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Expected reliability of cow's breeding value for average life-time milk production

Očekávaná spolehlivost odhadu plemenné hodnoty průměrné celoživotní mléčné užitkovosti krav

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ABSTRACT: Reliability of breeding value estimation of cows for average life-time milk production is modelled on the basis of animal model method. Only the first or the first three lactations are considered for prediction. The number of contemporaries within (HYS) herd-year-season (1 to 15), degree of relationship between contemporaries, number of half-sisters (10 to 100) and relationship with the father only or full relationship over 3 generations of ancestors are taken into account. Two levels of heritability are used (0.32 and 0.21). Within-the-herd variability changed with the increasing magnitude of HYS. With data on 3 lactations and all other information available, it is possible to achieve the reliability of prediction of breeding value for the average of life-time production r^2 = 0.535. It is by 12% higher than with the first lactation only. Reliability increases if the contemporaries are not related. Reliability also increases with the increasing number of contemporaries within HYS. When reaching 5 contemporaries, further increase in reliability is low. Reliability is influenced by the number of half-sisters. With 50 half-sisters and more, at least a 90% level of maximum possible reliability is attained, practically regardless of the number of contemporaries within the herd.

Keywords: breeding value; reliability; milk production; contemporary; half-sisters; animal model; length of season

ABSTRAKT: Spolehlivost odhadu plemenné hodnoty krávy pro průměrnou celoživotní mléčnou užitkovost je modelována na podkladě metody animal model. Jsou uvažovány pouze první, nebo první tři laktace. Zohledněny jsou počty vrstevnic uvnitř (HYS) stáda-roku-období (1 až 15), stupeň vzájemné příbuznosti vrstevnic, počty polosester (10 až 100), příbuznost pouze k otci, případně úplná příbuznost přes tři generace předků. Jsou použity dvě úrovně dědivosti (0,32 a 0,21). S velikostí HYS je měněna vnitrostádová proměnlivost. Při třech laktacích a maximálním využití všech informací lze dosáhnout spolehlivost předpovědi plemenné hodnoty průměru celoživotní užitkovosti r^2 = 0,535. To je o 12 % více než při použití pouze první laktace. Spolehlivost zvyšuje nejsou-li vrstevnice příbuzné. S nárůstem počtu vrstevnic uvnitř HYS stoupá spolehlivost. Při dosažení pěti vrstevnic je však již další zvyšování spolehlivosti malé. Spolehlivost ovlivňuje počet polosester. Při překročení přibližně 50 polosester je dosaženo přinejmenším 90 % maximálně dosažitelné spolehlivosti bez ohledu na počet vrstevnic ve stádě.

Klíčová slova: plemenná hodnota; spolehlivost; mléčná užitkovost; vrstevnice; polosestry; animal model; délka období

INTRODUCTION

The estimation of breeding value (u) is done with an error that is to be minimised by the test organisation, proper implementation of milk records and method of data evaluation. The total error consists of two parts – bias and the prediction error itself (Van Vleck, 1986). The total error variance (TEV) is the variance caused by the bias and the error of determination of breeding value.

$$\mathrm{TEV} = (BIAS)^2 + \mathrm{var}_{PE} \quad (1)$$

which can be specified for an individual (i)

$$\mathrm{TEV}_i = [E(\hat{u}_i - u_i)]^2 + V(\hat{u}_i - u_i) \quad (2)$$

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Breeding value estimation is done on the basis of BLUP method, therefore the estimations should be unbiased and only the second part of the given equation is considered for the estimation of breeding value reliability. Breeding value reliability is expressed by the coefficient of determination r^2, which directly depends on var_{PE} and variability of the estimated random effect σ^2_u

$$r^2 = \frac{cov_{\hat{u}u}}{var_{\hat{u}}\ var_u} = 1 - var_{PE} / \sigma^2_u \tag{3}$$

Methods of breeding value estimation are based on a solution of the equation system, and the exact reliability of estimated constants should be determined on the basis of elements of the inversion left hand side (LHS) matrix of the system (Searle, 1971; Henderson, 1984). To find a solution of the equation system, the variance ratio $k = \sigma^2_e/\sigma^2_u$ is often used. Then the reliability coefficient is:

$$r^2_i = 1 - k \times C_{ii} \tag{4}$$

where: C_{ii} = diagonal element of the inversion of LHS matrix, related to the evaluated individual (i)

In case that breeding value is estimated for the complex of traits by multidimensional models, then an index is used. In the previous equations, the variance components are substituted by the blocks of covariance matrices, multiplied from the left and right sides by vectors of weights of traits in the index (Schneeberger *et al.*, 1992). Grasser and Tier (1997) used for var_{PE} in a special case the value

$$(\mathbf{R}^{-1} + \mathbf{G}^{-1})^{-1} \tag{5}$$

where: **R** and **G** are the residual and genetic covariance matrices of traits

The iteration procedures are regularly used and therefore the inversion of the matrix is not known. For this reason, various approximate procedures are applied for the calculation of reliability. The simplest way (for example Čermák *et al.*, 1986) for estimation of the diagonal element of the inverted matrix is the inversion value of the diagonal element of the LHS matrix.

$$r^2_i = 1 - k/d_{ii} \tag{6}$$

where: d_{ii} = diagonal element of LHS matrix after absorption of HYS (herd-year-season) equations that express the effective number of observations w plus the coefficient k

$$d_{ii} = k + \sigma w_i$$

After substitution and simplification, the well known formula is obtained:

$$r^2 = \Sigma w/(\Sigma w + k) \tag{7}$$

which is used in simulation studies for prediction of the expected value of reliability. The course of reliability in dependence on the number of observations is typically curved, the increment is slowing down and its curve is approaching a limited value.

Some authors worked out the improved estimation of reliability by including other information. Meyer (1989) used the block from the LHS connected with individual, his parents and HYS in which the individual is presented. Then she approximately determined the elements of the inversion matrix on the basis of the given block inversion. In connection with the AM method, several generations of ancestors are used for breeding value estimation. Grasser and Tier (1997) transformed all information into the equivalent of effective number of progeny, originating from different sources. Harris and Johnson (1998) worked with partial reliabilities according to the source of information "corrected" by information already included in another source. Gengler and Misztal (1996) used the canonical transformation and suggested the methodology which allows to work also with incomplete data.

Reliability is already included in breeding value. Therefore it is less important for the actual selection of animals for the breeding purposes. The main use of this coefficient is to plan the organisation of milk recording and the procedure for the data evaluation to minimise the expected error.

Variability of breeding value and production deviation from contemporaries was described by Přibyl (1986). It depends on the number of observations, number of contemporaries for each observation, genetic and residual variability. The formula to determine the error of breeding value estimation in dependence on the number of tested bulls and the number of herds in which the test is done was derived by Herrendörfer *et al.* (1974). The effect of the relationship of animals on breeding value reliability was studied by Mostager (1970, 1971).

The planning of evaluation is connected with the assessment of groups of contemporaries for direct comparison of animals. In milk production it is given by the optimum HYS length. It is desirable that HYS should be as short as possible with equal environmental conditions for all the animals within it and simultaneously with the highest possible number of contemporaries. The effect of HYS magnitude, number of non-related contemporaries and the incidence of direct comparison of tested animals within HYS at a different level of heritability were studied by Tosh and Wilton (1994). A higher number of contemporaries in the group results in the higher accuracy of breeding value estimation but after the number of contemporaries in the group exceeds 5, it does not improve the estimation any longer.

The long HYS can lead to an estimation bias due to systematic trends. The effect of the season of the year on milk production was described by Kučera *et al.* (1999). Schmitz *et al.* (1991) showed that the prolongation of HYS led to introduction of systematic effects of the environment, which increased uncontrolled variability. With regard to the evaluation of bulls they arrived at a conclusion that the way of combining the animals into groups was not essential, but a more important role was played by the number of progeny. A higher number of contemporaries in the group from 2 to 3 improved the accuracy of evaluation but the increase over 10 contemporaries was not particularly beneficial. The variability within HYS in dependence on its magnitude was studied by Přibyl and Přibylová (2001b). Systematic effects of the environment explained up to 60% of total variability while genetic disposition from 11 to 14%. At the same time they determined the mean standard error of deviation of milk production of the observed cow from the group of contemporaries. In dependence on the number of contemporaries within HYS the mean standard error of deviation falls to the level of approximately 3/4 of the maximum value at one contemporary. From the number of 7 contemporaries it practically does not change with increase in their number. Consideration of the pedigree allowed further decrease in the error.

The animal breeding is aimed at average life-time milk production. The estimation of breeding value is under this condition. Prediction of breeding value for average life-time production according to the known first lactations is done with some reliability only (Přibyl and Přibylová, 2001a).

Breeding value of sires is usually determined with sufficient reliability thanks to a high number of the offspring. The aim of this study is to determine, on the basis of simulated calculations, the expected reliability of breeding value for average life-time milk production of the cow, in dependence on the number of contemporaries within HYS and a different number of paternal half-sisters.

MATERIAL AND METHODS

Breeding value for the first lactation

In dependence on the HYS magnitude from 1 to 15 contemporaries and the number of paternal half-sisters, the reliability of breeding values is simulated by means of the animal model. Only the first lactations and two effects are considered:

$$y = \text{HYS} + J + e \qquad (8)$$

where: J = random effect of an individual with the relationship matrix (relationship includes only the sire of the cows)

The cow is compared to a different number of contemporaries within the herd that are not related to it. Its father and fathers of contemporaries have also daughters in other herds, one daughter in each of them. All herds are of the same size. The father's offspring range from 10 to 100. The cases when all contemporaries are the progeny of one sire or all contemporaries over all herds are not related are considered.

Reliability is determined on the basis of the inversion matrix element according to equation (4). The heritability coefficient $h^2 = 0.32$ (corresponds approx. with Holstein Cattle), or $h^2 = 0.21$ (corresponds approx. with Czech Pied Cattle) for the animal model is according to Dědková and Wolf (2001). The value of the given heritability corresponds with HYS of the average number of about 9 individuals. With the increasing number of individuals within HYS it is prolonged which results in higher unexplained residual variability while genetic variability remains constant. In dependence on the HYS magnitude, the coefficient k, substituted into the equation system of the animal model (8), is calculated according to:

$$k = (t - h^2_{ZA})/h^2_{ZA} \qquad (9)$$

where: $t = \sigma^2_n/\sigma^2_{ZA}$

σ^2_n = variability within HYS at the number of individuals in HYS – n

σ^2_{ZA} = variability within HYS at the number of individuals in HYS according to the basic variant, where the heritability coefficient h^2_{ZA} was set

Milk production variability within HYS (Přibyl and Přibylová,2001b) is given by the function

$$\sigma^2_n = 0.43323832 + 0.00759844\,n - 0.00070867\,n^2 + 0.00004240\,n^3 - 0.00000096\,n^4 \qquad (10)$$

Reliability according to several lactations

Breeding is aimed at the average of life-time production. Breeding value is calculated according to several known first lactations included in an index (Přibyl and Přibylová, 2001a). We used the first three lactations. Reliability is established iteratively on the basis of the selection index theory, by which we adequately simulate MT – AM with relationship over 3 generations (both parents are known). Each cow has (v) contemporaries within the herd (from 1 to 15) that are not related to each other. Each dam has only one daughter with production. Each sire has (z) daughters (from 10 to 100), each in a different herd. The size of all herds is the same.

The index of the cow with three lactations is as follows:

$$\mathbf{P} \times \mathbf{b} = \mathbf{GC} \times \mathbf{EH} \qquad (11)$$

where: **P** = 3 × 3 covariance matrix of production deviation from contemporary within HYS for the first three lactations

b = vector of the weights of lactations in the index

GC = 3 × 10 genetic covariance matrix of lactations in the index to the lactations of total genotype

EH = vector of economic values of lactations

Reliability of the breeding value estimation according to the index is as follows:

$$r^2 = (\mathbf{b'} \times \mathbf{GC} \times \mathbf{EH})/(\mathbf{EH'} \times \mathbf{G} \times \mathbf{EH}) \quad (12)$$

where: $\mathbf{G} = 10 \times 10$ genetic covariance matrix of ten lactations of total genotype

The phenotype variances and covariances in the **P** matrix are corrected for variability in dependence on the HYS length by the coefficient t (equation 9). Furthermore, according to the effective number of observations w within HYS (Přibyl, 1986), which takes into consideration variability of deviation in accordance with the number of contemporaries

$$w = v/(1 + v) \quad (13)$$

where: v = number of contemporaries within HYS

Corrections are also made according to reliability of parental breeding values (Přibyl and Přibylová, 1996) because the pedigree information (about the animal observed as well as their contemporaries) reduces the random error of deviation

$$r_J^2 = (r_S^2 + r_D^2)/4 \quad (14)$$

where: r_P^2, r_S^2, r_D^2 = are reliabilities of estimation of the probands, their sire and dam

The total correction of variability is:

$$\sigma_P^2 = (t \times \sigma_{ZA}^2 - r_J^2 \times \sigma_g^2)/w \quad (15)$$

where: σ_g^2 = genetic variability

Genetic and economic parameters (Table 1) are taken from Dědková and Wolf (2001) and Přibyl and Přibylová (2001a).

The index for the sire is established by combination of (z) daughters according to equations (11) and (12).

In this case the matrix **P** is a combination of ($z \times z$) blocks. Diagonal blocks correspond to the matrix **P** from the cow's index. The blocks outside diagonal are $0.25\mathbf{G}_{33}$, where $\mathbf{G}_{33}$ is the block for the first three lactations from the genetic covariance matrix **G**.

In this case, the right side of the equation system (covariance of daughters' performance to the father) is a combination of repeated blocks 0.5**GC** of the cow's index.

The parents are considered in the index where the information on the proband, sire and dam is combined. The structure of information is complicated in this case. Therefore the equation system for the combination of sources was modified according to the reliabilities of partial indices (Přibyl and Přibylová, 1998). After corrections, the matrix **P** has dimension 3 × 3 and includes the reliabilities of partial breeding values (indices) of the proband r_J^2 (cow, or bull), sire r_S^2 and dam r_D^2.

$$\mathbf{P} = \begin{bmatrix} r_J^2 & 0.5r_J^2r_S^2 & 0.5r_J^2r_D^2 \\ 0.5r_J^2r_S^2 & r_S^2 & - \\ 0.5r_J^2r_D^2 & - & r_D^2 \end{bmatrix} \quad (16)$$

Similarly the right side:

$$\mathbf{GC} = \begin{bmatrix} r_J^2 \\ 0.5r_S^2 \\ 0.5r_D^2 \end{bmatrix} \quad (17)$$

Variability of the whole genotype after corrections is 1. Total reliability of the breeding value estimation of the proband, including parental information is

$$r^2 = \mathbf{b'} \times \mathbf{GC}$$

Table 1. Correlations between lactations (%) – above diagonal genetic, below diagonal phenotype, standard deviations for lactations in Czech Pied (C) and Holstein (H) cattle and discounted economic values (EH) with interest rate 5%

Lactation	1	2	3	4	5	6	7	8	9	10
1	–	91	90	85	80	75	70	65	60	55
2	70	–	98	95	90	85	80	75	70	65
3	60	70	–	98	95	90	85	80	75	70
4				–	98	95	90	85	80	75
5					–	98	95	90	85	80
6						–	98	95	90	85
7							–	98	95	90
8								–	98	95
9									–	98
σ_{gC}	324	372	387	388	386	385	377	373	361	361
s_{gH}	485	589	586	544	526	495	487	468	450	446
EH	0.369	0.221	0.153	0.103	0.067	0.041	0.024	0.012	0.007	0.003

In the previous step calculated values of cows and bulls were substituted for the value of the sire's and dam's reliabilities. For the given size of the herd and the given number of daughters of the sire, the whole technique is iteratively 3 times repeated (3 generations of ancestors) according to equations (14), (15), (11), (12), (16), (17) and (18).

RESULTS AND DISCUSSION

Reliability of breeding value in the first lactation

The reliability of the breeding value of a cow in the first lactations is simulated by means of AM. All contemporaries are the progeny of the same sire. The sire of the particular cow, similarly like the sire of contemporaries, has the same number (10 to 100) of daughters in the other herds that meet with daughters of other sires. Neither relationship to the dams nor to other generations of ancestors is considered. The reliability is shown in Table 2 and Figure 1.

In the case of heritability $h^2 = 0.32$ and if the contemporaries do not have any half-sisters, reliability of the breeding value estimation increases in dependence on the number of contemporaries from the value 0.16 to 0.260. With the increasing number of half-sisters it increases up to 0.253 (one contemporary, 100 half-sisters), and 0.326 (15 contemporaries, 100 half-sisters). According to both viewpoints, the increment is a curve, the increment of reliability is slowed down with higher amount of information. It reaches the upper limit within the range from 13 to 15 contemporaries.

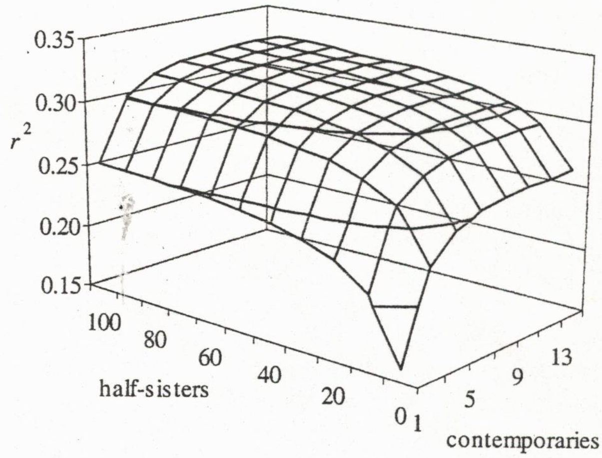


Figure 1. Cow's reliability, first lactation, contemporaries related ($h^2 = 0.32$)

The points with the same reliability that can be attained by various combinations of information are linked in the graph. In the consideration of the number of contemporaries only, the critical limit is 3 to 5, exceeding this limit results in negligible changes. As it follows from the above mentioned facts, after the fulfilment of minimal limits, the course of the graph is flat and the increment of reliability with the increased amount of information is not important.

In the breeding value estimation, the sire is practically always known. If the sire has several tens of daughters (30 and more), it becomes more important for the cow evaluation than the numbers of contemporaries within HYS. If the sire has only 10 daughters and the cow has only 3 contemporaries, the reliability of the breeding value estimation is higher than in the case of the highest pos-

Table 2. Reliability of breeding value estimation of the cow in the first lactation in dependence on the number of contemporaries and half-sisters in other herds. All contemporaries are progeny of the same sire

Contemporaries	Paternal half-sisters						
	0	10	20	40	60	80	100
$h^2 = 0.32$; 90% = 0.293							
1	0.160	0.207	0.225	0.240	0.247	0.251	0.253
3	0.226	0.264	0.278	0.290	**0.296**	**0.299**	**0.301**
5	0.245	0.280	**0.293**	**0.305**	0.310	0.313	0.315
9	0.257	0.290	**0.303**	0.314	0.319	0.322	0.324
15	0.260	0.292	**0.304**	0.316	0.321	0.324	**0.326**
$h^2 = 0.21$; 90% = 0.239							
1	0.113	0.157	0.177	0.197	0.206	0.212	0.216
3	0.161	0.198	0.216	0.233	**0.241**	**0.246**	**0.249**
5	0.175	0.21	0.227	**0.243**	0.251	0.256	0.259
9	0.184	0.218	0.234	**0.250**	0.258	0.262	0.265
15	0.186	0.219	0.235	**0.251**	0.259	0.263	**0.266**

sible number of contemporaries but without taking into account the pedigree. The limits of combinations of the numbers of contemporaries and half-sisters when 90% of the maximum attainable value of reliability has been exceeded (90% out of 0.326) are marked in bold in the table. Reliability on a 90% level of the maximum is reached at the number of 20 half-sisters if the number of contemporaries within HYS is higher than 5. If the number of half-sisters is 50, 90% of the maximum reliability is exceeded at a number of contemporaries 3. At the lower level of heritability ($h^2 = 0.21$), which corresponds to the situation in Czech Pied Cattle, the results have similar courses like in the previous case, but on a little lower level.

The given case is at the lower limit of the attained reliability when we presumed that all the contemporaries are related to the same sire. The lower the relationship between contemporaries, the higher the reliability of evaluation.

Table 3 shows an opposite case when the contemporaries of evaluated cow and all the contemporaries of its paternal half-sisters in other herds are fully unrelated (the sire has one daughter only in each herd).

The results of reliabilities have a similar course like in the previous case, but with a little steeper increment. The higher reliability is attained, it reached ($h^2 = 0.32$) the value $r^2 = 0.399$, which is by 22% more in comparison

Table 3. Reliability of breeding value estimation of the cow in the first lactation in dependence on the number of contemporaries and half-sisters in other herds. Contemporaries not related to each other

Contemporaries	Paternal half-sisters						
	0	10	20	40	60	80	100
$h^2 = 0.32$; 90% = 0.359							
1	0.160	0.209	0.239	0.272	0.289	0.300	0.307
3	0.235	0.289	0.317	0.344	0.356	**0.363**	**0.368**
5	0.258	0.312	0.339	**0.363**	**0.374**	0.381	0.385
9	0.273	0.327	0.353	**0.376**	0.386	0.392	0.396
15	0.276	0.331	0.356	**0.379**	0.389	0.395	**0.399**
$h^2 = 0.21$; 90% = 0.302							
1	0.113	0.153	0.183	0.219	0.239	0.252	0.262
3	0.166	0.215	0.245	0.278	0.294	**0.305**	**0.312**
5	0.181	0.232	0.263	0.293	**0.309**	0.319	0.325
9	0.191	0.243	0.274	**0.303**	0.318	0.327	0.333
15	0.194	0.246	0.276	**0.306**	0.321	0.33	**0.336**

Table 4. Reliability of breeding value estimation of the sire for average life-time production according to the first three lactations of daughters in dependence on the number of contemporaries within the herd and number of daughters

Contemporaries	Daughters					
	10	20	40	60	80	100
$h^2 = 0.32$; 90% = 0.812						
1	0.436	0.581	0.717	0.783	**0.822**	**0.849**
3	0.534	0.670	0.786	**0.839**	0.869	0.889
5	0.556	0.689	0.801	**0.850**	0.878	0.897
9	0.570	0.701	0.809	**0.857**	0.884	0.901
15	0.572	0.703	0.810	**0.858**	0.885	**0.902**
$h^2 = 0.21$; 90% = 0.779						
1	0.352	0.493	0.639	0.716	0.765	**0.798**
3	0.443	0.584	0.718	**0.784**	**0.823**	0.849
5	0.465	0.605	0.735	**0.798**	0.835	0.859
9	0.478	0.618	0.745	**0.806**	0.842	0.865
15	0.481	0.620	0.747	**0.808**	0.843	**0.866**

with Table 2. 90% of this highest reliability (90% out of 0.399) is exceeded if the amount of information exceeds 70 daughters of the sire and 3 contemporaries, or 40 daughters and 5 contemporaries, or 30 daughters and 7 contemporaries.

The given results are in accordance with Tosh and Wilton (1994), who showed the effect of the relationship of contemporaries and direct relatedness of animals on the reliability of the cow's breeding value estimation. The conclusions of their study are similar to ours. The same applies to the number of observations that are necessary for the evaluation.

In practical cases, the reliability is within the range of given extremes (Tables 2 and 3) because the contemporaries are always related to a certain degree.

If we want to predict the reliability of breeding value for the average of life-time production on the basis of the first lactation, it is necessary to multiply the given values by 0.90 (Přibyl and Přibylová, 2001a).

Reliability of prediction of life-time production according to first three lactations

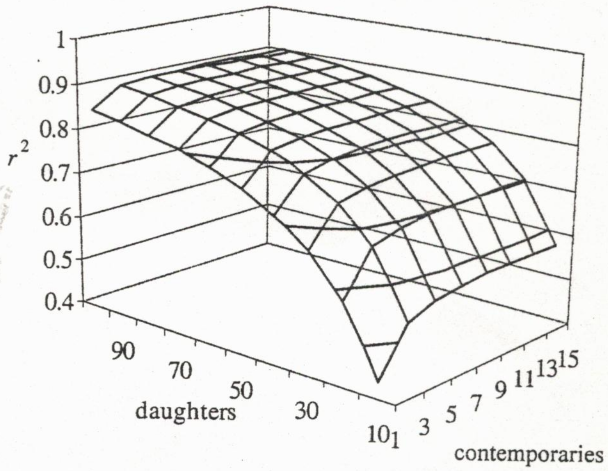
A breeding goal is the highest possible production on the average of the cow's life time (Přibyl and Přibylová, 2001a). Prediction is done according to the first three lactations. For simplification we use the same number of contemporaries in all three lactations for every cow. All contemporaries are not related to each other. Three generations of ancestors are used for the evaluation and previous generations have the same structure and amount of information as in the youngest generation.

Sires – 3 lactations

Reliability of the sire's breeding value calculated under the same conditions is presented for comparison. Reliability of the breeding value of the sire for the average of life-time production is given in Table 4 and Figure 2.

At a higher level of heritability the reliability is increasing from $r^2 = 0.436$ in the case of 1 contemporary within HYS and 10 daughters to $r^2 = 0.902$ with 15 contemporaries within HYS and 100 daughters, each with 3 lactations. As the generations of ancestors are considered, relatively high reliability is reached at a low amount of information (progeny and contemporary).

After the number of contemporaries in the herds reached 5, the reliability did not practically change with further increase in their number. An important role is played above all by the number of progeny. 90% of maximum reliability ($r^2 = 0.812$) is overrun at 80 daughters and only 1 contemporary within HYS, or 50 daughters and 3 contemporaries. With the increase in the number



2. Sire's reliability, 3 lactations ($h^2 = 0.32$)

of daughters, the effect of contemporaries becomes less important and differences in reliability according to the number of contemporaries decrease.

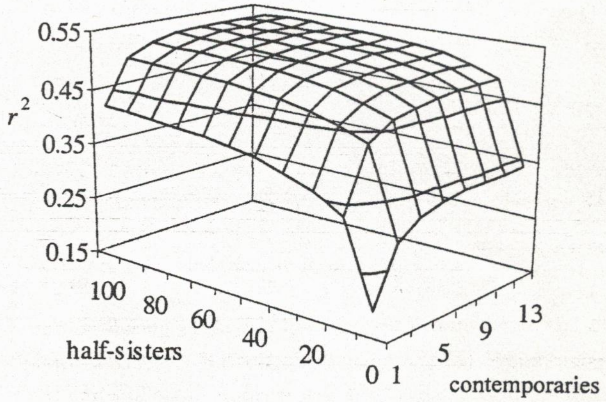
In heritability $h^2 = 0.21$ the reliability is lower in general and 90% of the maximum is achieved with a slightly higher amount of information.

With regards to the fact that in testing of sire, the sufficient number of progeny is provided in advance, it is possible to have a small number of contemporaries in herds (about 3) without any practical effect on the resulting reliability of the breeding value estimation.

Cows – 3 lactations

Reliabilities of estimation of the cow's breeding value according to 3 lactations are shown in Table 5 and Figure 3.

In the case of heritability $h^2 = 0.32$ and isolated evaluation of the herd, the breeding value for life-time production is predicted with reliability from 0.195 (1 contemporary) to 0.337 (15 contemporaries). If the parents are consid-



3. Cow's reliability, 3 lactations ($h^2 = 0.32$)

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