International Genetic Evaluation for female fertility traits

Hossein Jorjani [1,2]
[1]Interbull Centre, [2]Department of Animal Breeding and Genetics,
Swedish University of Agricultural Sciences,
Box 7023, S-750 07 Uppsala, Sweden
Hossein.Jorjani@hgen.slu.se

Abstract

Implementation of the method known as Multiple Trait Multiple Across Country Evaluation (MT-MACE) encountered an unexpected hurdle in the form of low genetic correlations in the bended correlation matrix of the 28x28 submitted traits. Consequently, it is recommended that ST-MACE to be used in the meantime so that the international genetic evaluation for female fertility traits can be started.

Introduction

Interbull pilot study for genetic evaluation of female fertility traits, which started in fall 2004, was based on the simple idea that female fertility is biologically so complex that no single measurement could reflect its entire complexity. This simple idea stems from the fact that the female animal (maiden heifer or cow) must go through a number of stages in every reproductive cycle. One way of classifying different stages of the reproductive cycle is as follows (for a different classification of the reproductive cycle see Van Doormaal *et al.,* 2004):

For maiden heifer: Demonstrating maturity and consequently heat; Conceiving after insemination(s); Carrying the calf to the term; For cow: Resisting fertility disorders after calving; Demonstrating heat after calving; Conceiving after insemination(s); Carrying the calf to the term; Repeating the cow cycle.

The biological complexity of female fertility (as shown above) can be summarized in five different abilities: a) Ability to show maturity/heat; b) Ability to conceive; c) Ability to carry on to the term; d) Ability to resist fertility disorders; and e) Ability to re-cycle.

One complicating factor that forces us to consider traits related to maiden heifers and cows separately is the moderate correlation between the same measurements in maiden heifers and cows. For example, Roxström *et al.* (2001) reported a genetic correlation of about 0.7 for the same measurements in maiden heifer and cow.

Among the five abilities mentioned above it was deemed that there are very few countries with data on the onset of maturity in maiden heifers and heat in maiden heifers and cows. Further, it was deemed that the abilities to carry on to the term and resisting fertility disorders are, at least partially, covered by the Interbull international genetic evaluations for calving ease and stillbirth. Therefore it was decided to concentrate on the (b) and (e) above, i.e. the ability to conceive and the ability to recycle. Measurements used in different countries may pertain to only one of these abilities or to both. For example, conception rate (CR) or number of inseminations (NI) are mostly related to the ability to conceive, while days open (DO) or calving interval (CI) combine these two abilities. Therefore, considering the two sorts of animals (maiden heifer and cow) and the two abilities (to conceive and to re-cycle) any individual country may have several measurements for female fertility. Given the low heritability values for fertility traits and the moderate correlations among measurements of each country, it seems prudent to consider the information from several measurements of each country simultaneously.

The method of evaluation used in Interbull international genetic evaluation (Interbull, 2006) is based on Schaeffer's (1994) the so-called Multiple Across Country Evaluation

(MACE) in which different national genetic evaluations from different countries are considered to be different traits. However, because the residual correlations among the traits are assumed to be zero, only one trait per country can be handled in the model. Therefore, Schaffer's 1994 method has also been known as Single Trait MACE (ST-MACE). Later, Schaeffer (2001; see also Sullivan *et al.,* 2005) introduced a new method which was capable of handling within country residual correlations and hence capable of inclusion of more than one trait from each country. This new method is commonly known as Multiple Trait MACE (MT-MACE).

Based on the arguments presented above, the aim of the Interbull pilot study for international genetic evaluation of female fertility traits was to implement the MT-MACE methodology for analysis of these traits.

Material and method

Input data were the results of national genetic evaluations (estimated breeding value (EBV) or predicted transmitting ability (PTA)) submitted by 11 evaluation centers with data from 14 countries. Trait definitions are shown in Table 1.

ST-MACE correlations

Simultaneous estimation of all correlations among the 28 submitted traits is computationally prohibitive. Therefore, country sub-setting of the data, as usually practiced in Interbull evaluations was employed. In the beginning one trait from each country was included in each analysis until the 11-variate combinations were almost exhausted. Then, the countries with only one submitted trait were set aside and 7-variate combinations including one trait from each of the remaining seven countries were used. When the 7-variate combinations were almost exhausted, 5-variate combinations were used until the minimum number of correlation estimates for any country/trait combination reached a minimum of 10 estimates. By doing so, for each country/trait combination between 10 and 55 separate and unique estimates were available. Bert Klei's MACE computer program package was used for estimation of across country genetic correlations.

MT-MACE correlations

There were seven countries with multiple traits submitted for the Interbull pilot study. However, country reported parameters from CAN, Nordic countries (DFS), IRL and ISR indicated that all or parts of residual correlations were either zero or almost equivalent to the convergence criteria for estimation of correlations (i.e. 10^{-6}). Therefore, it was deemed that only country traits with a residual correlation larger than 10^{-3} need to be handled simultaneously. Consequently, national de-regressed proof files from 11-variate country/trait combinations including up to three traits from each country were used in order to take care of non-zero residual correlations and consequently, to estimate across country/trait genetic correlations.

Bending of non-positive definite correlation matrices

Because MACE correlations were estimated in sub-sets and accumulated in a 28x28 matrix, there was a need to bend them. For this purpose the two methods of un-weighted and weighted bending (Jorjani *et al.,* 2003) were used. Number of common bulls (Table 2) was used as the weighting factor.

Result and discussions

Obviously, ST-MACE correlations could not be estimated for within country traits because non-zero residual correlations would have been ignored under this methodology. Across country ST-MACE correlations were generally positive and moderate to high, which indicated the feasibility of international genetic evaluations for fertility traits. However, again there were a relatively large number of near zero and negative correlations. Given the trait definitions and nature of submitted measurements, presence of near zero or negative correlations came as no surprise.

Estimation of across country correlations with ST-MACE methodology is a time honored practice and there is no doubt in their usefulness. However, this was the first time that this methodology was used to estimate genetic correlations for such a diversely defined group of traits with such a wide range of genetic correlations. A common observation after application of ST-MACE methodology is small fluctuations of estimated genetic correlations depending on the data sub-setting. This phenomenon had been preciously observed under both country sub-setting and bull sub-setting (see for example Jorjani *et al.,* 2005). In previous applications the fluctuations in correlations were rather negligible compared to the size of estimated correlations. In contrast, in the present study, the fluctuations could be as large as the size of the genetic correlation itself. One example pertains to the correlation between conception rate (CR) from FRA and calving to first insemination interval (CF) from CAN, both of which are legitimate fertility traits. Ten estimated correlations for this trait combination are -0.0408, -0.0462, -0.1002, -0.0217, 0.0555, -0.0343, -0.1001, -0.0384, -0.1038, 0.1390. It is evident that the fluctuations are at the same size as the estimated correlations and as the result the average of these 10 correlations is very close to zero. Another type of fluctuation indicated that the genetic correlations between two traits (e.g. daughter fertility from CAN and body condition score (CS) from IRE), may fluctuate between small positive and negative values depending on the presence or absence of other traits/countries in the analysis. These kinds of fluctuations were very pronounced in the MT-MACE estimated genetic correlations, which makes them very unreliable.

It is not clear why fluctuations are so large. At least three speculations come to mind. First, changes are the result of the REML procedure forcing the correlation matrix to be positive-definite. Second, there is a partial and/or semi-partial correlation among the traits that leads to the fluctuations. Third, these fluctuations are within the range of standard errors for the estimates and are nothing to be worried about. In any case, there are two consequences for the estimated correlations. The first consequence is that the number of near zero and negative correlations using MT-MACE are larger than using ST-MACE. The second consequence is concerned with the bending of the resulting correlation matrix.

Bending process can be compared to a process of regressing all elements of a correlation matrix towards the mean of all elements. If the correlation matrix contains a mixture of positive and negative correlations and there are also a large number of near zero elements, then naturally a lot of correlations will get smaller after bending. One way of summarizing the results of bending for the 378 trait/country combinations in a 28x28 correlation matrix is shown in Table 4 in which the average of correlations (or average of absolute value of correlations) between each trait and the other traits are shown for unweighted and weighted bending. First point to notice is that the averages of correlations are low (between 0.02 for age at first insemination from CAN, and 0.61 for conception rate from ISR). The second point to notice is the general reduction of correlations, especially after weighted bending. In all cases the resulting positive-definite matrix contained so many low correlations that it would have been meaningless to use them for estimation of international breeding values.

Conclusions

Logistically it is feasible to use MT-MACE methodology. However, unless all correlations among the traits included in the analyses are high and positive, the results would not be well received by researchers and end users. Therefore, it is recommended that for the time being ST-MACE methodology for groups of similarly defined fertility traits to be implemented until the outstanding issues related to the MT-MACE methodology be resolved.

Acknowledgement

I would like to express my gratitude towards my colleagues Thomas Mark, Pete Sullivan, Jette Jakobsen and Freddy Fikse. Even though we still need to wait for implementation of the MT-MACE methodology, however, we have gained a lot of experience from the practice and our discussions on very many miniscule details have pointed us towards many possible solutions for the problems at hand. I also would like to acknowledge the financial support of the Swedish Farmers' Research Fund (SLF).

References

Interbull 2006. www.interbull.org -> Genetic evaluations -> e.g. Production -> e.g. February 2006.

Jorjani, H., Klei, L. & Emanuelson, U. 2003. A simple method for weighted bending of genetic (co-)variance matrices. *J. Dairy Sci. 86,* 677-679.

Jorjani, H., Emanuelson, U. & Fikse, W.F. 2005. Data sub-setting strategies for estimation of across country genetic correlations. *J. Dairy Sci. 88,* 1214-1224.

Schaeffer, L.R. 1994. Multiple-country comparison of dairy sires. *J. Dairy Sci. 77,* 2671-2678.

Schaeffer, L.R. 2001. Multiple trait international bull comparisons. *Livest. Prod. Sci. 69,* 145-153.

Sullivan, P.G., Wilton, J.W., Schaeffer, L.R., Jansen, G.J., Robinson, J.A.B. & Allen, O.B. 2005. Genetic evaluation strategies for multiple traits and countries. *Livest. Prod. Sci. 92,* 195-205.

Van Doormaal, B.J., Kistemaker, G., Fatehi, J., Miglior, F., Jamrozik, J. & Schaeffer, L.R. 2004. Genetic evaluation of female fertility in Canadian dairy breeds. *Interbull Bulletin 32,* 86-89.

Table 1. Submitted traits, their definitions, and their reported heritabilities.

Country / Population	Trait name	Trait definition	h^2
Canada	NR	Non return rate at 56 days at first insemination, heifer	.020
	CF	Days between calving and first insemination, cow	.101
	NR	Non return rate at 56 days at first insemination, cow	.019
	AF	Age at first insemination (days)	.140
	DF	Daughter fertility (=65% NR_{cow} – 10% AF – 25 % CF)	.052
Austria, Germany	NR	Non return 90 days after 1st insemination	.020
Denmark, Finland, Sweden	NI	Number of AI's, heifer	.025
	CF	Days between calving and first insemination, cow	.042
	NI	Number of AI's, cow	.030
	FL	Days between first and last insemination, heifer	.020
	DO	Days open	.031
Spain	DO	Days open	.040
France	CR	Conception rate (success/failure)	.020
Great Britain	NR	Non return rate at 56 days	.018
	CI	Calving interval (days between 1st and 2nd calvings)	.033
	CS	Condition score (1=thin, 9=fat)	.237
Ireland	CI	Calving interval in lactation 1	.040
	CI	Calving interval across lactations (1-3)	.040
	CS	Body condition score	.240
Israel	CP	Percent conception per insemination	.015
	CR	Inverse of the number of inseminations to conception * 100	.020
The Netherlands	CF	Interval calving to first insemination (days)	.083
	NR	Non-return rate 56 days (binary trait)	.015
	CI	Calving interval (days)	.058
New Zealand	PM	PM21: presented for mating in first 21 days of mating period	.047
	CA	CAI: Cow bearing a calf in the herd's AI calving period	.020
	FI	Fertility index	.020
USA	DP	Daughter pregnancy rate (1% DP = 4 days in DO)	.040

Table 2. Number of common bulls (lower diagonals) and ¾ sibs (upper diagonal).

	CAN NR	CAN CF	CAN NR	CAN AF	CAN DF	DEA NR	DFS NI	DFS CF	DFS NI	DFS FL	DFS DO	ESP DO	FRA CR	GBR NR	GBR CI	GBR CS	IRL CI	IRL CI	IRL CS	ISR CP	ISR CR	NLD CF	NLD NR	NLD CI	NZL PM	NZL CA	NZL FI	USA DP
CAN NR	1348					463	230	203	202	230	206	210	309	355	306	268	164	164	163	2	6	251	250	211	213	213	213	626
CAN CF		1902				559	299	268	267	299	272	273	392	450	395	323	202	202	202	3	8	303	303	265	267	267	267	763
CAN NR			1969			573	312	280	279	312	284	286	407	465	410	336	214	214	214	3	8	313	315	276	277	277	277	776
CAN AF				1335		438	208	183	182	208	186	188	283	329	282	247	142	142	141	1	5	232	230	193	193	193	193	601
CAN DF					1936	573	312	280	279	312	284	262	407	465	410	336	214	214	214	3	8	313	315	276	277	277	277	776
DEA NR	171	197	231	133	231	8100	1063	997	997	1064	1008	861	1283	934	829	612	511	509	512	13	39	1264	1293	1192	531	534	534	1660
DFS NI	114	144	171	87	171	320	3627					539	799	645	607	433	390	389	391	9	37	589	611	593	405	408	408	805
DFS CF	88	119	142	66	142	288		3425				467	733	587	548	377	356	355	357	9	37	546	569	554	372	375	375	762
DFS NI	90	122	146	67	146	295			3482			522	735	587	548	377	355	354	356	8	36	546	570	554	371	374	374	762
DFS FL	114	144	171	87	171	321				3739		540	799	646	608	434	392	391	393	10	37	590	612	594	405	408	408	807
DFS DO	89	124	148	66	148	297					3448	524	743	596	557	386	361	360	362	8	36	554	578	562	381	384	384	772
ESP DO	166	219	258	128	237	866	361	284	327	367	328	2299	778	568	566	379	392	375	393	12	35	566	597	542	352	331	355	823
FRA CR	226	288	333	171	333	657	348	305	311	348	314	828	9093	907	830	616	522	521	523	10	38	1032	1058	983	552	555	555	1664
GBR NR	318	403	450	265	450	548	328	285	290	331	293	643	666	3245			682	676	682	12	35	750	768	720	559	562	562	1006
GBR CI	265	342	388	216	388	496	316	272	277	318	280	649	620		2896		626	620	626	12	33	672	687	666	523	526	526	892
GBR CS	204	249	286	161	286	346	231	202	205	232	207	415	399			1626	414	412	414	10	29	533	543	514	390	392	392	631
IRL CI	142	166	204	99	204	369	250	211	216	253	215	436	437	719	660	404	1182			12	29	471	483	465	393	397	397	461
IRL CI	141	165	203	98	203	366	248	209	214	251	213	417	435	713	654	401		1221		12	29	469	481	463	392	396	396	460
IRL CS	141	166	204	98	204	370	250	211	216	253	215	437	437	718	659	405			1041	12	30	474	485	467	393	397	397	461
ISR CP	0	1	1	0	1	10	5	5	5	5	5	8	5	8	8	6	11	11	11	15		12	12	12	13	13	13	6
ISR CR	3	5	5	3	5	32	25	23	23	25	23	29	27	29	28	22	29	29	30		61	42	43	43	38	38	38	42
NLD CF	144	180	207	111	207	693	257	234	234	257	237	504	558	507	459	309	318	317	318	6	22	4698			532	533	533	1085
NLD NR	158	194	228	119	228	805	309	277	280	309	282	614	621	603	546	368	390	388	390	10	33		5043		543	545	545	1097
NLD CI	128	162	192	95	192	727	280	255	257	280	259	518	563	529	492	323	340	339	339	6	26			4597	518	519	519	1018
NZL PM	159	208	243	123	243	308	217	192	195	217	199	315	338	462	435	242	303	301	303	10	34	407	459	423	1718			656
NZL CA	159	208	243	123	243	313	221	196	199	221	203	298	343	474	446	246	312	310	312	10	35	410	465	427		1772		659
NZL FI	159	208	243	123	243	313	221	196	199	221	203	319	343	474	446	246	312	310	312	10	35	410	465	427			1775	659
USA DP	367	508	536	325	536	638	203	209	206	204	211	537	724	663	564	318	254	252	254	3	15	512	536	478	467	469	469	19321

Table 3. Mean correlation estimates.

	CAN NR	CAN CF	CAN NR	CAN AF	CAN DF	DEA NR	DFS NI	DFS CF	DFS NI	DFS FL	DFS DO	ESP DO	FRA CR	GBR NR	GBR CI	GBR CS	IRL CI	IRL CI	IRL CS	ISR CP	ISR CR	NLD CF	NLD NR	NLD CI	NZL PM	NZL CA	NZL FI	USA DP
CAN NR						.91	.67	-.29	.67	.48	.15	.14	.71	.77	-.02	-.44	.22	.17	-.37	.26	.49	-.31	.92	.00	-.04	-.06	-.08	.24
CAN CF						-.34	.14	.94	.23	.44	.79	.72	-.03	.04	.82	.55	.65	.62	.50	.29	.47	.91	-.41	.81	.50	.53	.69	.63
CAN NR						.90	.56	-.34	.78	.37	.14	.10	.75	.74	.00	-.41	.12	.14	-.15	-.04	.53	-.31	.93	.02	-.06	-.02	-.09	.23
CAN AF						.15	-.02	.23	.08	.25	.16	.24	.20	-.50	.16	-.04	.06	.14	-.06	.15	.16	.22	-.36	.24	-.02	-.01	.08	.16
CAN DF						.79	.55	.08	.78	.47	.45	.42	.74	.50	.36	-.07	.36	.35	.03	.10	.55	.09	.76	.37	.19	.25	.23	.51
DEA NR	.91	-.34	.90	.15	.79		.71	-.14	.74	.54	.25	.30	.89	.46	.08	-.28	.34	.35	-.04	.19	.55	-.20	.79	.09	.03	.11	.12	.41
DFS NI	.67	.14	.56	-.02	.55	.71						.37	.54	.55	.30	.09	.26	.32	.02	.42	.47	.10	.66	.34	.31	.30	.23	.40
DFS CF	-.29	.94	-.34	.23	.08	-.14						.81	.15	.19	.88	.54	.73	.73	.53	.12	.56	.97	-.32	.89	.57	.67	.75	.72
DFS NI	.67	.23	.78	.08	.78	.74						.66	.78	.70	.59	.21	.54	.60	.28	-.07	.83	.36	.74	.66	.27	.30	.43	.77
DFS FL	.48	.44	.37	.25	.47	.54						.68	.51	.52	.63	.23	.54	.52	.27	.26	.64	.47	.44	.68	.44	.53	.53	.65
DFS DO	.15	.79	.14	.16	.45	.25						.90	.52	.41	.92	.43	.79	.80	.49	-.01	.75	.87	.13	.93	.54	.61	.72	.91
ESP DO	.14	.72	.10	.24	.42	.30	.37	.81	.66	.68	.90		.59	.38	.90	.28	.82	.83	.37	-.01	.64	.78	.17	.90	.61	.77	.84	.93
FRA CR	.71	-.03	.75	.20	.74	.89	.54	.15	.78	.51	.52	.59		.45	.36	-.17	.59	.61	.02	-.02	.62	.08	.65	.35	.21	.30	.39	.68
GBR NR	.77	.04	.74	-.50	.50	.46	.55	.19	.70	.52	.41	.38	.45				.40	.42	.20	.34	.67	.16	.85	.50	.24	.38	.34	.37
GBR CI	-.02	.82	.00	.16	.36	.08	.30	.88	.59	.63	.92	.90	.36				.88	.85	.50	.03	.77	.87	.01	.96	.65	.78	.83	.85
GBR CS	-.44	.55	-.41	-.04	-.07	-.28	.09	.54	.21	.23	.43	.28	-.17				.33	.38	.91	.05	.41	.56	-.24	.52	.37	.42	.41	.24
IRL CI	.22	.65	.12	.06	.36	.34	.26	.73	.54	.54	.79	.82	.59	.40	.88	.33				.15	.75	.75	.15	.85	.73	.87	.91	.80
IRL CI	.17	.62	.14	.14	.35	.35	.32	.73	.60	.52	.80	.83	.61	.42	.85	.38				-.19	.79	.69	.13	.81	.66	.80	.89	.81
IRL CS	-.37	.50	-.15	-.06	.03	-.04	.02	.53	.28	.27	.49	.37	.02	.20	.50	.91				-.36	.75	.54	-.02	.54	.45	.51	.47	.32
ISR CP	.26	.29	-.04	.15	.10	.19	.42	.12	-.07	.26	-.01	-.01	-.02	.34	.03	.05	.15	-.19	-.36			.18	.10	.09	-.03	-.11	.04	-.01
ISR CR	.49	.47	.53	.16	.55	.55	.47	.56	.83	.64	.75	.64	.62	.67	.77	.41	.75	.79	.75			.60	.62	.82	.40	.54	.64	.70
NLD CF	-.31	.91	-.31	.22	.09	-.20	.10	.97	.36	.47	.87	.78	.08	.16	.87	.56	.75	.69	.54	.18	.60				.64	.72	.79	.70
NLD NR	.92	-.41	.93	-.36	.76	.79	.66	-.32	.74	.44	.13	.17	.65	.85	.01	-.24	.15	.13	-.02	.10	.62				-.08	-.03	-.02	.30
NLD CI	.00	.81	.02	.24	.37	.09	.34	.89	.66	.68	.93	.90	.35	.50	.96	.52	.85	.81	.54	.09	.82				.67	.78	.83	.89
NZL PM	-.04	.50	-.06	-.02	.19	.03	.31	.57	.27	.44	.54	.61	.21	.24	.65	.37	.73	.66	.45	-.03	.40	.64	-.08	.67				.49
NZL CA	-.06	.53	-.02	-.01	.25	.11	.30	.67	.30	.53	.61	.77	.30	.38	.78	.42	.87	.80	.51	-.11	.54	.72	-.03	.78				.62
NZL FI	-.08	.69	-.09	.08	.23	.12	.23	.75	.43	.53	.72	.84	.39	.34	.83	.41	.91	.89	.47	.04	.64	.79	-.02	.83				.73
USA DP	.24	.63	.23	.16	.51	.41	.40	.72	.77	.65	.91	.93	.68	.37	.85	.24	.80	.81	.32	-.01	.70	.70	.30	.89	.49	.62	.73	

Table 4. Mean of correlations and mean of absolute values of correlations before and after unweighted and weighted bendings.

	Unweighted				Weighted			
	Mean Correlation Before bending	Mean Correlation After Bending	Mean of Absolute Value of Correlations Before bending	Mean of Absolute Value of Correlations After Bending	Mean Correlation Before bending	Mean Correlation After Bending	Mean of Absolute Value of Correlations Before bending	Mean of Absolute Value of Correlations After Bending
Non-return rate (56)	0.23	0.21	0.40	0.35	0.23	0.14	0.40	0.27
Calving-first insemination	0.34	0.28	0.51	0.41	0.34	0.26	0.51	0.36
Non-return rate (56)	0.22	0.20	0.37	0.33	0.22	0.15	0.37	0.27
Age at first insemination	0.02	0.02	0.20	0.16	0.02	0.03	0.20	0.12
Daughter fertility index	0.33	0.27	0.46	0.34	0.33	0.26	0.46	0.27
Non-return rate (90)	0.32	0.29	0.40	0.35	0.32	0.26	0.40	0.33
Number of inseminations	0.42	0.34	0.42	0.34	0.42	0.27	0.42	0.27
Calving-first insemination	0.48	0.38	0.56	0.43	0.48	0.33	0.56	0.40
Number of inseminations	0.55	0.46	0.56	0.46	0.55	0.40	0.56	0.40
First-last insemination	0.52	0.46	0.52	0.46	0.52	0.37	0.52	0.37
Days open	0.59	0.52	0.59	0.52	0.59	0.42	0.59	0.42
Days open	0.56	0.52	0.56	0.52	0.56	0.47	0.56	0.47
Conception rate (F/S)	0.42	0.39	0.44	0.40	0.42	0.36	0.44	0.38
Non-return rate (56)	0.38	0.33	0.44	0.38	0.38	0.30	0.44	0.35
Calving interval	0.54	0.48	0.54	0.48	0.54	0.45	0.54	0.45
Body condition score	0.19	0.16	0.33	0.28	0.19	0.14	0.33	0.25
Calving interval (lactation 1)	0.52	0.45	0.54	0.46	0.52	0.39	0.54	0.40
Calving interval (lactation 1-3)	0.50	0.43	0.54	0.44	0.50	0.38	0.54	0.40
Body condition score	0.23	0.18	0.34	0.24	0.23	0.15	0.34	0.22
% conception per insemination	0.10	0.09	0.17	0.12	0.10	0.00	0.17	0.00
(1/Num of insem)*100	0.61	0.48	0.61	0.48	0.61	0.12	0.61	0.12
Calving-first insemination	0.45	0.39	0.52	0.44	0.45	0.38	0.52	0.42
Non-return rate (56)	0.25	0.21	0.38	0.30	0.25	0.18	0.38	0.27
Calving interval	0.56	0.48	0.58	0.49	0.56	0.44	0.58	0.46
Presented for mating (21 d)	0.38	0.35	0.40	0.37	0.38	0.32	0.40	0.33
Cow bearing a calf	0.46	0.41	0.47	0.43	0.46	0.39	0.47	0.39
Fertility index	0.50	0.46	0.51	0.47	0.50	0.42	0.51	0.42
Daughter pregnancy rate	0.56	0.51	0.56	0.52	0.56	0.49	0.56	0.49