Indicators

E-17

Breeding Value Fertility

▪ Introduction

The fertility of a sire shows itself in two ways: in the fertilizing capacity of its semen and in the fertility of its daughters. The fertility of the daughters consists of traits that have a low heritability of 0.01 to 0.08. But because of the large genetic variation there is room for improvement by breeding. In this document the estimation of breeding values for daughter fertility will be examined more closely.

Fertility Traits

Fertility is a trait which can be measured in many different ways. Definitions which are used frequently are non-return rate at 56 days (NR56), non-return rate at 28 days (NR28), number of days open, calving interval (CI), the interval between calving and first insemination (ICI), the interval between first and last insemination (IFL), conception rate (CR), the number of inseminations per pregnancy, etc.

In addition, fertility traits can be measured on heifers, two-year-olds, and older cows. These three physiologically different groups of animals provide information on the fertility of an animal during the rearing period, during lactation while the animal is still growing, and during later lactation. Fertility measured on virgin heifers is predicted by the traits conception rate (CR-0), non-return rate at 56 days (NR56-0), and age at first insemination (AFI).

If fertility is to be taken into account when selecting animals for breeding, the question presents itself which fertility trait to use and what the breeding goal is.

Breeding Goal

Fertility traits can be divided into two types: traits measuring cycling ability and traits measuring the ability to conceive.

For the cycling ability, the number of days between two fertility situations is determined. For example: the number of days between calving and the first heat, or the number of days between two calvings. The ability to conceive can be expressed by an interval trait or a fertility score. The interval trait can be the number of days between first and last insemination. For the fertility score, a percentage of the animals which are in a certain reproductive status is measured. Examples are conception rate (CR), NR56, and NR28. NR56 is a 0/100 trait, which means pregnant or not pregnant at 56 days after insemination. To calculate this figure, a simple check is done whether an animal has been presented for mating (insemination, natural insemination, embryo transfer) within 56 days after the first insemination. If this is the case, the animal will get the status ‘not pregnant at day 56 after the first insemination’ (0). If this is not the case, the animal will get the status ‘pregnant at day 56 after the first insemination’ (100). An animal which is presented for a new insemination on day 85 for example, will have a 100 for NR56. The assumption is that it was pregnant on 56 days and only returned to heat after that. CR will be derived from all inseminations, necessary for a pregnancy. These inseminations are included in the model as repeated observations. A successful insemination will get the value 100, other inseminations are scored with 0.

A cow with a good fertility can be defined as a lactating animal that clearly shows its heat on time, and conceives after the first insemination. Whenever an animal meets these two requirements, it will automatically achieve a desired calving interval. Moreover, this cow requires little labour and needs one straw of semen to become pregnant.

The breeding goal is: a short calving interval with as few inseminations as possible per pregnancy.

- **Data**

Visible heats in animals can be deducted from the heat detection by the farmer. However, these data are not registered at national level. Insemination data, however, are available. From these, the interval between calving and first insemination (ICI) can be calculated. This trait has a strong correlation with the trait interval calving to first heat (genetic correlation stronger than 0.90), and has a strong relationship with the calving interval (a genetic correlation of 0.81). In addition, ICI can be determined for more cows than the calving interval (CI); CI can only be determined for 2/3 of the cows for which ICI can be determined. Equally important is the fact that it is necessary to have a next calving date to determine the CI. Especially cows with poor fertility will often not have a next calving date, however, they will often have an ICI. Therefore, a breeding value which only uses CI will have inaccurate breeding values. A cow without a next calving date will not have data on CI, and will therefore not be in the breeding value estimation, even though this is exactly the kind of animal which has a negative effect on fertility. If you want to use CI, you will have to use extra information on fertility, such as ICI. Even cows with poor fertility usually have been inseminated once and will therefore have an ICI. In ICI you will only miss the cows which will never become cyclic again, and therefore are never presented again for an insemination.
To conclude, ICI has a somewhat higher heritability than calving interval, therefore a breeding value for ICI is a good and early indicator of the calving interval.

Determining whether an animal is pregnant after the first insemination can be expressed with a score or an interval. As score, conception rate (CR) can be taken. The disadvantage of this trait is the fact that it is not available until late. It is also not available for all animals, because it can only be determined nine months after the cow has been inseminated. An alternative for CR is NR56. Advantages of CR above NR56 are, that it is used in many countries and can be used better for an international evaluation of breeding values. Also, the value of CR is based on all inseminations which allows correction for the treatment of the semen (sexed or conventional) per insemination.
Another alternative trait to describe the ability to conceive is the interval between first and last insemination (IFL). This trait will give, together with the interval between calving and first insemination, additional information about the calving interval. IFL has a strong genetic correlation with CR of -0.81 to -0.83, slightly stronger than the genetic correlation between NR56 and CR (0.78-0.80). IFL has a slightly higher heritability than NR56 (see Table 5).

Furthermore, it is important to know which data are used for the breeding value estimation. For virgin heifers the traits AFI and CR-0 are used in the breeding value estimation. From April 2019, also NR56 for virgin heifers (NR56-0) is calculated.

Data from the Netherlands and Flanders are used for the breeding value estimation. For the Netherlands, inseminations since September 1988 are used, and calving and lactation data since September 1978. Body condition scores which have been collected in the type classification program are available since 1998. For Flanders, insemination data are collected from January 1990, and calving and lactation data from September 1975 and body condition scores from June 2003.

To determine IFL, a next, valid calving is checked. Research has shown that it is important to include all IFL data, even when there is not a valid next calving. Data without valid next calving are valuable, because a part of the this data belongs to animals with reduced fertility. If there is no valid next calving, IFL is increased by 57 penalty days (De Haer, 2009).

Data edits are:

1. The cow that has been inseminated has to be herdbook-registered;
2. Only first lactation production data and body condition score are used;
3. Insemination data and calving data of the first three lactations of a cow are used;
4. The minimum age of the cow at first calving is 610 days;
5. NR56, ICI and IFL are included if the interval calving to first insemination is between 30 and 250 days;
6. NR56 is included if the insemination is at least 4 months before the last insemination date in the selected data set;
7. ICI is included if the calving date is at least 3 months before the last calving date in the selected data set;
8. IFL is included if the calving date is at least 12 months before the last calving date in the selected data set;
9. CI is included if the calving date is at least 18 months before the last calving date in the selected data set, and is less than 800 days. All CIs between 800 and 550 days are changed to 550;
10. IFL is 0 when there is only 1 registered insemination, or when re-insemination takes place within 4 days.
11. The maximum interval length for IFL is 220 days (without penalty days).
12. IFL will receive 57 penalty days when CI is more than 800 days.
13. NR56, ICI, IFL and CI are not included if there has been a flushing or a transplantation during lactation;
14. IFL based on insemination data is set to missing when running with the bull has taken place during lactation.
15. NR56 is not included if running with the bull has taken place before the animal has been mated at least two times (artificial insemination or natural service);
16. ICI is not included if running with the bull has taken place before the animal has been mated at least one time (artificial insemination or natural service);
17. If there is a period of 150 days or more between successive matings, or the CI is less than 210 days (both indications of an abortion), then NR56 and ICI are included in the breeding value estimation but CI is not. IFL will be derived from the interval between first and last insemination, occurring before the 150 days interval, increased with 57 penalty days.
18. If the number of days between the last insemination and the next calving date is greater than 400 days, the calving interval is not included;
19. IFL will receive 57 penalty days if the gestation length is not within 265 and 300 days and there is a next calving date. If the gestation length is more than 300 days and a valid next calving is present (and therefore valid CI), then IFL is calculated as CI-ICI-280 days (280 being the average gestation length). The long gestation length may be due to unregistered inseminations or natural services.
20. IFL will receive 57 penalty days if a next calving date is missing and a minimum period of 300 days is present between the last insemination date of the cow and the last calving date in the data set. If the next calving date in missing, but the period between the last insemination date of the cow and the last calving date in the data set is less than 300 days, IFL is missing.
21. AFI is calculated as the age of first insemination of virgin heifers. AFI is missing when date of first insemination or birthdate was unknown.
22. In general, CR is calculated based on all inseminations in a lactation. Each insemination is treated as a repeated observation. An insemination is scored 0 when there is a next insemination or when there is no pregnancy. The last insemination will be considered successful (score will be 100) when it results into a pregnancy. A gestation between 45-300 days is considered as a pregnancy or a pregnancy followed by an abortion. A gestation length of less than 45 days results in a missing value for the last insemination. A gestation length of more than 300 days is considered as a pregnancy resulting from another insemination, and therefore the score of the last insemination was set to 0. The last insemination is also unsuccessful when the next calving date is missing. If a virgin heifer is exported it is assumed that there was a pregnancy, and the last insemination is considered successful. If a cow is exported, the last insemination will be scored as missing (result unknown).

23. For cows with calving data, first inseminations have to occur within 30 to 250 days after calving, otherwise the last insemination is set to missing.
24. When CI is more than 800 days, the last insemination is set to missing .
25. Based on the number of first inseminations in a period of 1 year, and on the national average of 65%, a threshold for NR56 is calculated (see table 1). This threshold is an indication as to whether the farmer in question is reporting only the successful mating's. If a herd-year exceeds the threshold, NR56, ICI, IFL and CR data of that herd-year are not used in the breeding value estimation.

    The threshold is determined as follows:
    Threshold = p + 2.57 x √(p x q / n)
    p = 0.65, probability that an animal is not presented for insemination again within 56 days
    q = 1 – p = 0.35, probability that an animal is presented for insemination again within 56 days
    n = number of observations in a herd within one year
26. Extreme measurements of production traits are set to a maximum or minimum. The maximum and minimum are determined by the average production of a herd, plus or minus 3 times the phenotypic standard deviation respectively. The used standard deviations are 950, 37, and 29 for kg milk, kg fat and kg protein respectively. The productions are standardised to an age at calving of 24 months.

Table 1. NR56 thresholds, depending on the number of inseminations

Number of Inseminations	Limiting Value NR56
20	92.4
30	87.4
40	84.4
50	82.3
60	80.8
70	79.7
80	78.7
90	77.9
100	77.3
125	76.0
150	75.0
175	74.3
200	73.7

▪ Statistical Model

The breeding values for fertility traits are estimated with an animal model, using the BLUP-technique (Best Linear Unbiased Prediction). At the same time, milk, fat and protein yields, as well as the body condition score from the first lactation are analysed. Correlations between all traits are used in this process. Therefore, the breeding value estimation is a so-called multiple trait breeding value estimation. The reason to include these last four traits in the breeding value estimation is the fact that these traits are good predictors of fertility. By including these four predictors the reliability of the fertility breeding values will eventually increase, especially for the youngest sires, of which the daughters do not have much fertility information yet (no calving interval). When estimating breeding values, it is theoretically also more correct to take into account a correlated trait (milk production) for which a lot of selection has taken place during the past years. Production traits are not included anymore for the second and third lactation. They don't add any value, because the fertility information of the first lactation is already available.

Different statistical models are used for different traits:

$Y1_{ijklmnop}$ = $HIYS_i + IYP_j + HET_k + REC_l + INB_s + A_m + SX_n + DOW_o + B_p + Res_{ijklmnop}$
$Y2_{ijklmnopqr}$ = $HIYS_i + IYP_j + HET_k + REC_l + INB_s + A_m + SX_n + DOW_o + NINS_p + B_q + P_r + Res_{ijklmnopqr}$
$Y3_{ijklm}$ = $HIYS_i + IYP_j + HET_k + REC_l + INB_s + A_m + Res_{ijklm}$
$Y4_{ijklm}$ = $HCYS_i + CYP_j + HET_k + REC_l + INB_s + A_m + Res_{ijklm}$
$Y5_{iklmno}$ = $HSD_i + HET_k + REC_l + INB_s + AGE_n + LACT_o + A_m + Res_{iklmno}$
$Y6_{iklm}$ = $HBY_i + BM_j + HET_k + REC_l + INB_s + A_m + Res_{iklm}$

in which:

$Y1_{ijklmnop}$: Observation for NR56 (virgin heifers and cows) on cow m, in herd-insemination year-season i and in insemination year-period j, with heterosis effect k, recombination effect l and inbreeding effect s, with bull B_p used for the insemination (random effect), on day of the week DOW_o and effect of kind of semen/year/owner SX_n;

$Y2_{ijklmnopq}$: Observation per insemination for CR (virgin heifers and cows) on cow m, in herd-insemination year-season i and in insemination year-period j, with heterosis effect k, recombination effect l and inbreeding effect s, for insemination number $NINS_n$, on day of the $week_o$, effect of kind of semen/year/owner SX_n with bull B_q used for the insemination (random effect), and permanent environment effect of cow $P_{q;}$

$Y3_{ijklm}$: Observation for IFL on cow m, in herd-insemination year-season i and in insemination year-period j, with heterosis effect k, recombination effect l and inbreeding effect s;

$Y4_{ijklm}$: Observation for ICI, CI, Milk, Fat, Protein on cow m, in herd-calving year-season i and in calving year-period j, with heterosis effect k, recombination effect l and inbreeding effect s;

$Y5_{iklmno}$: Observation for Body Condition Score on cow m, with herd-scoring date i, heterosis effect k, recombination effect l and inbreeding effect s, age at condition score n and stage of lactation at scoring o;

$Y6_{iklm}$: Observation for AFI (virgin heifers) on heifer m, with herd-birth year i, birth month j, heterosis effect k, recombination effect l and inbreeding effect s;

$HIYS_i$: Herd-insemination year-season i. Season is defined as a period of one year in a herd. In each parity, year of insemination is based on year of insemination of the first parity, to improve comparison among cows of similar age. For virgin heifers year of first insemination is used;

$HCYS_i$: Herd-calving year-season i. Season is defined as a period of one year in a herd. In each parity, year of calving is based on year of first calving, to improve comparison among cows of similar age;

HSD_i : Herd-date of scoring i;

IYP_j : Insemination year-period j, in which the cow was inseminated. For every year 36 new classes are defined, each consisting of 10 days;

CYP_j : Calving year-period j, in which the cow has calved. For every year 36 new classes are defined, each consisting of 10 days;

HBY_i : Herd-birth year i;

BM_j : Month of birth j;

HET_k : Heterosis class k;

REC_l : Recombination class l;

INB_s : Inbreeding class s;

AGE_n : Age class at scoring n;

$LACT_o$: Stage of lactation o;

DOW_o : Day of the week o (1 t/m 14);

$NINS_p$: Rank number of an insemination within a lactation;

SX_n : Effect of treatment of semen: kind of semen (conventional or sexed), year of insemination, owner of the bull n;

B_p : Random effect of bull p used for the insemination;

P_q : Random effect of cow q as permanent environment effect;
A_m : Additive genetic effect (or breeding value) of cow m;
$Res_{ijklmopq}$: Residual term of each model, indicating the variation that is not explained by the model.

The effects A, B, P and Res are random effects, heterosis, recombination and inbreeding are covariables. The other effects are fixed. The observations for milk, fat and protein yield have been standardized to 24 months at calving.
With the above models, breeding values for both cows and bulls are estimated.

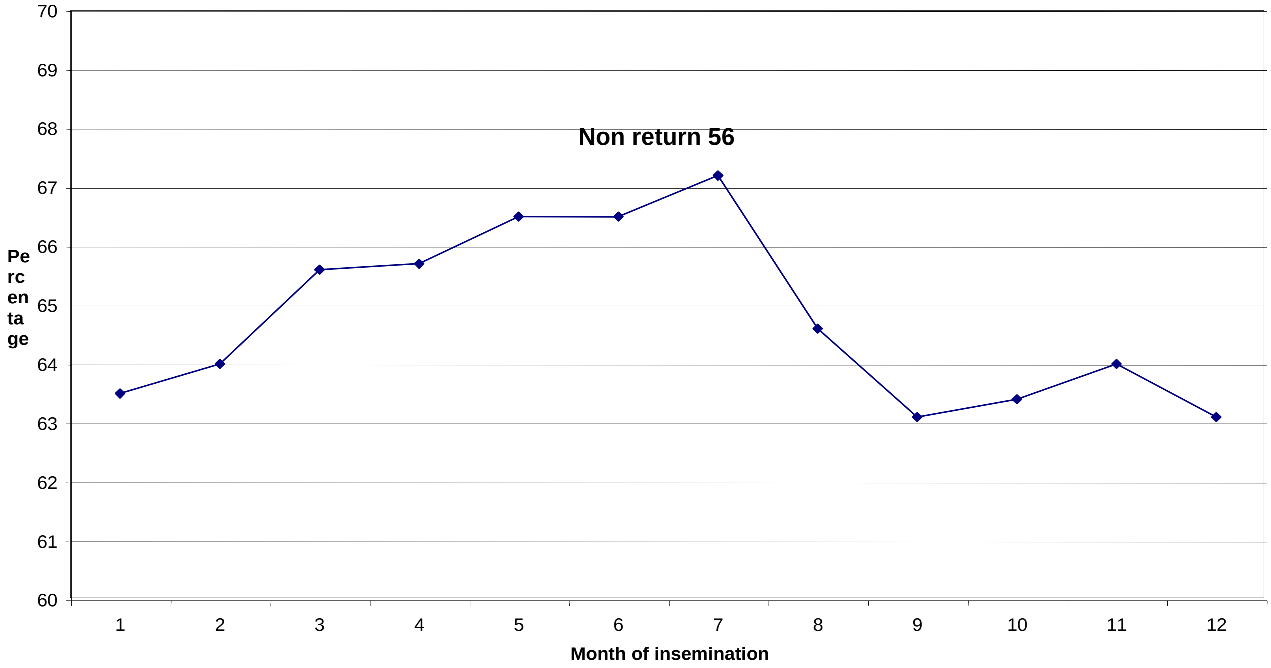
The Effects in the Model

The effects in the model are:
1. herd-insemination year-season;
2. herd-calving year-season;
3. herd-date of scoring;
4. insemination year-period
5. calving year-period;
6. herd-birth year;
7. month of birth;
8. heterosis and recombination;
9. inbreeding
10. age at scoring;
11. stage of lactation at scoring;
12. treatment of semen;
13. bull of insemination;
14. day of the week;
15. rank number of the insemination;
16. cow as permanent environment for CR;
17. genetic effect cow.

Herd-insemination year-season/Herd-calving year-season.
Between farms, large differences in fertility management exist. At the same time, the level of fertility in a herd may change over time. This is taken into account by comparing the cows with peers within a herd and a season of one year. The definition of a season is from the 1st of September last year up to, and including the 31st of August this year. From research of Tyrisevä *et al.* (2017) it was concluded that breeding values may be biased when herd-year-season is based on the last calving date. By using the last calving date, animals with poor fertility and therefore a longer CI are compared with younger animals with good fertility that have the same calving date. For a better comparison among peers, the herd-year-season effect in each parity will be based on the first calving date. When herd-year-season is based on date of insemination, for cows the day of first insemination in the first parity is used, for heifers day of first insemination.
If the insemination farm is not known (cows without NR56 and ICI data), then the farm is used on which the first Milk Production Recording took place.

Herd-date of scoring
For the analysis of body condition score, data are compared of heifers that are scored at the same herd and date.

Insemination year-period/Calving year-period
As it turns out, animals which are inseminated in the period of March up to, and including July, return less often than animals which are inseminated in the other months of the year (see Figure 1). At the same time, animals which calve in August/September are inseminated for the first time at an earlier stage than those that calve in April (see Figure 2). The interval between calving and first insemination is influenced by the month of calving. The difference in ICI between the calving months September and April is somewhat over 10 days.



For the trait calving interval figure 3 shows that cows which calve between June and October realize a shorter calving interval on average than cows that calve in other months. The average difference between those two periods is 10 days with a maximum of almost 20 days between March and August (see Figure 3).
The year of calving is also taken into account, because the changes from month to month differ per year.

Figure 1. Non-Return Percentage after 56 days per insemination month (1=Jan., 12 = Dec.)

Interval Calving to first insemination

Percentage

Da

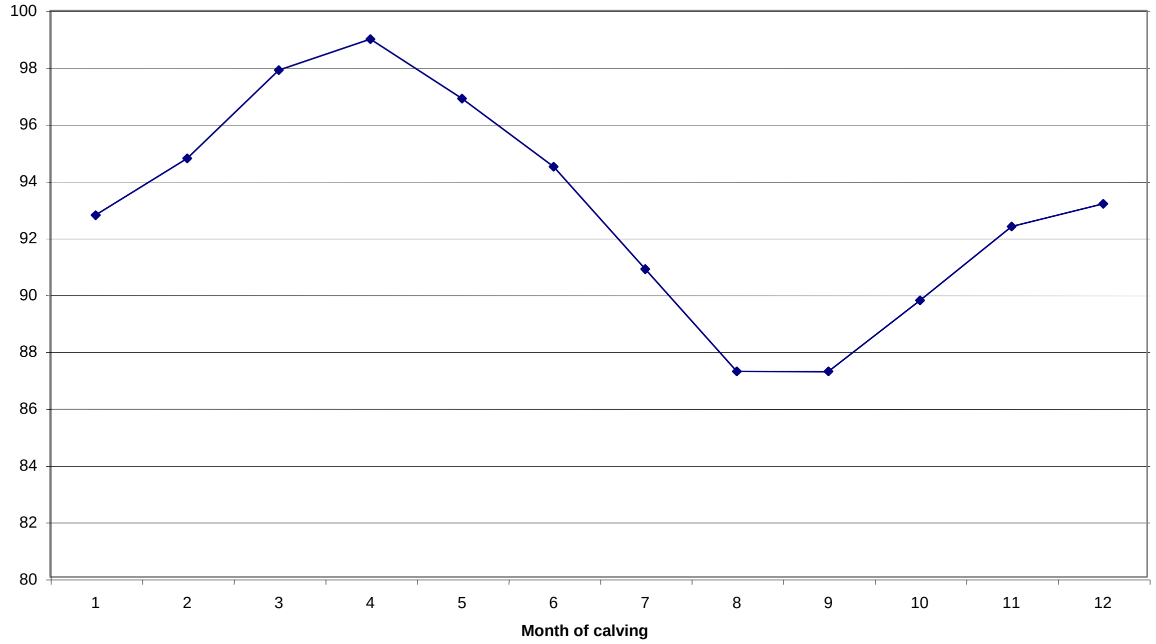
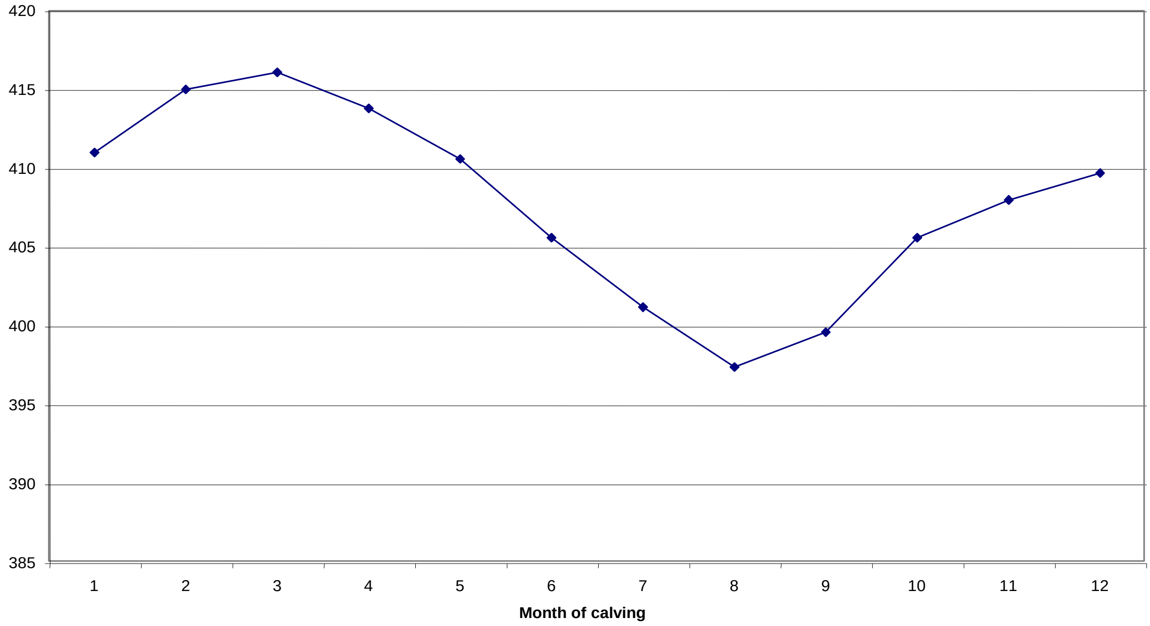


Figure 2. Interval between Calving and First Insemination (ICI), depending on the month of calving (1=Jan., 12 = Dec.)

Calving Interval

Figure 3. Calving Interval (CI), depending on the month of calving (1=Jan., 12 = Dec.)

Days



Herd-birth year
For the analysis of AFI, data are compared of virgin heifers that are at the same herd and birth year.

Month of birth
For the analysis of AFI data are corrected for month of birth (24 periods of half a month per year).

Heterosis and recombination effect
Heterosis and recombination effects play a role in crossbreeding. They are genetic effects, which are not passed on to the offspring. Research has shown the corrections must be made for these effects.

The extent of the heterosis is defined as the difference in level of the trait in the crossbreeding with the average of the parent breeds. Recombination occurs when at least one crossbred animal is used for breeding. The heterosis effect (het) of two breeds can be calculated using this formula:

$$het = [p_s(1-p_d) + p_d(1-p_s)]$$

in which:

p_s = breed blood portion sire
p_d = breed blood portion dam

The formula for recombination (rec) is as follows:

$$rec = [p_s(1-p_s) + p_d(1-p_d)]$$

If an animal comes from three different breeds, the number of heterosis and recombination effects also increases.
The effect of heterosis is 0.8 percent higher NR56, 2.6% higher CR, 0.6 day shorter ICI, 2.0 days shorter IFL, and 2.8 days shorter calving interval respectively, for animals with 100 percent heterosis.

Inbreeding

Inbreeding is the making of a mating between two animals whose DNA is more related to each other than the average relatedness in the population. Therefore, inbreeding leads to an increase in homozygosity. By comparing inbred animals with non-inbred animals on a trait, the negative effect of inbreeding can be estimated. Inbreeding is not heritable.

Age at scoring
If body condition score is analysed, a correction is made for age at scoring, as it influences the condition score. A total of 18 age classes are determined. Class 1 accounts for an age of 24 months or younger. Class 2 till 17 accounts for age at scoring of 25 till 40 months. Class 18 accounts for an age of 41 months or more.

Stage of lactation
As stage of lactation influences body condition score, the stage of lactation (months) is corrected for. A total of 13 lactation stages are determined, one for each month of lactation. Class 13 accounts for a stage of lactation at scoring of 13 months or more.

Treatment of semen
Treatment of semen will influence the semen quality and therefore the insemination results for traits like NR56, CR, IFL and CI. The most important treatment effect is sexing of semen. The kind of semen used (conventional or sexed) is recorded per insemination and may also be known through batch information of the insemination bull.
Sexing of semen may change during time and per owner. Therefore, when sexed semen is used, also year of insemination and owner are included in the effect. When conventional semen is used, year of insemination or owner is not included, as it is expected that the quality is constant over time. Depending on the source of information when conventional semen is used, conventional semen is divided into 3 groups: conventional semen confirmed by batch information; conventional semen only recorded at the insemination record; no information known about the kind of semen.
As CR is based on all inseminations, each insemination can be corrected for the quality of the semen used. Also, for NR56 the first insemination will be corrected for semen quality. From previous analyses it was derived that the success of the first insemination is reduced by 10% for virgin heifers and 8% for cows when sexed semen is used. As semen quality will also affect IFL and CI, these traits are corrected depending on the number of inseminations that were performed with sexed semen. Assuming a cycle length of 22 days and a reduced success rate of 10% (8%), the number of days for IFL and CI is reduced by:
Number of inseminations with sexed semen * rate of reduced success * 22 days.

Bull of insemination
The effect of the bull of insemination indicates the success rate, or pregnancy rate, of a bull. This effect may change with the age of the bull. To account for age of the bull, age is divided into 3 classes:
Age class 1: < 2 years
Age class 2: >= 2 years and < 3 years
Age class 3: >= 3 year
The bull effect is independent of parity or age of the cow and therefore, it is considered constant over parities. The average effect is 0 (as it is a random effect), but there is variation in rate of success between insemination bulls. The standard deviation in success rate for NR56 may be 3% (Table 2). NR56 as well as CR are corrected for bull of insemination.

Table 2. Standard deviation for the effect of bull of insemination on NR56 (%), per lactation (virgin heifers: NR56-0; cows: NR56-1, NR56-2, NR56-3).

	NR56-0	NR56-1	NR56-2	NR56-3
st.deviation	2.03	2.83	3.12	3.13

Day of the week

Day of insemination may influence the success of the insemination, for example inseminating on Monday instead of Sunday (see Table 3). The success may also be influenced by the person that performs the insemination: the executor or the farmer (DIY). Day of the week will correct for both effects: it consists of 14 classes, for each day and kind of insemination.

Table 3. The effect of day of the week on NR56 and CR (in %), per lactation (virgin heifers (0) and cows (1, 2, 3) and per kind of insemination. Kind of insemination distinguishes between farmer (DIY) and executor. Effects presented are relative compared to inseminations on Sunday.

		NR56-0	NR56-1	NR56-2	N56-3	CR-0	CR-1	CR-2	CR-3
Executor	Monday	-0.10	-0.46	-0.65	-0.60	-0.17	-0.87	-0.39	-0.37
	Tuesday	0.32	0.39	0.20	0.29	0.21	0.20	0.34	0.27
	Wednesday	0.23	0.26	0.13	0.05	0.27	0.22	0.29	0.22
	Thursday	0.23	0.17	-0.03	0.14	0.29	0.02	0.24	0.10
	Friday	0.11	0.37	0.05	0.16	0.20	0.03	0.14	0.06
	Saturday	0.32	0.33	0.34	0.40	0.44	0.30	0.39	0.24
	Sunday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIY	Monday	-0.46	-0.68	-0.72	-0.78	-0.73	-1.18	-0.98	-1.09
	Tuesday	0.10	0.03	0.20	0.00	-0.13	-0.17	-0.09	-0.14
	Wednesday	0.19	0.14	0.10	0.08	0.10	-0.13	0.01	-0.17
	Thursday	0.03	0.06	0.00	-0.13	-0.13	-0.24	-0.28	-0.44
	Friday	0.07	0.04	0.11	0.00	-0.06	-0.35	-0.11	-0.38
	Saturday	0.05	0.27	0.46	0.24	0.13	0.25	0.25	0.04
	Sunday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Rank number of insemination

For CR all inseminations are included. Rank number of the insemination may influence the success rate. To correct for this effect, rank number is included in the model for CR.

In table 4 the effect of rank number on CR is presented for the first 10 inseminations per parity. For virgin heifers (CR-0) results get worse from the third insemination, these are probably the young heifers that have difficulties to become cyclic. For older cows the effect is opposite: best results are at later inseminations.

Table 4. The effect of the rank number of the insemination on conception rate for virgin heifers and cows (CR-0, CR-1, CR-2, CR-3, per parity).

number	CR-0	CR-1	CR-2	CR-3
1	0.0	0.0	0.0	0.0
2	-0.2	4.3	4.5	5.1
3	-1.7	6.5	6.6	7.3
4	-4.0	7.5	7.3	7.9
5	-6.9	7.6	7.2	7.8
6	-9.8	7.2	6.7	7.7
7	-13.3	6.5	5.8	6.7
8	-16.1	6.1	4.7	5.8
9	-18.9	4.6	4.1	5.1
10	-21.5	3.8	2.9	4.1

Cow as permanent environment effect for CR
Cow is included for CR to account for permanent environment at the inseminations.

Cow
To estimate the genetic effect of the cow all ancestors of the animal are considered. In this way, genetic relations between animals are taken into account and sires will have a breeding value for fertility traits based on the data of their daughters.

▪ Traits

In total, 36 fertility traits are analysed in the breeding value estimation: six for virgin heifers and 30 for lactating cows.. For virgin heifers AFI, NR56-0 and CR-0 in two regions (The Netherlands and Flanders) are analysed. For lactating cows there are five fertility traits (NR56, ICI, CI, IFL and CR) in three lactations and 2 regions, which is 3 x 5 x 2 = 30 fertility traits. The heritabilities for the various traits are in Table 5, and the genetic correlations are in Table 6. Dutch and Flemish fertility traits are analysed as separate traits, as genetic variations and heritabilities of Flemish traits are different from Dutch traits (generally lower) (see Table 5).
Besides the 36 fertility traits, information from milk production and body condition score is used. This information is available at an early stage and provides better fertility breeding values (see paragraph Importance of the Use of Predictors).
The genetic correlations between identical Dutch and Flemish traits are 1.00 (Table 5).This means that breeding values of each animal for the Dutch and Flemish trait are identical. Genetic correlations between the different traits are used in the breeding value estimation. Therefore, the breeding value estimation for fertility traits is a so-called multiple trait breeding value estimation, which means that all available information regarding fertility is used to estimate breeding values as accurately as possible.
We can therefore also use the information on CI, even though this information is not available for all animals (a cow might be in the middle of a lactation or it doesn't have a next calving date anymore). Milk production and body condition score are also adding value to cows with a bad fertility, and therefore they are never presented for mating. These cows don't have NR56, ICI, CI, IFL or CR, whereas they are the cows with the biggest fertility problems. In that case, you can still use the information on milk production and body condition score, and so these animals also take part in the fertility breeding value estimation.

Table 5. Heritabilities (h^2) and genetic standard deviations of traits.

Trait	Lactation	Region	h^2	Genetic deviation	unit
AFI	0	NL	0.045	7.9	day
NR56	0	NL	0.013	4.5	%
CR	0	NL	0.018	4.1	%
AFI	0	FL	0.026	7.9	day
NR56	0	FL	0.013	4.5	%
CR	0	FL	0.015	4.4	%
NR56	1	NL	0.016	6.2	%
ICI	1	NL	0.081	9.9	day
CI	1	NL	0.062	14.7	day
IFL	1	NL	0.033	13.4	day
CR	1	NL	0.020	7.0	%
NR56	1	FL	0.012	5.2	%
ICI	1	FL	0.068	9.4	day
CI	1	FL	0.056	13.8	day
IFL	1	FL	0.033	11.7	day
CR	1	FL	0.020	7.0	%
NR56	2	NL	0.020	6.9	%
ICI	2	NL	0.099	11.0	day
CI	2	NL	0.075	15.6	day
IFL	2	NL	0.033	12.7	day
CR	2	NL	0.017	6.3	%
NR56	2	FL	0.016	6.0	%
ICI	2	FL	0.074	10.0	day
CI	2	FL	0.053	13.2	day
IFL	2	FL	0.034	11.9	day
CR	2	FL	0.017	6.3	%
NR56	3	NL	0.020	6.9	%
ICI	3	NL	0.097	11.0	day
CI	3	NL	0.078	15.8	day
IFL	3	NL	0.033	12.6	day
CR	3	NL	0.020	6.8	%
NR56	3	FL	0.022	7.1	%
ICI	3	FL	0.064	9.3	day
CI	3	FL	0.049	12.6	day
IFL	3	FL	0.036	12.5	day
CR	3	FL	0.020	6.8	%
Milk	1	NL/FL	0.342	624.8	kg
Fat	1	NL/FL	0.264	21.3	kg
Protein	1	VL/FL	0.276	17.5	kg
Body condition	1	NL/FL	0.207	0.51	pt

cntry	NL																		FL																				
lact	0			1					2					3					0			1					2					3							
trait	AFI	CR0	NR56-0	NR56	ICI	CI	IFL	CR	NR56	ICI	CI	IFL	CR	NR56	ICI	CI	IFL	CR	AFI	CR0	NR56-0	NR56	ICI	CI	IFL	CR	NR56	ICI	CI	IFL	CR	NR56	ICI	CI	IFL	CR	MILK	FAT	PRT
AFI	1.00																																						
CR0	-0.06	1.00																																					
NR56	0.25	0.71	1.00																																				
NR56	0.26	0.63	0.69	1.00																																			
ICI	0.45	0.01	0.19	0.32	1.00																																		
CI	0.42	-0.33	-0.24	-0.15	0.86	1.00																																	
IFL	0.26	-0.50	-0.19	-0.47	0.57	0.85	1.00																																
CR	-0.03	0.71	0.68	0.78	-0.25	-0.69	-0.81	1.00																															
NR56	0.21	0.51	0.64	0.92	0.36	-0.09	-0.36	0.70	1.00																														
ICI	0.35	0.07	0.22	0.40	0.92	0.76	0.52	-0.17	0.43	1.00																													
CI	0.30	-0.20	-0.17	-0.08	0.81	0.91	0.76	-0.59	-0.07	0.83	1.00																												
IFL	0.19	-0.41	-0.11	-0.45	0.47	0.75	0.89	-0.74	-0.44	0.50	0.79	1.00																											
CR	0.03	0.59	0.58	0.79	-0.09	-0.53	-0.73	0.91	0.80	-0.10	-0.54	-0.80	1.00																										
NR56	0.29	0.32	0.51	0.87	0.41	-0.03	-0.27	0.59	0.93	0.46	-0.03	-0.36	0.72	1.00																									
ICI	0.35	0.06	0.21	0.35	0.92	0.78	0.55	-0.20	0.41	0.94	0.82	0.48	-0.07	0.44	1.00																								
CI	0.32	-0.15	-0.13	-0.07	0.80	0.91	0.77	-0.60	-0.07	0.82	0.93	0.76	-0.54	-0.06	0.83	1.00																							
IFL	0.12	-0.27	-0.09	-0.45	0.42	0.70	0.84	-0.72	-0.45	0.46	0.71	0.90	-0.79	-0.44	0.46	0.80	1.00																						
CR	0.06	0.38	0.44	0.74	-0.04	-0.44	-0.64	0.81	0.79	-0.03	-0.43	-0.72	0.91	0.79	-0.04	-0.53	-0.83	1.00																					
AFI	**1.00**	-0.06	0.25	0.26	0.45	0.42	0.26	-0.03	0.21	0.35	0.30	0.19	0.03	0.29	0.35	0.32	0.12	0.06	1.00																				
CR	-0.07	**1.00**	0.69	0.63	0.01	-0.33	-0.51	0.70	0.51	0.07	-0.19	-0.42	0.59	0.32	0.06	-0.14	-0.27	0.38	-0.07	1.00																			
NR56	0.25	0.71	**1.00**	0.70	0.19	-0.24	-0.19	0.69	0.64	0.22	-0.17	-0.12	0.58	0.52	0.22	-0.13	-0.09	0.44	0.25	0.69	1.00																		
NR56	0.26	0.65	0.75	**1.00**	0.32	-0.15	-0.47	0.80	0.92	0.40	-0.08	-0.45	0.80	0.87	0.35	-0.07	-0.45	0.75	0.26	0.62	0.76	1.00																	
ICI	0.45	0.01	0.20	0.32	**1.00**	0.86	0.57	-0.25	0.36	0.92	0.81	0.47	-0.08	0.41	0.92	0.81	0.42	-0.04	0.45	-0.01	0.20	0.32	1.00																
CI	0.42	-0.34	-0.25	-0.15	0.86	**1.00**	0.85	-0.69	-0.09	0.76	0.91	0.75	-0.53	-0.03	0.78	0.91	0.70	-0.44	0.42	-0.30	-0.25	-0.15	0.86	1.00															
IFL	0.26	-0.50	-0.20	-0.47	0.57	0.85	**1.00**	-0.82	-0.36	0.52	0.76	0.89	-0.73	-0.27	0.55	0.77	0.84	-0.65	0.26	-0.54	-0.20	-0.47	0.57	0.85	1.00														
CR	-0.05	0.68	0.60	0.77	-0.28	-0.67	-0.88	**1.00**	0.68	-0.16	-0.55	-0.81	0.89	0.60	-0.20	-0.55	-0.77	0.81	-0.05	0.66	0.60	0.77	-0.28	-0.67	-0.88	1.00													
NR56	0.21	0.53	0.69	0.92	0.36	-0.09	-0.36	0.72	**1.00**	0.43	-0.07	-0.44	0.81	0.93	0.41	-0.07	-0.45	0.79	0.21	0.50	0.69	0.92	0.36	-0.09	-0.36	0.70	1.00												
ICI	0.35	0.07	0.23	0.40	0.92	0.76	0.52	-0.17	0.43	**1.00**	0.83	0.50	-0.10	0.46	0.94	0.82	0.46	-0.03	0.35	0.08	0.23	0.40	0.92	0.76	0.52	-0.16	0.43	1.00											
CI	0.30	-0.21	-0.20	-0.08	0.81	0.91	0.76	-0.60	-0.07	0.83	**1.00**	0.79	-0.54	-0.03	0.82	0.93	0.71	-0.43	0.30	-0.17	-0.19	-0.08	0.81	0.91	0.76	-0.57	-0.07	0.83	1.00										
IFL	0.19	-0.41	-0.11	-0.45	0.47	0.75	0.89	-0.74	-0.44	0.50	0.79	**1.00**	-0.80	-0.36	0.48	0.76	0.90	-0.72	0.19	-0.46	-0.12	-0.45	0.47	0.75	0.89	-0.78	-0.44	0.50	0.79	1.00									
CR	0.02	0.56	0.50	0.78	-0.10	-0.51	-0.75	0.88	0.80	-0.10	-0.52	-0.83	**1.00**	0.72	-0.07	-0.52	-0.81	0.90	0.02	0.56	0.50	0.78	-0.09	-0.51	-0.75	0.88	0.80	-0.10	-0.52	-0.83	1.00								
NR56	0.29	0.31	0.50	0.87	0.41	-0.03	-0.27	0.59	0.93	0.46	-0.03	-0.36	0.71	**1.00**	0.44	-0.06	-0.44	0.78	0.29	0.33	0.51	0.87	0.41	-0.03	-0.27	0.59	0.93	0.46	-0.03	-0.36	0.72	1.00							
ICI	0.35	0.07	0.24	0.35	0.91	0.78	0.55	-0.19	0.41	0.94	0.81	0.48	-0.06	0.44	**1.00**	0.83	0.46	-0.03	0.35	0.05	0.24	0.35	0.92	0.78	0.55	-0.19	0.41	0.94	0.81	0.48	-0.07	0.44	1.00						
CI	0.32	-0.16	-0.16	-0.07	0.80	0.91	0.77	-0.60	-0.07	0.82	0.93	0.76	-0.55	-0.06	0.83	**1.00**	0.80	-0.53	0.32	-0.12	-0.16	-0.07	0.81	0.91	0.77	-0.58	-0.07	0.82	0.93	0.76	-0.53	-0.06	0.83	1.00					
IFL	0.12	-0.27	-0.09	-0.45	0.42	0.70	0.84	-0.72	-0.45	0.46	0.71	0.90	-0.79	-0.44	0.46	0.80	**1.00**	-0.83	0.12	-0.30	-0.09	-0.45	0.42	0.70	0.84	-0.75	-0.45	0.46	0.71	0.90	-0.81	-0.44	0.46	0.80	1.00				
CR	0.05	0.35	0.36	0.73	-0.05	-0.42	-0.67	0.78	0.78	-0.02	-0.41	-0.75	0.89	0.79	-0.04	-0.51	-0.86	**1.00**	0.05	0.36	0.36	0.73	-0.05	-0.42	-0.67	0.79	0.77	-0.03	-0.41	-0.75	0.90	0.79	-0.04	-0.51	-0.86	1.00			
MILK	-0.14	-0.12	-0.09	-0.09	0.41	0.42	0.31	-0.28	-0.11	0.32	0.35	0.24	-0.19	-0.01	0.24	0.30	0.25	-0.14	-0.14	-0.12	-0.09	-0.09	0.40	0.42	0.31	-0.30	-0.11	0.32	0.35	0.24	-0.19	-0.01	0.24	0.30	0.25	-0.14	1.00		
FAT	-0.07	-0.09	-0.06	-0.02	0.29	0.27	0.16	-0.16	-0.11	0.22	0.23	0.16	-0.14	0.01	0.19	0.24	0.18	-0.11	-0.07	-0.10	-0.05	-0.02	0.29	0.27	0.16	-0.16	-0.11	0.22	0.23	0.16	-0.15	0.01	0.19	0.24	0.18	-0.11	0.64	1.00	
PRT	-0.19	-0.19	-0.12	-0.13	0.31	0.34	0.25	-0.25	-0.19	0.27	0.30	0.22	-0.20	-0.04	0.20	0.26	0.20	-0.14	-0.19	-0.21	-0.12	-0.13	0.31	0.34	0.25	-0.25	-0.19	0.27	0.30	0.22	-0.21	-0.04	0.20	0.26	0.20	-0.15	0.92	0.59	1.00
BCS	-0.14	-0.11	-0.13	-0.19	-0.41	-0.38	-0.17	0.03	-0.12	-0.36	-0.33	-0.13	-0.01	-0.13	-0.29	-0.32	-0.06	-0.03	-0.14	-0.10	-0.13	-0.19	-0.41	-0.38	-0.17	0.04	-0.12	-0.36	-0.33	-0.13	-0.01	-0.13	-0.29	-0.32	-0.06	-0.02	-0.36	-0.32	-0.32

Table 6. Genetic correlations on a biological scale between the traits AFI, NR56, ICI, CI, IFL and CR in lactation 0, 1, 2 and 3 for 2 regions and production traits in lactation1. *Correlations in **bold** are correlations between identical traits in The Netherlands and Flanders. These correlations are 1.00, meaning that the breeding values for the Dutch trait and the Flemish trait have the same ranking order.*

Derived Breeding Values

The 30 cow fertility traits (NR56, ICI, CI, IFL and CR in three lactations and 2 regions) are combined into five overall breeding values, and one fertility index. The five overall breeding values are calculated from the breeding value for the three different lactations as follows:

$$BV_{overall} = 0.41 \times BV_1 + 0.33 \times BV_2 + 0.26 \times BV_3$$

in which:

BV_i : breeding value for a fertility trait in lactation *i*.
The derivation of the factors (0.41, 0.33 and 0.26) is described in chapter E7.

The breeding value for Days Open (DO) is derived as an index with the overall traits ICI and IFL:

$$FW_{DO} = 0{,}51 \times (FW_{ICI\text{-}all} – 100) + 0{,}62 \times (FW_{IFL\text{-}all} – 100) + 100$$

Next, the overall breeding values for IFL and ICI are combined in the fertility index (see below for the derivation).

All these derived traits also have their own heritability and genetic standard deviation, see Table 7. The genetic correlations between the derived traits are in Table 8 and those between the derived and underlying traits are in Table 9.

Table 7. Heritabilities (h^2) and genetic standard deviation for the derived traits

Trait	h^2	Genetic Standard Deviation	unit
NR overall	0.044	6.4	%
ICI overall	0.176	10.3	days
CI overall	0.142	14.9	days
IFL overall	0.075	12.5	days
CR overall	0.044	6.4	%
DO	0.134	10.0	days
FER index	0.085	4.1	pt

As is shown in Table 7, the heritability of the overall traits NR56, ICI, CI, IFL and CR is higher than the heritabilities of the corresponding traits in Table 5. NR56, for example, has a heritability in Table 2, which is 0.02 or lower. In Table 7 overall NR56 (a combination of NR56 in lactation 1, 2 and 3) has a heritability of 0.044. This may seem strange, because this is higher than the heritability in one of the three lactations. The reason for this is the fact that the genetic correlations between NR56 are much higher than the environmental correlations. The consequence is that with a NR56 observation in lactation 1, 2 and 3, you are better able to eliminate the effect of the environment on the observation, and therefore you will realize a higher heritability.

Table 8. Genetic correlations of breeding values between derived traits

Trait	FER index	DO	NR overall	ICI overall	CI overall	IFL overall	CR overall
FER index	1.00						
DO	0.98	1.00					
NR overall	0.42	0.31	1.00				
ICI overall	0.77	0.85	-0.20	1.00			
CI overall	0.97	0.98	0.30	0.86	1.00		
IFL overall	0.95	0.91	0.64	0.57	0.88	1.00	
CR overall	0.82	0.74	0.84	0.31	0.73	0.94	1.00

Table 8 shows correlations between breeding values of sires, as a measure for genetic correlations of overall traits. The interval traits (ICI, IFL and CI) have a scale opposite to the biological meaning, indicating that a higher breeding value represents a shorter interval length. Genetic correlations are comparable to or a little stronger than genetic correlations of the underlying traits in Table 6. Furthermore, the fertility index is correlated very strongly with IFL and CI overall and to a lesser extent, ICI and CR overall. As the weight for IFL is twice the weight for ICI in the fertility index and IFL has a strong correlation with this index, IFL is the trait with the largest influence on the fertility index. A shorter interval between first and last insemination and therefore a higher breeding value for IFL, will result in a higher breeding value for the fertility index.

Table 9. Genetic correlations between the derived traits and the underlying traits

Trait	NR56 overall	ICI overall	CI overall	IFL overall	CR overall
Lactation 1	0.98	0.98	0.98	0.98	0.98
Lactation 2	0.99	0.99	0.99	0.99	0.99
Lactation 3	0.97	0.99	0.99	0.97	0.96

Table 9 shows that the overall traits are correlated very strongly with the underlying traits. The reason is that the underlying traits themselves also have very high genetic correlations between lactations.

▪ Fertility Index

The fertility index consists of $CR_{heifers}$, ICI, IFL, and CR. The weights of the traits are chosen to achieve a positive trend for all traits when selection is based in the fertility index. The index is calculated as:
Fertility index = 0,23 x ($FW_{CRheifers}$–100) + 0,23 x ($FW_{ICI\text{-}all}$–100) + 0,35 x ($FW_{IFI\text{-}all}$–100) + 0,35 x ($FW_{CR\text{-}all}$–100) + 100

Base definitions

See chapter 'Bases for breeding values and base differences'.

Publication

Presentation
The breeding values for fertility are presented as relative breeding values with an average of 100 and a standard deviation of 4. The average is determined by a group of animals which forms the base of the breeding value. The standard deviation of all bases is determined by the bulls from the Black&White base (see above at Base definitions).
A breeding value above 100 means that the daughters of the bull have an above average fertility. Note that the scale of the breeding values for interval traits (ICI, IFL, CI) is opposite to the biological scale: a shorter interval will result in a higher breeding value.

The sire passes half of its breeding value on to its daughters. A sire with a breeding value for calving interval of 104 has daughters with a calving interval which is on average 6.7 days shorter. A breeding value of 104 for NR56 means that those daughters have a 2.9% better non-return on 56 days than on average. For the interval calving to first insemination, the daughters from a sire with a breeding value of 104 have a 4.6 days shorter interval than daughters from a sire with a breeding value of 100.
The standard deviation for IFL is 12.4 and CR has a genetic standard deviation of 6.4%. The genetic correlation between these traits is –0.93. A sire with a breeding value of 104 for IFL will have daughters with a shorter interval first-last insemination of on average 5.6 days and also a higher conception rate of on average 2.7%.
When selecting a sire with a fertility index of 101, the daughters can be expected to have an IFL of 1.3 days shorter and an interval calving-first insemination which is on average 0.9 days shorter in comparison with daughters from a sire with an fertility index of 100.

Publication Requirements
See chapter 'Publication rules sires'.

Literature

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