

AGE OF DAM, SEX AND ENVIRONMENTAL INTERACTIONS AFFECTING PREWEANING AVERAGE DAILY GAINS OF BEEF CATTLE

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Records on 25,571 Angus and 69,058 Hereford calves were used to calculate herd, cow and error components of variance by Henderson's Method 2. Repeatability of preweaning average daily gain was found to be 0.27 for Angus and 0.33 for Hereford. Best linear unbiased estimates were calculated for age of dam - sex - type of feeding (creep vs. noncreep) and for age of dam - sex - herd performance level subclasses for both Angus and Hereford. Three-way interactions were found to be statistically nonsignificant as were age of dam by type of feeding interactions for both breeds. Age of dam by sex and sex by type of feeding interactions were found to be significant, as were age of dam by herd performance level and sex of calf by herd performance level.

Le contrôle des aptitudes de 25,571 veaux Angus et 69,058 veaux Hereford a servi à calculer les éléments de variance des troupeaux, des vaches et de l'erreur par la méthode 2 d'Henderson. On a déterminé que la reproductibilité du gain moyen journalier avant sevrage était de 0.27 pour les Angus et de 0.33 pour les Hereford. On a calculé les meilleures estimations linéaires sans erreur systématique pour les interactions âge de la mère - sexe - type d'alimentation (dérobée contre non dérobée) et âge de la mère - sexe - niveau d'aptitudes du troupeau pour les veaux Angus et Hereford. Les interactions triples étaient statistiquement non significatives, tout comme les interactions âge de la mère $\times$ type d'alimentation pour les deux races. Les interactions âge de la mère $\times$ sexe et sexe $\times$ type d'alimentation étaient significatives, tout comme les interactions âge de la mère $\times$ niveau d'aptitudes du troupeau et sexe du veau $\times$ niveau d'aptitudes du troupeau.

The Canadian Federal-Provincial Record of Performance Program for Beef Cattle utilizes age of dam adjustment factors for preweaning average daily gain (ADG) that are considered appropriate regardless of sex of calf, creep feeding, herd performance levels, and breed. These factors are based on estimates of age of dam differences and sex differences such as those reported by Koch and Clark (1955), Marlowe and Gaines (1958), Brown (1960), Lehmann et al. (1961), Flock et al. (1962), Cundiff et al. (1966*b*), Cardellino and Frahm (1971), and Francoise et al. (1973). Although nonsignificant age of dam by sex, age of dam by creep feeding, and sex of calf by creep feeding interactions have been reported (Cundiff et al. 1966*a*; Cardellino and

Frahm 1971; Marlowe and Gaines 1958), significant interactions of sex of calf by creep feeding have also been reported (Cundiff et al. 1966*a*). No studies on three-way interactions nor of interactions of age of dam and sex with herd performance level have been reported. Neither have previous studies simultaneously considered age of dam, age of calf, sex of calf, feeding system, herd effect and cow selection.

The objectives of this study were:

- (1) to determine the significance of interactions of age of dam with sex of calf and environmental factors;
- (2) to determine the significance of sex of calf by environmental interactions;
- (3) to determine age of dam by sex by environmental subclass means, accounting

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for herd and cow differences, which could be used to develop either additive or multiplicative adjustment factors.

DATA

Data originated from 149,456 Canadian Record of Performance beef records of calves born during the period 1964–1970, including several breeds and all sexes. For the purpose of this study, certain edits were necessary. These included the following:

- (a) only Angus and Hereford breeds were considered;
- (b) all steers were deleted;
- (c) limits on age of dam were 22–192 mo;
- (d) limits on weaning weight were 68–431 kg;
- (e) limits on age at weaning were 130–280 days; and
- (f) missing average daily gain records were deleted.

Table 1 shows the number of records lost at each stage and the number of records remaining after editing. Fourteen age-of-dam groups were formed for the analysis. These groups were formed to determine if a finer breakdown was better than the usual year-of-age breakdown. Two types of environmental factors were considered; creep-fed versus non-creep-fed systems; and levels of herd performance based on herd averages classified into low, medium, and high levels. For both types of environmental factors, herds were nested within one level of a factor. For example, a herd was classified into either the creep-fed or noncreep-fed system, but not both. Herds that switched from one type of feeding system to the other were regarded as two different herds. Table 2 shows the distribution of herds and observations by levels of herd performance for 454 Angus herds and 995 Hereford herds. Angus and Hereford data were analyzed separately.

MODEL AND METHODS

The objectives of the study determine, in part, the elements of the model. The model should reflect the true underlying sampling process that generated the data, being also as simple as possible. The initial objective was to determine the presence of interactions among age of dam, sex of calf, and type of environment. If ages of dam were broken down by months, then 171 ages $\times$ 2 sexes $\times$ 2 feeding systems gives 684 subclasses with relatively few observations per subclass and possibly some empty subclasses. One method of simplifying the problem was to group several months together. This was based on numbers of observations and the general pattern of calving.

Table 1. Summary of data edits

Item	Angus	Hereford
Records at start	29,401	77,180
Steers	788	1,412
Weaning wt and age of dam	217	674
Weaning age	1,781	3,948
Missing values	1,044	2,088
Total remaining	25,571	69,058

The result was 14 age-of-dam groups which gave a total of 56 subclasses with feeding systems and 84 subclasses with levels of herd performance.

The limits for age at weaning in this study were 130–280 days. Previous studies have shown a linear relationship of age at weaning with ADG for 120–250 days of age. Thus, there are 30 days (beyond 250 days) in which the relationship with ADG may not be linear. Therefore, age-at-weaning squared was also included as a covariate in the model.

Selection differences, between cows that had more than one calf and those with only one, need to be eliminated by including cow effects in the model. Cows are nested within herds which are nested within feeding systems or herd levels of performance. The assumption was made that the variance of cow differences was the same from herd to herd and for creep-fed and noncreep-fed environments.

Herd differences were an important source of influence on ADG. Within a herd, differences in date calves are weaned can be viewed as a time effect specific to each herd, and not common to all herds. By including these time effects in the model, however, the degrees of freedom for error are reduced to zero since a cow would have only one calf in any time group. Several alternatives were considered and time effects were not included in the model, assuming time effect within herd would have less effect on age of dam–sex–environment subclasses than cow selection would have.

The model can be written as:

$$Y_{ijkmo} = (ANS)_{ijk} + b_1D + b_2D^2 + H_{jm} + C_{jmn} + e_{ijkmo}$$

where Y_{ijkmo} = a preweaning average daily gain record; A_i = an effect due to the i^{th} age-of-dam group; N_j = an effect due to the j^{th} feeding system or the j^{th} level of herd performance; S_k = an effect due to the k^{th} sex, either bull or heifer; $(ANS)_{ijk}$ = all main effects, two-way, and three-way interactions of age of dam by type of environment; D = the continuous vari-

Table 2. Distribution of herds and observations by levels of herd performance

Range (kg/day)	Angus		Hereford	
	No. herds	No. observations	No. herds	No. observations
<i>Low</i>				
<.454	0	0	1	9
.454-.494	0	0	1	1
.495-.540	2	32	4	480
.541-.585	4	81	5	45
.586-.630	9	107	9	168
.631-.676	11	825	25	2,693
.677-.721	24	930	64	4,138
.722-.767	55	2,963	128	9,687
<i>Medium</i>				
.768-.812	61	4481	156	13,409
.813-.857	116	8,036	216	16,450
<i>High</i>				
.858-.903	70	3,955	150	9,988
.904-.948	45	2,462	109	7,737
.949-.993	29	906	67	2,521
.994-1.039	15	524	32	1,289
1.040-1.084	9	238	13	146
1.085-1.129	4	31	9	162
1.130-1.175	0	0	5	109
1.176-1.220	0	0	0	0
>1.364	0	0	1	26

able of age at weaning; H_{jm} = a random effect common to all records made in the m^{th} herd within the j^{th} environment. The expected value is zero with variance σ_h^2 ; C_{jmn} = a random effect common to all calves of the n^{th} cow in the m^{th} herd and j^{th} environment. The expected value is zero with variance σ_c^2 ; e_{ijkmn} = a random effect associated with each record with expected value zero and variance σ_e^2 .

The method of analyzing the data has been discussed previously in the literature primarily for applications to dairy sire evaluation. Best linear unbiased prediction procedures (BLUP) were developed in 1949 by Henderson and applied to several types of animal breeding problems. Proofs of properties of solutions from BLUP appeared subsequently (Henderson 1950, 1963, 1973; Henderson et al. 1959). A necessary requirement for using BLUP procedures in this case is that the variances for herds, cows, and error be known. The true parameter values are never really known, but previous estimates in the literature are often used on the assumption that these values do not change greatly over time. It was considered that reliable estimates of the variance components were lacking, and

estimates were first calculated from the data using the model previously described and Henderson's Method 2. The effect of using estimates of variance components from the same data that are to be analyzed for fixed and random effects is not practically important on the resulting solutions from BLUP procedures. The important consequence is the change in standard errors and prediction errors of the fixed and random effect solutions. Of course, large biases in solutions could occur if the variances utilized are totally incorrect both for the data and the population from which that data were sampled. In this respect, the best variance components to utilize in BLUP, next to the true population parameters, are those estimated from the data being analyzed.

Method 3 of estimating variance components could not be used due to the large number of herds and cows, and Method 1 could not be used due to the presence of fixed effects in the model. Descriptions of Method 2 and the uniqueness of estimates are present in the literature (Henderson 1953; Searle 1968, 1971; Henderson et al. 1974).

Repeatability was estimated by

$$\hat{r} = 1 / (1 + \hat{\sigma}_e^2 / \hat{\sigma}_c^2)$$

where $\hat{\sigma}_e^2$ and $\hat{\sigma}_c^2$ are estimates of error and cow variances, respectively, from Henderson's Method 2. Table 3 shows the resulting estimates of variance components and repeatability. The variance component estimates for Herefords are slightly larger than those for Angus, but the ratios of the variances to the error variance are similar. Repeatability estimates are low but within the range of previously reported values (Cunningham and Henderson 1965; Hohenboken and Brinks 1969; Kennedy 1972).

The ratios of variance component estimates were then utilized in the BLUP procedure. The first step of this procedure is to set up the least squares equations as if herds and cows were fixed. Before solving these equations, the ratio of error to herd variances is added to all diagonals of the herd equations and the ratio of error to cow variances is added to all diagonals of the cow equations. Variance ratios are added to the diagonals due to the assumptions that herd and cow effects are random variables with zero means and known variances. This provides more accurate predictions of herd and cow differences than usual least squares methods which treat all effects as fixed. Hence solutions for fixed effects are improved by these assumptions. Due to the large number of herds and cows the BLUP equations for the full model can not be stored in the memory of a computer. Therefore, the following absorption process was used since solutions to the fixed effects were of primary concern.

Step 1. Data were sorted by cow within herd within environment.

Step 2. Least squares equations for fixed effects and one herd and one cow were collected.

Step 3. After one cow equation was collected, the appropriate variance ratio was added to the diagonal and the cow equation absorbed into the herd and fixed effects equations.

Step 4. After all cows within a herd had been

absorbed, the ratio of error to herd variances was added to the diagonal element of the herd equation and absorbed into the fixed effects equations.

Step 5. Steps 2, 3, and 4 were repeated until all herds and cows were processed.

This procedure is easily programmed and executed as data are being read in from magnetic tape. Solutions for fixed effects from the resulting absorbed equations are identical to solving the entire BLUP equations. The estimates of ANS subclass means are shown in Tables 4, 5, 6, and 7. Tests of hypotheses were made using the general linear hypothesis as discussed in Searle (1971). Results of these tests are summarized in Table 8.

RESULTS AND DISCUSSION

There was no evidence that three-way interactions were significant except for age of dam by sex by feeding system for Herefords. No reports on this interaction were found in the literature.

There was no evidence that age of dam interacted with type of feeding. In a study of weaning weights, Cundiff et al. (1966a) also reported a nonsignificant age of dam by type of management interaction. There was, however, a significant age of dam by level of herd performance interaction not reported previously in the literature. Increases in cow age apparently result in smaller increases in calf gains at high herd levels than at lower herd levels.

Age of dam also appears to interact with sex for both Angus and Herefords. Cundiff et al. (1966a) and Cardellino and Frahm (1971), however, found opposite results.

Sex of calf appears to interact with both type of feeding and herd levels. Marlowe and Gaines (1958) analyzed their data for each feeding system separately, and found the differences between sexes to be similar

Table 3. Method 2 estimates of variance components, repeatability, and variance ratios for preweaning average daily gain (ADG)

	Angus	Hereford
Herd variance (kg/day) ²	.0058	.0094
Cow variance (kg/day) ²	.0031	.0048
Error variance (kg/day) ²	.0084	.0098
Repeatability	.27	.33
Error/cow ratio	2.6921	2.0174
Error/herd ratio	1.4606	1.0354

Table 4. Age of dam by sex by feeding system estimated subclass means for preweaning ADG (kg/day) for Angus

Age of dam (mo)	Noncreep				Creep			
	Males		Females		Males		Females	
	EM†	SE‡	EM	SE	EM	SE	EM	SE
22-24	.796	.008	.734	.007	.832	.013	.755	.013
25-30	.804	.006	.719	.006	.836	.010	.743	.010
31-35	.844	.007	.766	.007	.906	.011	.808	.012
36	.860	.007	.761	.007	.885	.012	.798	.012
37	.850	.007	.767	.007	.892	.015	.792	.014
38-42	.837	.008	.769	.008	.883	.012	.792	.012
43-47	.878	.007	.787	.007	.913	.011	.817	.011
48	.879	.007	.797	.007	.920	.012	.835	.012
49	.880	.007	.799	.008	.914	.014	.821	.013
50-54	.861	.008	.789	.008	.909	.013	.816	.012
55-66	.892	.005	.806	.005	.915	.009	.836	.009
67-78	.898	.005	.809	.005	.931	.009	.830	.009
79-102	.903	.005	.814	.005	.930	.008	.849	.008
103-192	.902	.005	.810	.005	.946	.008	.837	.008

†EM = Estimated subclass mean.

‡SE = Standard error (kg/day).

in both feeding systems, indicating no interaction of sex with type of feeding. However, Cundiff et al. (1966a) did find a significant interaction, but did not make a joint adjustment for sex and feeding system in their next study (1966b) indicating that on a practical basis this interaction was not important.

For Angus the regressions of ADG on age at weaning for both herd levels and feeding systems were $b_1 = -0.0010$ and $b_2 = -0.000008$. The corresponding regressions for Herefords were $b_1 = -0.0006$ and $b_2 = -0.000006$. Although the hypothesis tests were highly significant these regressions

Table 5. Age of dam by sex by feeding system estimated subclass means for preweaning ADG (kg/day) for Herefords

Age of dam (mo)	Noncreep				Creep			
	Males		Females		Males		Females	
	EM†	SE‡	EM	SE	EM	SE	EM	SE
22-24	.756	.007	.693	.006	.822	.012	.756	.010
25-30	.752	.005	.699	.004	.816	.007	.745	.007
31-35	.830	.005	.744	.005	.894	.008	.809	.009
36	.815	.005	.743	.005	.893	.008	.805	.008
37	.817	.005	.746	.005	.870	.009	.810	.009
38-42	.785	.005	.748	.005	.865	.009	.788	.009
43-47	.861	.005	.783	.005	.928	.009	.830	.008
48	.859	.005	.786	.005	.928	.008	.835	.008
49	.851	.005	.785	.005	.929	.009	.828	.009
50-54	.862	.006	.778	.006	.919	.010	.839	.010
55-66	.883	.004	.804	.004	.949	.007	.860	.007
67-78	.895	.004	.821	.004	.966	.007	.862	.007
79-102	.901	.004	.821	.004	.968	.006	.868	.007
103-192	.894	.004	.811	.004	.952	.007	.861	.007

†EM = Estimated subclass mean.

‡SE = Standard error (kg/day).

Table 6. Age of dam by sex by level of herd performance estimated subclass means for preweaning ADG (kg/day) for Angus

Age of dam (mo)	<i>Low</i>				<i>Medium</i>				<i>High</i>			
	Males		Females		Males		Females		Males		Females	
	EM†	SE‡	EM	SE	EM	SE	EM	SE	EM	SE	EM	SE
22-24	.659	.016	.616	.015	.801	.010	.732	.008	.898	.012	.824	.013
25-30	.668	.012	.609	.011	.799	.007	.714	.007	.918	.009	.814	.009
31-35	.739	.014	.666	.012	.845	.009	.764	.009	.957	.012	.859	.013
36	.757	.017	.657	.014	.852	.009	.764	.009	.953	.011	.847	.011
37	.699	.019	.659	.015	.848	.010	.766	.010	.966	.013	.851	.013
38-42	.736	.014	.656	.012	.816	.010	.769	.010	.968	.013	.857	.013
43-47	.782	.014	.678	.011	.862	.009	.791	.009	.987	.011	.869	.012
48	.778	.018	.709	.017	.872	.010	.793	.009	.979	.011	.884	.012
49	.768	.019	.694	.017	.878	.010	.803	.011	.973	.012	.871	.013
50-54	.751	.017	.683	.014	.873	.012	.781	.012	.952	.013	.887	.015
55-66	.784	.009	.706	.008	.885	.005	.802	.005	.985	.006	.894	.007
67-78	.792	.009	.712	.009	.889	.005	.804	.005	1.000	.007	.890	.007
79-102	.787	.008	.719	.007	.893	.005	.813	.005	1.005	.005	.898	.005
103-192	.773	.007	.703	.006	.897	.004	.809	.004	1.015	.005	.899	.005

†EM - Estimated subclass mean.

‡SE - Standard error (kg/day).

have little effect on ADG considering the range of age usually encountered. These values agree with those summarized by Kennedy (1972), but are smaller than those reported by Koch and Clark (1955). The inclusion of age at weaning and age at weaning squared as covariates in the model could be ignored in future analyses on preweaning ADG.

The question of the importance of these interactions in correction of preweaning ADG by either additive or multiplicative factors for age of dam and sex of calf for cow culling purposes and for age of dam for either bull or heifer replacements remains to be considered. The effectiveness of currently used multiplicative age-of-dam adjustments is unknown. The results in this study indi-

Table 7. Age of dam by sex by level of herd performance estimated subclass means for preweaning ADG (kg/day) for Herefords

Age of dam (mo)	<i>Low</i>				<i>Medium</i>				<i>High</i>			
	Males		Females		Males		Females		Males		Females	
	EM†	SE‡	EM	SE	EM	SE	EM	SE	EM	SE	EM	SE
22-24	.640	.011	.606	.010	.743	.010	.686	.008	.901	.011	.801	.011
25-30	.651	.006	.612	.006	.743	.005	.684	.005	.877	.006	.805	.006
31-35	.727	.008	.659	.007	.829	.006	.746	.006	.945	.008	.838	.008
36	.715	.008	.654	.008	.813	.006	.746	.006	.938	.007	.840	.007
37	.710	.009	.648	.008	.801	.006	.744	.006	.946	.007	.857	.008
38-42	.694	.009	.642	.008	.803	.007	.740	.007	.923	.008	.857	.008
43-47	.753	.008	.694	.008	.857	.007	.778	.006	.987	.007	.877	.007
48	.753	.008	.687	.008	.859	.006	.787	.006	.979	.007	.882	.007
49	.737	.009	.687	.009	.848	.007	.782	.007	.987	.008	.882	.008
50-54	.762	.010	.688	.010	.856	.008	.776	.008	.974	.009	.880	.010
55-66	.775	.005	.711	.005	.885	.004	.801	.004	1.000	.004	.906	.004
67-78	.786	.005	.731	.005	.898	.004	.818	.004	1.013	.004	.909	.005
79-102	.798	.004	.726	.004	.902	.003	.821	.003	1.015	.004	.915	.004
103-192	.783	.004	.719	.004	.896	.003	.809	.003	1.005	.004	.907	.004

†EM - Estimated subclass mean.

‡SE - Standard error (kg/day).

Table 8. Tests of hypotheses

Source	DF	Mean squares (kgs/day) ²	
		Angus	Hereford
<i>Feeding systems</i>			
A	13	.75**	4.13**
N	1	.14**	.69**
S	1	15.86**	36.72**
AN	13	.01	.01
AS	13	.02*	.06**
NS	1	.04*	.25**
ANS	13	.01	.02*
R†	2	1.38**	1.26**
<i>Levels of herd performance</i>			
A	13	.94**	5.04**
N	2	1.75**	3.18**
S	1	17.78**	43.48**
AN	26	.02**	.03**
AS	13	.02**	.06**
NS	2	.19**	.79**
ANS	26	.01	.01
R†	2	1.32**	1.20**

*P = 0.05 level of significance.

**P = 0.01 level of significance.

†Regressions for age at weaning and age at weaning squared.

cate that simultaneous adjustment for two or more factors should be considered. At present no adjustments are made for sex of calf in the Canadian Federal Record of Performance (ROP) Program. A comparison of several additive and multiplicative adjustment procedures derived from estimated subclass means in this study with the currently used ROP factors is the obvious next step. Suitable criteria for making these comparisons need to be evaluated at the same time.

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BROWN, C. J. 1960. Influence of year and season of birth, sex, sire and age of dam on weights of beef calves at 60, 120, 180, and 240 days of age. *J. Anim. Sci.* **19**: 1062-1070.

CARDELLINO, R. and FRAHM, R. R. 1971. Evaluation of two types of age of dam correction factors for weaning weight in beef cattle. *J. Anim. Sci.* **32**: 1078-1083.

CUNDIFF, L. V., WILHAM, R. L. and PRATT, C. A. 1966a. Effects of certain factors and their two-way interactions on weaning weight in beef cattle. *J. Anim. Sci.* **25**: 972-982.

CUNDIFF, L. V., WILLHAM, R. L. and PRATT, C. A. 1966b. Additive versus multiplicative correction factors for weaning weight in beef cattle. *J. Anim. Sci.* **25**: 983-987.

CUNNINGHAM, E. P. and HENDERSON, C. R. 1965. Repeatability of weaning traits in beef cattle. *J. Anim. Sci.* **24**: 188-191.

FLOCK, D. K., CARTER, R. C. and PRIODE, B. M. 1962. Linear body measurements and other birth observations on beef calves as predictors of preweaning growth rate and weaning type score. *J. Anim. Sci.* **21**: 651-655.

FRANCOISE, J. J., VOGT, D. W. and NOLAN, Jr., J. C. 1973. Heritabilities of and genetic and phenotypic correlations among some economically important traits of beef cattle. *J. Anim. Sci.* **36**: 635-639.

HENDERSON, C. R. 1949. Estimates of changes in herd environment. *J. Dairy Sci.* **32**: 706-716.

HENDERSON, C. R. 1950. Estimation of genetic parameters. *Ann. Math. Stat.* **21**: 309. (Abstr.).

HENDERSON, C. R. 1953. Estimation of variance and covariance components. *Biometrics* **9**: 226-252.

HENDERSON, C. R. 1963. Selection index and expected genetic advance. *Statistical genetics and plant breeding. Nat. Acad. Sci.-Nat. Res. Council. Pub. no. 982.*

- HENDERSON, C. R. 1973. Sire evaluation and genetic trends. *Proc. Anim. Breed. Genet. Symp. in honor of Dr. Jay L. Lush*. Amer. Soc. Anim. Sci.-Amer. Dairy Sci. Assoc., Washington, D.C.
- HENDERSON, C. R., KEMPTHORNE, O., SEARLE, S. R. and VON KROSIGK, C. M. 1959. The estimation of environmental and genetic trends from records subject to culling. *Biometrics* **15**: 192-218.
- HENDERSON, C. R., SEARLE, S. R. and SCHAEFFER, L. R. 1974. Invariance and calculation of Method 2 of estimating variance components. (in press).
- HOHENBOKEN, W. D. and BRINKS, J. S. 1969. Effect of environmental corrections on repeatability of weaning weight in Angus. *J. Anim. Sci.* **29**: 534-540.
- KENNEDY, B. W. 1972. Data edit and age of calf adjustment. Thesis research report. Cornell University, Ithaca, New York.
- KOCH, R. M. and CLARK, R. T. 1955. Influence of sex, season of birth, and age of dam on economic traits in range beef cattle. *J. Anim. Sci.* **14**: 386-397.
- LEHMANN, R. P., GAINES, J. A., CARTER, R. C., BOVARD, K. P. and KINCAID, C. M. 1961. Selection indexes for weaning traits in beef calves. *J. Anim. Sci.* **20**: 53-57.
- MARLOWE, T. J. and GAINES, J. A. 1958. The influence of age, sex, and season of birth of calf, and age of dam on preweaning growth rate and type score of beef calves. *J. Anim. Sci.* **17**: 706-713.
- SEARLE, S. R. 1968. Another look at Henderson's methods of estimating variance components. *Biometrics* **24**: 749-788.
- SEARLE, S. R. 1971. *Linear models*. Wiley, New York.