**) at 56 and 90 d, success of first inseminations (**SF**), and conception rate. Interval from first to last insemination and DFS also depend on the dairy producer's decision and farm management. Conception rate, NR, and SF are threshold traits and require a specific methodology to estimate variance components (Moreno et al., 1997). The INS is a direct fertility measurement. It can be treated as a continuous trait and has a clear economic interpretation. In this way, FCOST are properly calculated, as costs can be quantified for doses of semen, veterinary fees, hormonal treatments, and opportunity costs caused by delayed income from milk and calf sales in cows with poor fertility. However, this trait requires proper AI records, and it is not always available in each dairy cattle population.

The purpose of this study was to predict FCOST in dairy cattle by INS level and derive a profit equation. Other aims were to estimate the economic value of fertility traits and to calculate profit per cow according to reproductive ability.

MATERIALS AND METHODS

Data

Milk yield data from 1988 to September 2003 and insemination records from 1986 to December 2001 were provided by the regional Holstein Associations from the Basque and Navarra Spanish Autonomous Regions. Only cows with both milk and reproductive records were introduced in the data set. A minimum of 100 DIM and 1000 kg of milk yield per lactation were required. Gestation period was considered to be 282 d. Restrictions and rules for validation were required to assure the quality of reproductive data.

Rules for validating insemination information traits. The following editing rules were considered:

- Natural services, embryo transfers, and AI during the gestation period were omitted.

- Artificial inseminations before 1987 were eliminated to avoid errors at the beginning of the reproductive recording scheme.
- Because gestation diagnosis was recorded in each insemination, SF was defined as '1' if the result of the first insemination was positive (gestation) and '0' otherwise.
- If the successful insemination date was within 56 d (90 d) after the first insemination, NR56 (NR90) was defined as '1'. Otherwise, NR56 (NR90) was defined as '0'. If there was no positive diagnostic, NR56 (NR90) was defined as '0'.
- Days from calving to first insemination date were recorded as DFS. Lactations were omitted if DFS was <25 d, >160 d, or unknown.
- The INS was recorded as the number of AI from d 25 to 330 after calving. If there was no AI during that period, INS was considered as a missing value.
- Herds with a lower average than 1.5 INS per cow or higher than 3.5 INS per cow were eliminated.
- Days from calving to successful AI date were recorded as DO. This trait was a missing value when positive gestation diagnostic was not registered. Records with DO >330 d were eliminated.
- Interval from first to last insemination was recorded as days from first to successful insemination date. If positive gestation was not recorded, it was a missing value.
- Successive calving dates had to range from 300 to 600 d. If the following calving date was not available, CI was considered a missing value. Otherwise, lactation and insemination records were not considered.
- First calving before 18 mo or after 40 mo of age was not registered.

The INS was analyzed. Records with >7 INS were omitted. At least 5 records per contemporary group were required in statistical analysis (Ugarte et al., 1992). After merging and editing both data sets, a total of 120,713 lactations and 225,085 insemination records of 63,160 lactating cows were analyzed.

Economic data from year 1999 used in this study were provided by NEIKER (the Basque Institute for Agricultural Research). Average fixed cost (including labor, veterinary, and housing costs) and prices of milk, calf, feed, doses of semen, hormonal treatments, and veterinary fees in the Basque Autonomous Region were used (Table 1). Navarra is an Autonomous Region close to the Basque Region with similar economic and management circumstances.

Phenotypic Trend

Phenotypic trends from years 1988 to 2001 were estimated for productive and fertility traits. Traits ana-

Table 1. Price (in US dollars) of kg of milk (MP), seminal dose (SD), first (HD₁) and second (HD₂) hormonal doses, veterinary fees (VET), calf (CP), cow fixed cost (FXC), heifer fixed cost (FXCh), heifer fertility cost (FERTh), energetic feed unit (pUFL), heifer feed cost (FCh), and salvage value (SV); PV is percentage of herds that use veterinary service to inseminate cows, and hm and cm are heifer and cow mortality, respectively. Interest rate = *i*.

	US dollars (\$)	%
MP	0.30	...
SD	18.15	...
HD ₁	7.26	...
HD ₂	14.52	...
VET	15.13	...
CP	206.06	...
FXC	715.74	...
FXCh	361.95	...
FERTh	33.13	...
pUFL ¹	0.17	...
SV	398.24	...
FCh	665.71	...
PV	...	50
hm	...	12
cm	...	7
<i>i</i>	...	3

¹UFL = milk forage unit (Unité Fourragère Lait; INRA, 1978).

lyzed for lactating cows in each year were 305-d adjusted milk yield (**KGM305**) and actual (non-adjusted) milk yield (**KGM**), DIM, CI, dry period (**DP**) (days), DO, AFC, INS, DFS, NR56, NR90, and SF. Herd, parity, and year were included in the model using the GLM procedure, and Bonferroni test was used to contrast means among years (SAS, 1998).

Productive and Fertility Traits According to INS

Yield and fertility traits categorized by INS from 49,191 lactation records from year 1998 to 2001 were analyzed using a GLM procedure (SAS, 1998). Yield traits were KGM305, KGM, actual fat and protein, DIM, lifetime production, and number of lactations in the herd. Lifetime production and number of lactations in the herd were analyzed by average INS level per lifetime. Also CI and DP were analyzed. Herd year, parity, and INS were included in the model. Mean contrasts for INS were estimated by the Bonferroni method. In this study, no changes caused by variations on DO and other related intervals of the previous lactation were considered in milk yield in current lactation. Only recent years were considered, as the dairy industry has undergone significant changes in management, yield, and reproduction in the last decade.

FCOST

Fertility costs were calculated for each INS level by adding up costs from doses of semen, hormonal treatments, culling because of fertility, and opportunity cost

caused by delayed incomes from milk and calf in the next lactation. Every cost term is expressed in US dollars per year and described subsequently.

Doses of semen cost. This included semen cost and a veterinary fee when non-farm staff performed inseminations:

$$DSC = INS \cdot [SD + PV \cdot VET]$$

where DSC = doses of semen cost, SD = average price of seminal doses, PV = average percentage of herds using veterinary services to inseminate cows, and VET = average veterinary fee for each insemination.

Hormonal treatment cost. Hormonal treatments were applied on cows that had to be inseminated at least 3 times, often in terms of synchronizing estrus or to eliminate a possible corpus luteum, ovarian cysts, and other physiological disorders. No hormonal treatment cost was quantified in the first and second inseminations, but such cost was quantified in the third insemination and successive ones. The cost of the first hormonal treatment was lower than later treatments because the latter were more complex and expensive:

$$HTC = (HD_1 + 2 \cdot VET) + (INS - 3) \cdot [HD_2 + 2 \cdot VET]$$

where HTC = hormonal treatment costs, HD₁ = first hormonal dose cost, HD₂ = second and subsequent doses cost, and VET = veterinary fee.

Culling cost. Culling cost because of fertility was estimated as a percentage of herd replacement cost. An economic term for replacement cost is herd amortization. Culling cost because of fertility in each AI was estimated as:

$$CC = RSK \cdot HA$$

where CC = culling cost; RSK = culling risk because of fertility (in percentage), per INS in current lactation; and HA = herd amortization.

Feed and fixed costs of rearing a heifer, semen cost, and heifer and cow mortality were taken into account to calculate herd amortization:

$$HA = \frac{1}{LH \cdot \frac{CI}{365}} \cdot \frac{1}{1 - hm} \cdot (FCh + FERTh + FXCh) - SV \cdot \left(\frac{1}{LH \cdot \frac{CI}{365}} - cm \right)$$

where HA = herd amortization, LH = number of lactations in herd, FCh = heifer feed costs, FERTh = heifer

reproduction cost, FXCh = heifer fixed costs, SV = salvage value, and hm and cm = heifer and cow mortality, respectively. Those costs were calculated following Pérez-Cabal and Alenda (2003) procedure.

The fertility culling risk (percentage) had to be estimated per INS level and lactation because the reasons for culling were not available in the data records. For this purpose, total culling percentage in current lactation by INS level was calculated. A cow was considered culled in the current lactation with n INS if it did not have a following lactation record after a period of 3 yr. It was assumed that the values obtained for culling with 1, 2, and 3 INS in first lactation and with 1 and 2 INS in second lactation were not due to fertility, but to other reasons. An average value was calculated for this assumed nonreproductive culling. Culling risk by INS level and current lactation was estimated as the difference between total culling percentage (for each lactation and INS level) and the assumed nonreproductive culling.

An equation for culling risk was regressed from INS and current lactation using the GLM procedure (SAS, 1998). Zero risk was assumed when the regression value was negative.

Milk opportunity cost. This cost measures the income delay attributable to an unsuccessful first insemination. The CI is longer when first AI fails and the cow needs to be inseminated again. In this case, an income delay from next lactation is expected. This cost was calculated as follows:

$$MOC = \Delta MY \cdot PrM \cdot \frac{i}{12} \cdot n$$

where MOC = milk opportunity cost, ΔMY = difference between yield obtained if first insemination would have been successful and yield obtained when lactation is lengthened because of increasing INS (no change in milk production at following lactation was assumed), PrM = total milk price (including bonuses for fat and protein), i = interest rate, and n = time in months that a cow takes to get pregnant after the first insemination (a luteal cycle length of 21 d was considered).

Calf opportunity cost. A wider CI because of an unsuccessful first AI delays the income from calf sales. This cost can be expressed as follows:

$$COC = PrC \cdot \frac{i}{12} \cdot n$$

where COC = calf opportunity cost, PrC = calf price, and i and n = interest rate and time, respectively, as described for milk opportunity cost.

Total FCOST. The total FCOST is the sum of the 5 terms just described:

$$FCOST = DSC + HTC + CC + MOC + COC.$$

Records were obtained from 12,486 cows calving in 2001 to calculate FCOST for up to 7 INS. The FCOST was calculated relating to INS level (up to 7 INS). An equation was adjusted for FCOST from linear and quadratic INS level using the GLM procedure (SAS, 1998).

Profit Equation

The adjusted equation of FCOST was included in a bioeconomic model to calculate profit and derive economic values. A profit equation was estimated using productive and economic circumstances of an average cow calving in year 2001 to estimate economic values of fertility traits. A total of 12,486 lactation records were considered from that year.

Fertility cost and the economic concept of amortization were added to the model developed by Pérez-Cabal and Alenda (2003). Actual lactation yield was used instead of KGM305. Milk yield and costs were expressed per year by dividing by CI. Profit (PROF) per cow per year can be described by the following equation: $PROF = R - C$, where R = average revenues during a year per cow and C = average costs during a year per cow.

$$R = [KGM \cdot MP + (1 - CM) \cdot CP] \cdot \frac{365}{CI}$$

$$C = FCC + FCOST + FXC + (1 - RSK) \cdot HA$$

where MP = milk price including bonus and penalties, CM = calf mortality, CP = calf price, FCC = cow feed cost, FXC = fixed costs per animal, and HA = herd amortization when fertility culling is not considered (to avoid double-counting fertility culling cost).

Because yield, costs, and the number of lactations in herd varied by INS level, profit was calculated taking into account those circumstances.

Fertility economic value. The economic value of trait χ (EV_χ) was calculated by deriving the profit function with respect to trait χ (Groen, 1989b; Pieters et al., 1997).

$$EV_\chi = \frac{\delta R}{\delta \chi} - \frac{\delta C}{\delta \chi}.$$

For traits involved in a quota system (KGM, fat, and protein), the procedure used was

$$EV_\chi = \frac{\delta R}{\delta \chi} - \frac{\delta C}{\delta \chi} + \frac{1}{N}(R - C) \frac{\delta N}{\delta \chi}$$

Table 2. Mean and standard deviation for 305-d adjusted (KGM305) and actual (nonadjusted) milk yield (KGM), fat, protein, days in milk (DIM), cumulated lifetime milk production (LP), number of lactations in herd (LH), calving interval (CI), dry period (DP), days open (DO), age at first calving (AFC), days to first insemination (DFS), number of inseminations per service period (INS), nonreturn rate at 56 d (NR56) and 90 d (NR90), and percentage of success at first insemination (SF) from 1988 to 2001 and from 1998 to 2001. N = number of records.

	1988–2001			1998–2001		
	N	Mean	SD	N	Mean	SD
KGM305	116,518	7715	2056	47,909	8564	1942
KGM	120,662	8231	2617	49,191	9283	2619
Fat (kg)	120,479	308	100	48,994	345	99
Protein (kg)	120,687	258	86	49,169	294	84
DIM	120,636	326	59.7	49,191	334	62.0
LP (kg)	13,664	19,845	12,901	8463	19,487	11,661
LH	13,664	2.2	1.4	8463	2.0	1.1
CI (d)	96,346	400	60.0	30,523	389	61.6
DP (d)	89,707	79	32.4	29,738	74	27.9
DO (d)	113,375	117	57.1	46,088	121	59.8
AFC (d)	52,108	854	106.4	20,681	848	104.9
DFS (d)	120,713	81	27.7	49,191	80	27.9
INS	113,375	1.87	1.18	46,088	1.96	1.24
NR56 (%)	120,713	70	0.13 ¹	49,191	66	0.21 ¹
NR90 (%)	120,713	80	0.12 ¹	49,191	77	0.20 ¹
SF (%)	120,713	48	0.14 ¹	49,191	45	0.22 ¹

¹These values are mean standard errors instead of standard deviations because threshold traits are recorded only as 0 or 1.

where R and C = average annual revenues and costs per cow, respectively, and N = number of lactating cows.

RESULTS AND DISCUSSION

Phenotypic Trend

Table 2 shows mean and standard deviations for analyzed traits in terms of both periods (1988 to 2001 and 1998 to 2001). Only 40% of milk yield records had reproductive information. Trends in yield and fertility traits from 1988 to 2001 are shown in Table 3. The number of DIM increased about 1 mo, and milk yield increased >3500 kg per lactation in both adjusted and actual lactations. Fertility traits have been deteriorated. More INS were needed, leading to greater CI and DO (by about 20 d). Indicators of AI success (NR56, NR90, and SF) were reduced >10% from 1988 to 2001. Trends for DFS and DP were different. Days to first service remained constant, and DP was reduced from 84 d in year 1988 to an average of 69 d in recent years, probably because of improved management.

Differences between years were significant for every trait (Table 3). Two periods could be differentiated for almost all fertility traits, before year 1993 and after 1995. Fertility began to be adversely affected from 1995, during the highest increase in milk yield per year. An increase in milk production and a decrease in fertility traits occurred by year 1994. There was a considerable increase in number of records and herds that could have influenced the phenotypic trend. Differences in AFC

did not follow any trend, suggesting that fertility in heifers did not deteriorate.

Those results agree with other studies where there was an increase of yield traits and a worsening of reproductive ability (Thaller, 1997; Veerkamp et al., 2001; Brotherstone et al., 2002), suggesting that fertility deterioration has led to larger DIM.

Productive and Fertility Traits by INS Level

The least square means for productive and fertility traits by INS level are shown in Table 4. The KGM305 was significantly higher as more INS were required. Significant differences were found for KGM305, KGM, fat, and protein yield in actual lactation, DIM, CI, and DP. Cows that needed more INS had higher yields but also longer CI and DP.

When an average of 2 INS per lifetime were needed, lifetime production was 23,341 kg in 3.1 lactations. One-half of that lifetime production and number of lactations was obtained when 7 INS were required. Cows that required >2 INS had higher milk yield per lactation, but lower lifetime production.

Cows that had an average of one INS per productive life had fewer lactations (2.5 lactations) than expected. This is, probably, not due to poor fertility but to voluntary culling because of lower yield. The lifetime production of those cows was the same as cows that needed an average of 5 INS. Lifetime production for cows with an average of one INS per lifetime was much lower

Table 3. Phenotypic means from 1988 to 2001 for 305-d adjusted (KGM305) and actual (nonadjusted) milk yield (KGM), days in milk (DIM), calving interval (CI), dry period (DP), days open (DO), age at first calving (AFC), number of inseminations per service period (INS), days to first insemination (DFS), nonreturn rate at 56 d (NR56) and 90 d (NR90), and percentage of success at first insemination (SF). N = number of records.

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
N	3355	4072	4156	3938	4581	4563	7322	9146	10,672	11,462	11,741	14,760	10,204	12,486
KGM305	5422 ^k	5774 ^j	6073 ⁱ	6257 ^h	6343 ^h	6631 ^g	7080 ^f	7620 ^e	7871 ^d	7945 ^d	8320 ^c	8432 ^c	8575 ^b	8942 ^a
KGM	5583 ^j	5935 ⁱ	6245 ^h	6491 ^g	6624 ^g	6947 ^f	7549 ^e	8225 ^d	8436 ^c	8515 ^c	9041 ^b	9092 ^b	9173 ^b	9827 ^a
DIM	309 ^{gh}	308 ⁱ	309 ^{gh}	313 ^{fg}	318 ^{ef}	319 ^e	326 ^d	332 ^{cd}	329 ^{de}	327 ^{de}	337 ^{ab}	331 ^c	327 ^{de}	340 ^a
CI (d)	393 ^{de}	390 ^e	391 ^{de}	396 ^{de}	398 ^{bc}	398 ^{bc}	402 ^{ab}	406 ^a	399 ^{bc}	404 ^{ab}	403 ^{ab}	398 ^{bc}	404 ^{ab}	405 ^a
DP (d)	84 ^a	82 ^{ab}	82 ^a	83 ^a	80 ^{bc}	79 ^b	76 ^c	74 ^{cd}	68 ^{cde}	77 ^{cd}	66 ^e	67 ^e	77 ^{de}	65 ^{de}
DO (d)	106 ^h	105 ^h	106 ^h	111 ^f	113 ^{ef}	113 ^{ef}	118 ^{bde}	121 ^{abc}	119 ^{bd}	116 ^{cdef}	124 ^a	120 ^{abc}	118 ^{bde}	122 ^{ab}
AFC (d)	857 ^{bed}	847 ^{cde}	852 ^{cde}	850 ^{cde}	860 ^{abc}	860 ^{abc}	863 ^{ab}	869 ^a	860 ^{bc}	852 ^{bde}	855 ^{bde}	848 ^{cde}	843 ^e	846 ^{de}
INS	1.7 ^{fg}	1.7 ^g	1.6 ^g	1.8 ^{ef}	1.8 ^{ef}	1.8 ^{ef}	1.9 ^{de}	1.9 ^{abcd}	1.9 ^{bd}	1.9 ^{dc}	2.0 ^{ab}	2.0 ^{abc}	1.9 ^{bcd}	2.0 ^a
DFS (d)	79 ^{ef}	78 ^f	80 ^{cdef}	81 ^{abc}	82 ^{ab}	82 ^{ab}	83 ^a	83 ^a	83 ^a	80 ^{bde}	81 ^{abcd}	80 ^{cdef}	78 ^{ef}	80 ^{cdef}
NR56 (%)	78 ^{abc}	79 ^{abc}	80 ^a	76 ^{bc}	77 ^{bc}	76 ^c	73 ^d	70 ^{de}	71 ^{de}	71 ^{de}	62 ^f	70 ^e	71 ^{de}	61 ^f
NR90 (%)	87 ^a	87 ^a	88 ^a	86 ^a	87 ^a	86 ^a	83 ^b	81 ^{bc}	82 ^{bc}	81 ^c	73 ^d	81 ^{bc}	81 ^{bc}	73 ^d
SF (%)	56 ^{abc}	56 ^{ab}	57 ^a	54 ^{bcd}	52 ^{de}	53 ^{cd}	51 ^{def}	48 ^f	49 ^f	49 ^f	42 ^g	48 ^f	50 ^{ef}	40 ^g

^{a,b,c,d,e,f,g,h,i,j,k}Means within trait with different superscripts differ ($P < 0.05$).

than cows with an average of 2 INS because of shorter productive life and lower milk yield per lactation. One cow with an average of 2 INS per lifetime could have a lactation with 3 INS. As Table 4 shows, actual KGM was higher as more INS were required because of an increase in DIM.

FCOST

The average cow calving in 2001 produced for 3.13 lactations, yielding an average of 9827 kg of milk in 340 DIM with 3.7 and 3.2% fat and protein, respectively, per lactation. Calving interval was 405 d with a DP of 65 d; an average of 2.0 INS were needed (Table 3).

Culling cost. The average herd amortization for an average cow calving in 2001 was \$262/yr (US dollars). Table 5 shows percentage of total culling according to INS per lactation and expected culling risk because of fertility. From those data, estimated fertility culling risk (RSK) per INS and current lactation (L) was estimated with a coefficient of determination (R^2) of 0.94 as: $RSK = -23.21 + 2.86 \cdot INS + 12.08 \cdot L$.

The estimated fertility culling risk increased for older cows and increasing INS. Young cows were inseminated more times before culling. Bascom and Young (1998) reported that 20% of total culling was due to reproduction, which was given as the first reason for culling. Usually, there are multiple reasons for culling. In most cases, production, fertility, health, temperament, and other disorders are involved. A 12.4% average culling because of fertility as single cause was estimated in this report to obtain direct economic values for fertility traits.

The methodology described for estimating culling because of fertility was indirect, but excluding fertility culling from FCOST would have been inappropriate.

Total FCOST. Table 6 shows different partial costs involved in FCOST, FCOST, and profit per cow per year by INS level. Fertility costs increased as more INS were needed. Cost of semen was always more than one-third of total FCOST. Fertility culling cost was proportionally less important as a component of total cost as more INS were needed; this was attributed to cost of semen and mostly because the hormonal treatment costs were higher. Fertility culling cost was quantified with one INS because an estimated fertility culling risk exists in the second and subsequent lactations. Milk and calf opportunity costs were always <3% of total FCOST. Because of low beef prices in later years, the calf opportunity cost might not be important in economic studies related to fertility (Sorensen and Ostergaard, 2003). Milk opportunity cost is also non-determinant in FCOST.

Table 4. Least square means according to INS (number of inseminations per service period) level for 305-d adjusted (KGM305) and actual (nonadjusted) milk yield (KGM), fat and protein per actual lactation, days in milk (DIM), calving interval (CI), days of dry period (DP), number of lactations in herd (LH), and cumulated lifetime milk production (LP; in kg). N = number of records. Data period was from 1998 to 2001.

INS	N	KGM305	KGM	Fat	Protein	DIM	CI	DP	LH ¹	LP ¹
1	22,133	8324 ^e	8978 ^f	331 ^f	285 ^g	305 ^f	364 ^g	59 ^d	2.5 ^{ab}	16,477 ^{cd}
2	12,346	8666 ^d	9827 ^e	364 ^e	314 ^f	340 ^e	406 ^f	66 ^{cd}	3.1 ^a	23,341 ^a
3	6207	8842 ^c	10,600 ^d	393 ^d	340 ^e	373 ^d	445 ^e	72 ^c	2.8 ^{ab}	22,439 ^{ab}
4	3154	8945 ^c	11,240 ^c	419 ^c	363 ^d	399 ^c	480 ^d	81 ^b	2.3 ^{bc}	18,714 ^{bc}
5	1399	9151 ^b	11,904 ^b	446 ^b	384 ^c	420 ^b	507 ^c	87 ^{ab}	2.1 ^{bc}	17,296 ^{cd}
6	561	9125 ^b	12,151 ^b	453 ^b	395 ^b	432 ^b	526 ^b	94 ^a	1.7 ^c	13,882 ^{de}
7	213	9298 ^a	12,675 ^a	475 ^a	413 ^a	451 ^a	553 ^a	102 ^a	1.6 ^c	12,664 ^e

a,b,c,d,e,f,g Means within each trait with different superscripts differ ($P < 0.05$).

¹LH and LP were calculated by average INS level per lifetime; remaining traits were calculated by INS per lactation.

FCOST function. A significant ($P < 0.05$) quadratic relationship between FCOST and INS was found with an R^2 of 0.99:

$$FCOST = -18.08 + 41.11 \cdot INS + 1.91 \cdot INS^2.$$

A quadratic increase in FCOST was estimated as more INS were applied. Fertility cost of 6 INS were 233% higher than 3 INS (Table 6).

Profit by INS Level

Cows that became pregnant at first or second AI had similar profitability (by \$774/yr [US dollars]). Cows that became pregnant after 2 INS yielded more milk (by 1000 kg) than those with one INS, but the former had longer CI and higher costs. Increasing INS decreased profit (Table 6), even with higher yield. Increasing INS from 2 to 3 reduced profitability by >\$97/yr (US dollars). More than 3 INS led to a loss of >\$210/yr per cow (US dollars). High yielding cows had higher costs and lower profit because of poorer reproduction ability, larger CI

and DP, higher culling risk, and lower lifetime production (Tables 4 and 6). From the point of view of management, health, and feeding, cows with higher milking yield are more complex; therefore, keeping cows that require >3 INS would be questionable. Vargas et al. (2002) reported positive profit by improving fertility in a dairy cattle population in Costa Rica.

Fertility economic value. Economic values for productive and reproductive traits and mature BW are shown in Table 7. An increase of one unit in INS would reduce profitability by −\$67.32/yr per cow (US dollars). Other researchers report lower economic values for conception rate (Boichard, 1990; Sölkner and Fuerst, 2002; Vargas et al., 2002), probably because some of the described FCOST were not considered.

Enlarging CI by 1 d reduced profitability by −\$4.90/yr per cow (US dollars). Similar values have been found in other studies (Price et al., 1999; Kadarmideen and Simm, 2002). Lower values were estimated for service period length and calving to first insemination interval by Pedersen and Jensen (1996).

Table 5. Percentage of total culled cows (Tcull) and expected culling risk because of fertility (Rsk Cull) according to number of insemination per service period (INS) and lactation. N = number of records.

INS	N	First lactation		Second lactation		Third lactation		Fourth and subsequent lactations				
		Tcull (%)	Rsk Cull ¹ (%)	Tcull (%)	Rsk Cull (%)	Tcull (%)	Rsk Cull (%)	N	Tcull (%)	Rsk Cull (%)	Tcull (%)	Rsk Cull (%)
1	10,792	11	0	6991	22	0	3729	31	14	2658	47	30
2	5097	12	0	3785	22	0	2135	32	15	1532	48	31
3	2356	15	0	1807	26	9	1073	39	22	797	48	30
4	1044	19	2	885	27	10	488	39	22	393	56	39
5	452	20	3	396	28	11	245	47	29	189	58	41
6	179	20	3	171	35	18	110	46	29	81	67	50

¹Rsk Cull (%) = Tcull (%) − μ . Rsk Cull was considered zero (nonreproductive culling) for 1, 2, and 3 INS in first lactation and for 1 and 2 INS in second lactation. μ = total culling percentage for 1, 2, and 3 INS in first lactation and for 1 and 2 INS in second lactation (17%). It is assumed as nonreproductive culling.

Table 6. Doses of semen cost (DSC), hormonal treatment cost (HTC), culling cost (CC), milk opportunity cost (MOC), calf opportunity cost (COC), total fertility cost (FCOST), and profit (PROF) in US dollars per year per average calving cow in 2001 by INS (number of inseminations per service period) level.

INS	DSC	HTC	CC	MOC	COC	FCOST	PROF
1	\$23.11	\$0.00	\$18.25	\$0.00	\$0.00	\$41	\$770
2	\$46.23	\$0.00	\$27.35	\$0.22	\$0.31	\$74	\$779
3	\$69.35	\$33.72	\$36.45	\$0.87	\$0.64	\$142	\$681
4	\$92.47	\$73.97	\$45.54	\$2.21	\$0.96	\$215	\$569
5	\$115.58	\$114.22	\$54.64	\$4.43	\$1.27	\$290	\$503
6	\$138.70	\$154.47	\$63.74	\$7.19	\$1.60	\$365	\$363
7	\$161.81	\$194.71	\$72.84	\$10.61	\$1.91	\$442	\$288

When CI was considered as the sum of DIM and DP, the economic value for DIM was positive (\$1.19/yr per cow [US dollars]). However, economic value for DP was exactly the same as for CI (−\$4.90/yr per cow [US dollars]). Dry period and CI had the same economic weight, as the profit equation assumed a constant DIM when enlarging CI. Therefore, DP increased along with CI. Calving interval is not an accurate fertility measure because it does not differentiate between higher profitability caused by enlarging DIM or lower profit from increasing DP. When ≥ 4 INS are needed, DP increases significantly leading to a significant decrease in profitability. Calving interval can also be enlarged voluntarily for management purposes. However, results in this study show that DFS did not change significantly in the last decade, probably because dairy producers do not desire a late conception and begin to inseminate about 80 d after calving.

Remaining economic values are similar to those obtained by Pérez-Cabal and Alenda (2003); protein was

the most important yield trait with an economic value of \$4.04/yr per cow (US dollars). Increasing productive life by 1 d increased profitability by \$0.22 (US dollars). Negative economic values were found for mature BW and AFC (−\$0.67 and −\$0.28 US dollars, respectively).

The economic importance of fertility traits per unit of phenotypic standard deviation (from lactating cows since 1998 to 2001) relative to protein was moderate (24%) to high (64%) for INS and CI, respectively (Table 7). The economic importance of CI was 49, 64, and 89% considering CI records from 300 to 450 d, 300 to 500 d, and 300 to 600 d, respectively. The CI economic importance was highly influenced by data editing. Importance for the remaining traits was low (8 and 22% for AFC and DIM, respectively) to moderate (35 and 40% for productive life and DP, respectively).

CONCLUSIONS

Fertility cost was included in the profit equation developed by Pérez-Cabal and Alenda (2003). The economic aspect of fertility was properly described by INS. Doses of semen, hormonal treatment, and culling costs in cows with poor fertility lead to lower lifetime production, shorter productive life, and lower profit.

The economic analysis in this study demonstrates the usefulness of considering INS as the main fertility trait when these data are available, because it allows proper calculation of FCOST. This trait has a significant economic value (24%) relative to protein. To evaluate female fertility, it is essential to have a specific reproductive recording scheme. It is necessary to detect cows that show estrus early in lactation and get pregnant in a short period with a minimum number of inseminations.

If insemination records are not recorded, genetic correlation of CI or DO with INS could be used to develop a selection index. It would be advisable to question whether CI is an appropriate trait to improve fertility, because it is not available until the second lactation and is confounded with management decisions and the profit obtained from enlarging the milking period. How-

Table 7. Economic values and economic importance relative to protein for actual kilograms of milk, fat, and protein (PROT); productive life (THL); mature BW; age at first calving (AFC); number of inseminations per service period (INS); calving interval (CI); DIM; and dry period (DP).

	Economic value	
	(\$/yr per cow)	(\$/yr per cow)/ SD unit ¹
Milk (kg)	\$0.13	\$0.95
Fat (kg)	\$1.02	\$0.30
PROT (kg)	\$4.04	\$1.00
THL (days)	\$0.22	\$0.35
BW (kg)	−\$0.67	\$0.10
AFC (d)	−\$0.28	\$0.08
INS	−\$67.32	\$0.24
CI (d)	−\$4.90	\$0.64 ²
DIM	\$1.19	\$0.22
DP (d)	−\$4.90	\$0.40

¹Economic value per phenotypic standard deviation unit (from lactating cows from 1998 to 2001) relative to actual protein.

²Corresponding standard deviation was calculated considering 300 < CI < 500. An economic value per SD of 49 and 89% would have been estimated considering 300 < CI < 450 and 300 < CI < 600, respectively.

ever, this trait is available in milk recordings of all dairy populations; therefore, genetic evaluations for this fertility trait would be more accurate.

Because milk yield selection has been accompanied by deteriorated fertility in Spanish dairy cattle (as in other populations), it would be recommended that genetic variance components be estimated. Selection indexes that include fertility traits can be obtained based on the economic values of this study and estimating fertility traits genetic variance and covariance matrices. Traits from milk recording schemes (such as CI or DO) could be included in the selection index by relating them to economic value of INS, as INS is a direct measure of female fertility and is directly related to FCOST.

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