

COMPARISON OF THE EFFECTIVENESS OF MULTIPLICATIVE AND ADDITIVE ADJUSTMENT FACTORS IN PREWEANING AVERAGE DAILY GAIN OF BEEF CATTLE

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Sixteen adjustment procedures were used to correct 16,529 Angus and 47,293 Hereford preweaning average daily gain records from the 1971-1972 Canadian Federal-Provincial Record of Performance (ROP) Program. Two criteria were defined to determine the appropriateness of additive- or multiplicative-type adjustments and to determine the best of 16 adjustment procedures. Included in the comparisons were the currently used multiplicative ROP age-of-dam factors. Tests for interactions of time with age-of-dam by sex-of-calf by environment subclasses indicated a preference for additive-type factors. The best adjustment procedure of those compared for removing age-of-dam effects and interactions of age of dam with sex and environment was the additive simultaneous adjustment for age of dam, sex of calf, and feeding system. Both the scientific and practical implications of this study were considered important.

On a utilisé seize techniques de correction sur les données de gain moyen quotidien après-sevrage de 16,529 veaux Angus et de 47,293 veaux Hereford. Ces données provenaient du Programme fédéral-provincial canadien de contrôle des aptitudes pour 1971 et 1972. Deux modèles mathématiques ont servi à établir la valeur des corrections de types additif ou multiplicateur, et à choisir les meilleures des seize techniques de correction. Les comparaisons comprenaient les facteurs multiplicateurs pour l'âge de la mère, couramment utilisés dans le Programme du contrôle des aptitudes. Les épreuves d'interaction entre le temps, l'âge de la mère, le sexe du veau et les sous-classes de types d'élevage ont fait ressortir une préférence pour les facteurs de type additif. Parmi les techniques de correction utilisées pour éliminer les effets de l'âge de la mère et les interactions âge de la mère-sexe-type d'élevage, la meilleure était la correction additive simultanée pour l'âge de la mère, le sexe du veau et le système d'alimentation. On considère les résultats de cette étude importante, autant des points de vue scientifiques que pratiques.

Adjustment factors for age of dam have been used by cattlemen for comparing calf preweaning average daily gains (ADG) from dams of various ages in order to select replacement heifers and bulls, or to cull cows from the breeding herd. The effectiveness of currently used adjustment factors in eliminating age-of-dam effects is unknown. Recent results for the Angus and Hereford breeds have shown significant interactions of age of dam with sex of calf, age of dam with levels of herd performance, and sex of calf with feeding systems and with levels of herd performance (Schaeffer and Wilton 1974). These results indicate that simultan-

eous adjustment for two or more factors may be more appropriate than the simple factors now used. At present no adjustments are made for sex of calf in the Canadian Federal-Provincial Record of Performance (ROP) Program for Beef Cattle (1972-73), and only one set of factors is used across all breeds of cattle that are recorded.

Another consideration is whether multiplicative or additive factors should be used, since both types have been used during the history of the Canadian ROP Program. A similar problem in dairy cattle is the age-month of calving adjustment of milk and fat yields. Statistically, adjustment factors are often derived from estimates of subclass

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means obtained from linear model procedures. The problem arises in using such means to adjust future records or a different set of data.

The objectives of this study were to compare the effectiveness of different adjustment procedures in eliminating age-of-dam, sex-of-calf, and environment effects and their interactions from preweaning average daily gains, and to determine the most appropriate type of adjustment for Angus and Hereford preweaning ADG records.

DATA

Canadian ROP records collected from 1964 through 1970 were used in a previous study (Schaeffer and Wilton 1974) to estimate age-of-dam by sex-of-calf by environment subclass means, eliminating herd and cow effects. The estimated means were used to develop 14 sets of adjustment factors. These and two versions of the currently used age-of-dam adjustment factors are described in Table 1. Data for 1971–1972 became available and were used in comparing the 16 sets of adjustment factors. Thus, the factors were applied to data other than the data from which they were derived, although still Canadian ROP records.

The following edits were made before making any comparisons: (1) only Angus and Hereford records were used; (2) all steers were deleted; (3) limits on age of dam were 22 to 192 mo; (4) limits on weaning weight were 68–431 kg; (5) limits on age at weaning were 130–280 days; (6) all missing values were deleted;

(7) all duplicate records were deleted. A total of 25,309 Angus and 68,850 Hereford records remained after these edits for data prior to 1971, and an additional 16,529 Angus and 47,293 Hereford records were obtained from the 1971–1972 calving years. Approximately 11% of the original data for all years was lost through the edit procedure.

MODEL AND METHODS

Two criteria were selected for determining the best of 16 adjustment procedures described in Table 1. Each criterion utilizes a different model to achieve the required objectives.

Criterion 1

The first objective is to determine whether additive- or multiplicative-type factors are suitable for adjusting preweaning average daily gain (ADG) by examining the interactions of time with age-of-dam by sex by environment subclasses. The presence of interactions of age of dam with time would indicate that possibly multiplicative adjustments should be used. This would be further determined by graphing the estimated subclass differences to check for a definable interaction. The absence of any interaction of age of dam with time would imply constant differences over time, and favor the use of additive age-of-dam adjustment factors.

All records from 1964 to 1972 were combined into four time periods of 3, 2, 2, and 2 yr to form age-of-dam by sex by environment subclasses with adequate number of observations. Age of dam was classified into four groups, 22–30, 31–42, 43–54, and 55–192 mo, referred to

Table 1. Description of adjustment procedure

Set	Code	Description	Type†
1	ROP	Currently used ROP factors	M
2	SROP	ROP factors with sex adjustment	M
3	A:S:HL	Age-within-sex, within-herd levels	M
4	A:HL	Age-within-herd levels to midsex base	M
5	AS:HL	Age–sex-within-herd levels, base is male, 5-yr-old	M
6	A:S:HL	Age-within-sex, within-herd levels	A
7	A:HL	Age-within-herd levels to midsex base	A
8	AS:HL	Age–sex-within-herd levels, base is male, 5-yr-old	A
9	A:S:F	Age-within-sex-within-feeding-system	M
10	A:F	Age-within-feeding-system to midsex base	M
11	AFS	Age–sex–feeding system, base is creep, male, 5-yr	M
12	AS:F	Age–sex-within-feeding-system, base is male, 5-yr	M
13	A:S:F	Age-within-sex-within-feeding-system	A
14	A:F	Age-within-feeding-system to midsex base	A
15	AFS	Age–sex–feeding system, base is creep, male, 5-yr	A
16	AS:F	Age–sex-within-feeding-system, base is male, 5-yr	A

†M, multiplicative; A, additive.

in this study as 2-, 3-, 4-, and 5-yr-olds, respectively. Further subdivision of age of dam into groups with smaller intervals was found to be unnecessary (Schaeffer and Wilton 1974). Two types of environments considered were levels of herd performance (low, medium, and high) and feeding systems (noncreep versus creep).

Each breed was analyzed separately using the following model:

$$y_{ijklmno} = (TANS)_{ijkl} + H_{km} + C_{kmn} + e_{ijklmno}$$

where $y_{ijklmno}$ = an adjusted preweaning ADG record;

T_i = a constant common to all records in i^{th} time period;

A_j = a constant common to all dams in the j^{th} age-of-dam group;

N_k = a constant common to all records in the k^{th} environment level;

S_l = a constant common to each sex-of-calf group;

$(TANS)_{ijkl}$ = contains all main effects, two-way, three-way, and four-way interactions of time, age of dam, environment, and sex of calf;

H_{km} = a random effect common to all records in the m^{th} herd with the k^{th} environment level with mean zero and variance σ_h^2 ;

C_{kmn} = a random effect common to the calves of the n^{th} cow in the m^{th} herd within the k^{th} environment level with mean zero and variance σ_c^2 ;

and $e_{ijklmno}$ = a random error term associated with each record with zero mean and variance σ_e^2 .

The assumed population parameters for σ_h^2 , σ_c^2 , and σ_e^2 were 0.0058, 0.0031, and 0.0084 for Angus, and 0.0094, 0.0048, and 0.0098 for Herefords, respectively, in kg^2/day^2 (Schaeffer and Wilton 1974). Henderson's (1973) best linear unbiased prediction procedures (BLUP) were used to estimate (TANS) subclass means eliminating random herd and cow effects, and hypothesis tests were computed as outlined by Searle (1971).

Criterion 2

Seven additive and seven multiplicative sets of adjustment factors were constructed from the results of a previous study utilizing the data from 1964 through 1970. In addition, the currently used ROP multiplicative adjustments with and without a 10% sex adjustment (Beef Improvement Federation Recommendation 1972) were used to adjust all records made in 1971 and 1972. Different adjustment factors were used for each breed except the ROP factors, which were used for both Angus and Hereford. Adjusted records were analyzed for the presence of age-of-dam and age-of-dam interaction effects. The better sets of adjustment factors would be those that eliminate all age-of-dam effects and interactions, and also agree with the results of criterion 1. It is likely that all sets of factors remove age-of-dam effects, but not the interactions of sex and environment with age of dam. The number of observations for each ANS subclass are given in Tables 2 and 3.

The model used for this criterion was:

$$p_{ijklmno} = (ANS)_{ijkl} + H_{km} + C_{kmn} + e_{ijklmno}$$

where $p_{ijklmno}$ is an ADG record adjusted by the p^{th} set of factors. The definitions of other elements are the same as in criterion 1. Time effect was excluded since data were from only one time period.

Table 2. Distribution of observations by age of dam and levels of herd performance for 1971-1972 data

Age of dam (yr)	Low		Medium		High	
	Males	Females	Males	Females	Males	Females
<i>Angus</i>						
2	145	199	366	415	448	497
3	185	281	374	458	551	559
4	173	231	368	398	493	465
5	729	1,036	1,815	2,090	2,160	2,093
<i>Hereford</i>						
2	749	796	1,077	1,255	932	1,012
3	909	1,081	1,415	1,614	1,283	1,337
4	860	894	1,318	1,417	1,153	1,169
5	3,080	3,396	5,505	5,642	4,800	4,599

Table 3. Distribution of observations by age of dam and feeding system for 1971-1972 data

Age of dam (yr)	Noncreep		Creep	
	Males	Females	Males	Females
<i>Angus</i>				
2	811	918	148	193
3	920	1,102	190	196
4	860	953	174	141
5	4,022	4,506	682	713
<i>Hereford</i>				
2	2,161	2,430	597	633
3	2,938	3,290	669	742
4	2,698	2,846	633	634
5	10,791	11,164	2,594	2,473

RESULTS AND DISCUSSION

The use of a linear model to estimate age-of-dam effects implies that additive factors should be used to correct observations. This statement is true, assuming that a linear model is appropriate for estimating age-of-dam differences. Multiplicative factors have been used in the past in order to equalize means and variances of each age-of-dam group. Usually, as the mean of a population increases so does the variance of the records, but the question here is whether or not the variance of records within each age-of-dam group is the same. Indications from this set of data (Table 4) and that of Cundiff et al. (1966) suggest that it is reasonable to assume equal variances in each age-of-dam group. Additive adjustments should be used in order not to change the variance of records within an age-of-dam group. For the data from which adjustment factors are derived, either multiplicative or additive factors should adequately eliminate the age-of-dam effects, but not necessarily for other data.

An additive factor suggests that the difference between two means is constant over a period of time even if the individual means increased or decreased with time. If plotted on a graph, the lines for the two means would be parallel. Multiplicative factors suggest that these lines should either diverge or converge over time, and the difference between two means changes proportionally to changes in the means. Neither assumption may be true, making it necessary to include these effects in a model every time new data are to be analyzed. An analysis of age-of-dam by time interaction over 8 yr would give an indication of the appropriate type of adjustment.

Searle and Henderson (1960) considered the effects of types of adjustments on (1) repeatability, (2) coefficients of variation, (3) age-group means, (4) variance components, and (5) regressions on age. They concluded that (1) none of the five criteria could be used singly as a basis for comparison, (2) age corrections have nothing to do with repeatability, and (3) if coefficients of varia-

Table 4. Raw means and standard deviations of unadjusted 1971-1972 Angus and Hereford preweaning average daily gain records by age-of-dam groups (kg/day)

Age of dam (yr)	Angus		Hereford	
	Males	Females	Males	Females
2	.80±.13	.73±.12	.75±.15	.70±.13
3	.84±.15	.77±.12	.80±.15	.74±.12
4	.87±.14	.79±.12	.85±.15	.78±.13
5	.90±.13	.81±.12	.88±.15	.80±.12

tion were to be equal for all age groups, then multiplicative factors should be used. However, equalizing coefficients of variation implies that other adjustments (i.e. environmental trends) should also satisfy this criterion. Searle and Henderson (1960) considered this restriction unreasonable. The other criteria only determined whether age effects had been eliminated by the adjustment procedures.

The criterion of equalizing subclass means and variances can be readily accomplished by setting all records to a constant value, as pointed out by Searle and Henderson (1960). Also, any adjustment procedure can be modified to yield any desired mean and variance. This criterion does not guarantee that the adjustment procedure has eliminated all age-of-dam effects.

Since interactions between age of dam, sex, and levels of herd performance may exist, an appropriate criterion would be to select any adjustment procedure that eliminates these interactions as well as the main age-of-dam effects. Other interactions that were not present in the unadjusted data should not appear as a result of the adjustment procedure.

Table 5 shows the raw means and standard deviations of adjusted ADG records for 1971–1972. The reason for differences in raw means is due to the different bases to which each set of factors adjusts. In all cases, the raw mean of adjusted records is higher than the raw mean of unadjusted records, since adjustments increase all records to a mature-cow basis. It is interesting to note that although the mean of a particular multiplicative adjustment procedure (e.g. set 4) is the same as that of the corresponding additive adjustment procedure (e.g. set 7), the variance of additively adjusted records is lower than that of multiplicatively adjusted records. Also, the variances of additively adjusted records are less than the variance of unadjusted records; however, the variances of records within age-of-dam groups are equal, as shown in Table 4. The use of multiplicative factors tends to change the variance by the square of the factor used for a particular age-of-dam group. Since all multiplicative factors were equal to or greater than one, then all variances would be increased over those for unadjusted records. Now the variances of records within age-of-dam groups are no longer equal. The

Table 5. Raw means and standard deviations of adjusted ADG records for 1971–1972 data in kg/day

Set	Code†	Type‡	Angus		Hereford	
			Mean	SD	Mean	SD
0	unadjusted		.855	.154	.821	.162
1	ROP	M	.888	.158	.853	.163
2	SROP	M	.932	.158	.894	.165
3	A:S:HL	M	.875	.154	.853	.160
4	A:HL	M	.875	.154	.853	.160
5	AS:HL	M	.924	.155	.895	.164
6	A:S:HL	A	.878	.150	.853	.156
7	A:HL	A	.875	.151	.853	.155
8	AS:HL	A	.924	.147	.895	.154
9	A:S:F	M	.876	.156	.853	.163
10	A:F	M	.876	.156	.853	.162
11	AFS	M	.952	.159	.947	.174
12	AS:F	M	.924	.155	.894	.165
13	A:S:F	A	.876	.152	.853	.156
14	A:F	A	.876	.152	.853	.156
15	AFS	A	.950	.143	.948	.150
16	AS:F	A	.923	.143	.895	.152

†ROP, current ROP factors; S, sex; A, age of dam; HL, herd levels; F, feeding systems; and :, within.

‡M, multiplicative; A, additive.

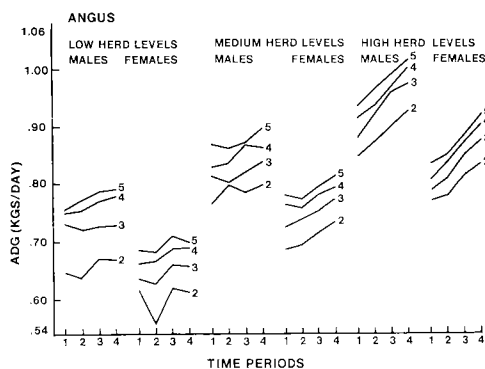


Fig. 1. Change in estimated age-of-dam means over time-within-herd level by sex-of-calf subclasses for Angus (2, 2-yr-olds; 3, 3-yr-olds; 4, 4-yr-olds; 5, 5 yr or older).

same effects were observed and discussed by Cundiff et al. (1966). On this basis, they concluded that additive age-of-dam adjustments were appropriate.

On a within-sex, age-of-dam, environment subclass basis, the ranking of animals from uncorrected data would be identical to rankings obtained from corrected values using any of the factors considered in this paper. However, within a herd, over all sexes and ages of dam, calves will not necessarily rank similarly for additive- versus multiplicative-adjusted records. This type of comparison of calves is useful in the evaluation of sires and the selection of cows and, therefore, the

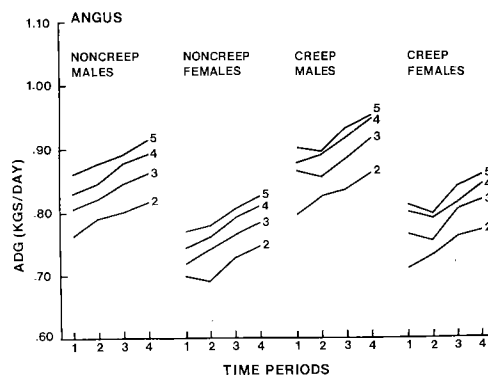


Fig. 3. Change in estimated age-of-dam means over time-within-feeding-system by sex-of-calf subclasses for Angus (2, 2-yr-olds; 3, 3-yr-olds; 4, 4-yr-olds; 5, 5 yr or older).

importance of using the most appropriate adjustment procedure is emphasized. The criteria defined in this paper were chosen to resolve this problem. Two important aspects of this study are (1) the scientific consideration of additive versus multiplicative adjustments, and (2) the practical implications and applications of the scientific results.

Criterion 1

Figures 1 through 4 show the changes in estimated means for each age-of-dam group within sex by environment subclasses over time. These means are free of random herd

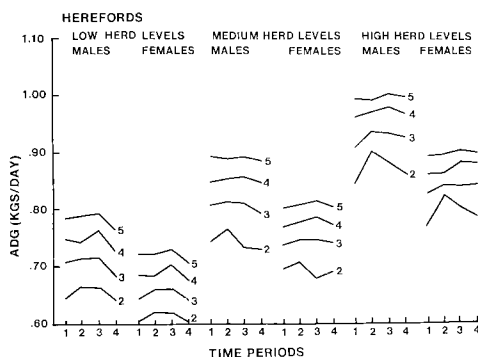


Fig. 2. Change in estimated age-of-dam means over time-within-herd level by sex-of-calf subclasses for Herefords (2, 2-yr-olds; 3, 3-yr-olds; 4, 4-yr-olds; 5, 5 yr or older).

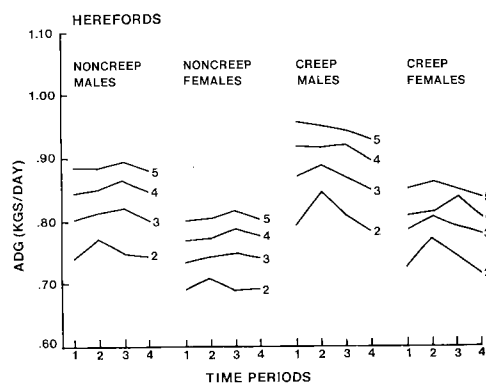


Fig. 4. Change in estimated age-of-dam means over time-within-feeding-system by sex-of-calf subclasses for Herefords (2, 2-yr-olds; 3, 3-yr-olds; 4, 4-yr-olds; 5, 5 yr or older).

and cow effects. The first obvious difference in these figures is the increase in means over time for the Angus breed, whereas means for the Hereford breed have essentially remained the same with time. This may or may not be due to the changing evolution of Canadian beef herds and the growing numbers of cattle in each breed. This may not be important considering the small percentage of calves that are ROP-tested, and which are included in this study (Federal-Provincial ROP for Beef Cattle 17th Annual Report 1972-73). The Angus cattle on ROP appear to be improving steadily, but at a different rate for each herd level and at similar rates for each feeding system. The Hereford cattle, however, show a slight decline in means over time, especially in the creep-feeding system.

Comparing the graphs with the results of the hypothesis tests (Table 6), significant time by herd level interactions exist for both Angus and Hereford. This is apparently an important interaction for Angus, since the higher level herds are improving at a faster rate than medium or low level herds. For the Hereford breed, the low and medium level herds show slightly declining or constant means over time, while the high level herds may be improving. The implication of this interaction is a preference for multiplicative herd level adjustments, if such adjustments are considered important and appropriate. Adjustment for herd level or different age-of-dam by sex adjustments within herd levels may be inappropriate due to different genetic components in each herd level.

Time by feeding system interaction was nonsignificant for Angus data, but significant for Hereford data, due to the apparent decline in means over time within the creep-feeding system.

Time by sex interactions were significant, but the mean squares for this interaction were small compared to the time by herd level mean squares. When feeding systems were the environment in the model, time by sex interactions were less important, although present at the 0.05 probability level in the Hereford data. The graphs do not show any noticeable trend, so that practically this interaction may not be important.

Time by age-of-dam interactions were significant for both environments in the Hereford data only. This could have been caused by the 2-yr-old and 4-yr-old age-of-dam groups which gave sporadic changes over time, whereas differences between the 3-yr-old and 5-yr-old group tended to be constant over time. For Angus, these interactions were nonsignificant, implying that additive adjustment procedures were more suitable. The implications of the Angus results are more important, since it was in the Angus breed that improvements in means over time took place. The difference in means for various age-of-dam groups remained constant, even though the means were increasing. Thus, additive age-of-dam by sex adjustments seem more appropriate than multiplicative factors.

Three- and four-way interactions of time with the other factors were largely nonsignificant, except for a few in the Hereford data. Other interaction results agree with previous research (Schaeffer and Wilton 1974). These results provide confidence in the use of an additive adjustment procedure over a long period of time without worrying about changes with time.

Relative values of the coefficient of determination, R^2 , were obtained using the sums of squares accounted for by the fixed effects (*TANS*) subclasses instead of the overall total sums of squares. Thus, the R^2 values in Table 6 add to 100%, and are larger than if herd and cow effects had also been included in the calculations. The main effects of time, age of dam, sex, and environment constituted from 95 to 98% of the variation, leaving only 2-5% for all the interactions combined. From this viewpoint, none of the interactions appears to be "biologically" significant for either Angus or Hereford breeds. This result also favors the use of additive adjustment factors.

Criterion 2

The 1971-1972 records were used to determine the effectiveness of removal of age-of-dam effects by the 16 different adjustment procedures. Tables 7, 8, 9, and 10 present the hypothesis test results from this part of the study. Most of these results are predictable from the types of adjustment that were

Table 6. Mean square (kg^2/day^2) for time by age-of-dam by sex by environment interactions

Source	df†	Herd performance levels				Feeding systems			
		Angus	R^2	Hereford	R^2	Angus	R^2	Hereford	R^2
T, time	3	.863**	5.1	.566**	1.0	.927**	7.4	.524**	1.2
A, age of dam	3	5.510**	32.5	31.697**	56.1	4.054**	32.4	24.970**	57.1
N, environment	2	2.437**	9.6	4.595**	5.4	.220**	0.6	.790**	0.6
S, sex of calf	1	24.316**	47.8	57.635**	34.0	21.883**	58.2	50.720**	38.6
TA	9	.004	0.1	.070**	0.4	.007	0.2	.084**	0.6
TN	6	.173**	2.0	.119**	0.4	.016	0.1	.141**	0.3
TS	3	.023*	0.1	.061**	0.1	.013	0.1	.036*	0.1
AN	6	.038**	0.5	.084**	0.3	.017	0.1	.005	0.0
AS	3	.040**	0.2	.345**	0.6	.015	0.1	.317**	0.7
NS	2	.200**	0.8	1.068**	1.3	.047*	0.1	.467**	0.4
TAN	18	.014	0.5	.028**	0.3	.014	0.3	.032**	0.2
TAS	9	.008	0.2	.009	0.0	.005	0.1	.010	0.1
TNS	6	.008	0.1	.005	0.0	.004	0.0	.027*	0.1
ANS	6	.018	0.2	.009	0.0	.007	0.1	.016	0.0
TANS	18	.009	0.3	.008	0.1	.006	0.1	.008	0.0

*Significance at 0.05 level.

**Significance at 0.01 level.

†df, degrees of freedom; R^2 , relative coefficients of determination.

Table 7. Mean squares (kg^2/day^2) of hypothesis tests for 16 sets of adjusted records for Angus with N = levels of herd performance

Set	Code†	Type‡	df:	Source						
				A 3	N 2	S 1	AN 6	AS 3	NS 2	ANS 6
0	Unadjusted			3.055**	1.964**	10.671*	.014	.041**	.156**	.008
1	ROP	M		.503**	2.268**	12.250**	.068**	.008	.183**	.011
2	SROP	M		.557**	2.484**	.026	.073**	.016	.088**	.010
3	A:S:HL	M		.001	1.858**	12.184**	.014	.009	.180**	.008
4	A:HL	M		.001	1.858**	11.728**	.014	.013	.164**	.008
5	AS:HL	M		.001	2.182**	.006	.015	.010	.044**	.008
6	A:S:HL	A		.347**	1.570**	8.467**	.284**	.312**	.510**	.269**
7	A:HL	A		.002	1.865**	10.671**	.012	.041**	.156**	.008
8	AS:HL	A		.002	2.168**	.002	.013	.008	.042**	.007
9	A:S:F	M		.010	2.152**	12.473**	.047**	.008	.169**	.010
10	A:F	M		.010	2.152**	11.691**	.047**	.014	.172**	.010
11	AFS	M		.011	2.436**	.003	.054**	.010	.081**	.009
12	AS:F	M		.010	2.379**	.002	.051**	.009	.078**	.009
13	A:S:F	A		.008	1.957**	12.508**	.014	.007	.149**	.008
14	A:F	A		.008	1.957**	10.661**	.014	.041**	.156**	.008
15	AFS	A		.008	1.887**	.004	.014	.007	.146**	.007
16	AS:F	A		.008	1.961**	.004	.014	.007	.146**	.007

*Significance at 0.05 level; **significance at 0.01 level.

†ROP, current ROP factors; S, sex; A, age of dam; HL, herd levels; F, feeding systems; and :, within.

‡M, multiplicative; A, additive.

Table 8. Mean squares (kg^2/day^2) of hypothesis tests for 16 sets of adjusted records for Angus with N = feeding systems

Set	Code†	Type‡	Source							
			df:	A 3	N 1	S 1	AN 3	AS 3	NS 1	ANS 3
0	Unadjusted			1.823**	.116**	7.942**	.006	.006	.041*	.010
1	ROP	M		.476**	.138**	9.210**	.012	.005	.052*	.013
2	SROP	M		.521**	.154**	.063**	.012	.001	.023	.012
3	A:S:HL	M		.005	.116**	9.040**	.008	.008	.051*	.013
4	A:HL	M		.005	.115**	8.680**	.008	.002	.048*	.012
5	AS:HL	M		.005	.138**	.001	.007	.008	.012	.012
6	A:S:HL	A		.073**	.093**	7.723**	.005	.024*	.077**	.026*
7	A:HL	A		.007	.111*	7.930**	.008	.007	.042*	.010
8	AS:HL	A		.007	.130**	.000	.007	.007	.016	.011
9	A:S:HL	M		.001	.105**	8.848**	.000	.004	.012	.004
10	A:F	M		.001	.105**	8.733**	.000	.001	.045*	.012
11	AFS	M		.001	.005	.000	.000	.004	.001	.003
12	AS:F	M		.001	.120**	.000	.000	.004	.001	.003
13	A:S:F	A		.001	.101**	8.784**	.000	.003	.011	.004
14	A:F	A		.001	.101**	7.942**	.000	.006	.041*	.010
15	AFS	A		.001	.004	.007	.000	.003	.003	.004
16	AS:F	A		.001	.110**	.007	.000	.003	.003	.004

*Significance at 0.05 level; **significance at 0.01 level.

†ROP, current ROP factors; S, sex; A, age of dam; HL, herd levels; F, feeding systems; and :, within.

‡M, multiplicative; A, additive.

Table 9. Mean squares (kg^2/day^2) of hypothesis tests for 16 sets of adjusted records for Herefords with N = levels of herd performance

Set	Code†	Type‡	df:	Source						
				A 3	N 2	S 1	AN 6	AS 3	NS 2	ANS 6
0	Unadjusted			16.999**	3.440**	22.939**	.059**	.244**	.606**	.011
1	ROP	M		.513**	3.951**	26.051**	.169**	.120**	.695**	.013
2	SROP	M		.552**	4.315**	.652**	.182**	.127**	.200**	.011
3	A:S:HL	M		.019	3.165**	28.602**	.072**	.047**	.483**	.030**
4	A:HL	M		.019	3.165**	25.960**	.072**	.117**	.630**	.011
5	AS:HL	M		.018	3.721**	.333**	.076**	.052**	.003	.030**
6	A:S:HL	A		.010	3.198**	29.158**	.049**	.036*	.493**	.024*
7	A:HL	A		.010	3.198**	22.939**	.049**	.244**	.606**	.011
8	AS:HL	A		.010	3.763**	.332**	.050**	.036*	.004	.024*
9	A:S:F	M		.018	3.916**	28.967**	.152**	.042**	.742**	.015
10	A:F	M		.018	3.913**	26.035**	.151**	.115**	.687**	.013
11	AFS	M		.019	4.334**	.298**	.180**	.055**	.208**	.014
12	AS:F	M		.017	4.314**	.259**	.163**	.048**	.188**	.013
13	A:S:F	A		.014	3.428**	29.663**	.057**	.031*	.628**	.011
14	A:F	A		.014	3.427**	22.939**	.057**	.244**	.605**	.011
15	AFS	A		.013	3.067**	.318**	.057**	.032*	.526**	.011
16	AS:F	A		.014	3.479**	.316**	.057**	.032*	.528**	.011

*Significance at 0.05 level; **significance at 0.01 level.

†ROP, current ROP factors; S, sex; A, age of dam; HL, herd levels; F, feeding systems; and :, within.

‡M, multiplicative; A, additive.

Table 10. Mean squares (kg^2/day^2) of hypothesis tests for 16 sets of adjusted records for Herefords with N = feeding systems

Set	Code†	Type‡	df:	Source						
				A 3	N 1	S 1	AN 3	AS 3	NS 1	ANS 3
0	Unadjusted			12.198**	.284**	17.810**	.018	.177**	.157**	.007
1	ROP	M		.451**	.320**	20.277**	.014	.086**	.187**	.009
2	SROP	M		.489**	.346**	.139**	.017	.085**	.112**	.012
3	A:S:HL	M		.028*	.259**	21.825**	.035*	.038**	.146**	.005
4	A:HL	M		.027*	.259**	19.996**	.034*	.092**	.167**	.008
5	AS:HL	M		.029*	.300**	.096**	.042**	.037**	.042*	.006
6	A:S:HL	A		.014	.266**	22.191**	.026*	.029*	.140**	.004
7	A:HL	A		.014	.266**	17.747**	.025	.181**	.154**	.006
8	AS:HL	A		.015	.309**	.104**	.028*	.026*	.034	.004
9	A:S:F	M		.029*	.233**	22.903**	.047**	.020	.275**	.009
10	A:F	M		.029*	.232**	20.182**	.047**	.084**	.175**	.009
11	AFS	M		.031*	.062*	.084**	.057**	.022	.014	.015
12	AS:F	M		.032*	.330**	.076**	.056**	.020	.011	.014
13	A:S:F	A		.009	.257**	23.266**	.025	.015	.265**	.008
14	A:F	A		.009	.257**	17.810**	.025	.177**	.157**	.007
15	AFS	A		.009	.045*	.112**	.025	.015	.000	.008
16	AS:F	A		.009	.375**	.112**	.025	.015	.000	.008

*Significance at 0.05 level; **significance at 0.01 level.

†ROP, current ROP factors; S, sex; A, age of dam; HL, herd levels; F, feeding systems; and :, within.

‡M, multiplicative; A, additive.

used. For example, set 3 factors adjusted for age of dam within each sex and within each herd level, and thus sex and herd level effects are still present in the adjusted records, as well as the sex by herd level interaction.

These four tables illustrate the failure of the currently used ROP factors to remove age-of-dam effects, as well as the further disadvantage of introducing an age-of-dam by herd level interaction which did not exist in the unadjusted Angus data. The 10% sex-of-calf adjustment also failed to remove sex-of-calf differences. The relative magnitudes of mean squares for adjustment sets 1 through 16 show the superior ability of the newer adjustment factors over the current ROP factors, but differences between

additive and multiplicative adjustment sets are very minor.

For Angus, sets 3, 4, 5, 8, 13, 15, and 16 removed age-of-dam and age-of-dam interaction effects. Four of these sets are the additive-type factors. For Hereford, age-of-dam by herd performance level interaction was statistically significant for all adjustment procedures. Since there were large numbers of Herefords, very small differences could be detected. These differences were no larger than in Angus and were biologically unimportant. Thus, on a practical basis, sets 13, 15, and 16 would remain as viable procedures. Since adjustments for herd levels or within-herd levels may include adjustments for genetic differences, sets 13, 15, and 16 appear suitable for removing the

Table 11. Estimated age-of-dam by sex-of-calf by levels of herd performance subclass means (kg/day) for preweaning ADG for 1971–1972 data for Angus

Set	Code†	Type‡	Age of dam (yr)	Low		Medium		High	
				Males	Females	Males	Females	Males	Females
0	Unadjusted		2	.671	.612	.789	.726	.917	.826
			3	.735	.662	.830	.767	.966	.866
			4	.780	.689	.857	.789	.993	.894
			5	.794	.703	.889	.807	1.012	.912
1	ROP	M	2	.774	.707	.907	.834	1.055	.951
			3	.810	.726	.914	.845	1.062	.955
			4	.821	.725	.899	.827	1.044	.940
			5	.792	.703	.889	.807	1.012	.913
2	SROP	M	2	.773	.779	.906	.918	1.055	1.046
			3	.810	.799	.914	.930	1.062	1.050
			4	.821	.798	.899	.909	1.044	1.033
			5	.792	.773	.889	.888	1.012	1.003
3	A:S:F	A	2	.771	.699	.885	.807	1.016	.912
			3	.785	.703	.880	.812	1.012	.912
			4	.807	.708	.880	.803	1.016	.912
			5	.794	.703	.889	.807	1.012	.912
4	AFS	A	2	.798	.816	.912	.925	1.039	1.025
			3	.816	.821	.907	.930	1.039	1.025
			4	.835	.826	.907	.921	1.043	1.025
			5	.821	.821	.916	.925	1.034	1.025
5	AS:F	A	2	.771	.785	.885	.898	1.016	1.002
			3	.785	.794	.880	.903	1.012	1.002
			4	.803	.798	.880	.894	1.016	1.002
			5	.794	.794	.889	.898	1.012	1.002
Standard errors			2	.012	.011	.009	.008	.008	.008
			3	.011	.010	.009	.008	.007	.007
			4	.012	.011	.009	.008	.008	.008
			5	.009	.009	.007	.007	.006	.006

OP, current ROP factors; S, sex; A, age of dam; F, feeding system; and :, within.
†, multiplicative; A, additive.

majority of age-of-dam and/or sex differences within herd levels. Also, if selection of cows is conducted within a herd level, then this interaction is not practically important.

Set 13 does not make any adjustment for sex or feeding system. The interaction of sex with feeding systems was eliminated in the Angus data, but not in the Hereford data. Sets 15 and 16 were equal in removing sex and sex by feeding-system interactions for Angus, but both sets failed to statistically eliminate sex differences in the Hereford data. These breed differences are also due to the smaller standard errors on estimated subclass means for Herefords than for Angus. Tables 11 through 14 show the estimated subclass means and standard errors for data

adjusted by sets 1, 2, 13, 15, and 16, free of herd and cow effects.

Tables 11 through 14 show that the current ROP factors tended to overadjust 2-3-, and 4-yr-old Angus records in each herd level, and underadjusted all 2-yr-old Hereford records. The greater accuracy in sex adjustments can also be seen in sets 15 and 16 versus set 2.

Sets 15 and 16 appear to "practically eliminate age-of-dam effects within herd levels although there were enough age-of-dam variations remaining in low level herd to create statistically significant results in Tables 7 and 9. On a practical basis, a method could be argued to be adequate since the differences in adjusted means are rarely greater than 0.05 kg/day, but clearly

Table 12. Estimated age-of-dam by sex-of-calf by levels of herd performance subclass means (kg/day) of preweaning ADG for 1971-1972 data for Herefords

Set	Code†	Type‡	Age of dam (yr)	Low		Medium		High	
				Males	Females	Males	Females	Males	Females
0	Unadjusted		2	.644	.608	.735	.689	.862	.789
			3	.689	.649	.794	.739	.925	.844
			4	.735	.685	.853	.776	.971	.880
			5	.776	.717	.889	.807	.998	.903
1	ROP	M	2	.744	.699	.845	.792	.993	.908
			3	.757	.712	.874	.814	1.020	.930
			4	.771	.718	.894	.813	1.018	.926
			5	.774	.716	.887	.808	1.001	.903
2	SROP	M	2	.744	.769	.845	.872	.993	.998
			3	.757	.784	.874	.896	1.020	1.023
			4	.771	.790	.894	.894	1.019	1.018
			5	.774	.787	.888	.889	1.002	.993
13	A:S:F	A	2	.785	.726	.875	.807	1.002	.907
			3	.767	.717	.871	.807	1.007	.912
			4	.771	.717	.885	.803	1.002	.912
			5	.776	.717	.889	.807	.998	.903
15	AFS	A	2	.844	.862	.925	.943	1.048	1.034
			3	.821	.853	.925	.943	1.052	1.043
			4	.826	.853	.939	.939	1.048	1.043
			5	.835	.853	.939	.943	1.048	1.030
16	AS:F	A	2	.785	.807	.875	.889	1.002	.989
			3	.767	.798	.871	.889	1.007	.998
			4	.771	.794	.885	.889	1.002	.998
			5	.776	.794	.889	.889	1.002	.984
Standard errors			2	.007	.007	.006	.006	.006	.006
			3	.007	.007	.006	.006	.006	.006
			4	.007	.007	.006	.006	.006	.006
			5	.006	.006	.005	.005	.005	.005

†ROP, current ROP factors; S, sex; A, age of dam; F, feeding systems; and ., within.

‡M, multiplicative; A, additive.

sets 13, 15, and 16 are more precise in removing age-of-dam effects than the current ROP factors.

A third criterion is needed at this point, such as the purpose of making adjustments and the use of adjusted records. For heifer or bull selection, comparisons are based within a sex, making adjustments for sex unnecessary. For cow culling purposes, a herd level or feeding-system adjustment is not crucial for within-herd comparisons, but sex-of-calf adjustments are needed. Any comparison of cows across herds (which would be invalid) would require herd level or feeding-system adjustments. For sire evaluation purposes, all of these adjustments plus breed-of-dam corrections would be necessary for accurate evaluations.

Considering the results of the above criteria, set 15 seems to be the statistically and practically appropriate adjustment procedure for Angus and Hereford beef cattle. Thus, preweaning ADG records should be additively corrected for the simultaneous effects of age of dam, sex of calf, and feeding system. Different factors should be used for each breed of cattle, and possibly for breeds other than Angus or Hereford additive adjustments may not be appropriate.

Due to the general definition of creep feeding, the creep-feeding environment within different herds may be too variable to warrant adjustments for feeding system, and would therefore need to be removed as a herd effect. Age-of-dam by sex-of-calf ad-

Table 13. Estimated age-of-dam by sex-of-calf by feeding system subclass means (kg/day) for preweaning ADG for 1971–1972 data for Angus

Set	Code†	Type‡	Age of dam (yrs)	Noncreep		Creep	
				Males	Females	Males	Females
0	Unadjusted		2	.812	.741	.858	.765
			3	.862	.781	.912	.819
			4	.889	.806	.943	.840
			5	.916	.823	.952	.861
1	ROP	M	2	.937	.853	.990	.882
			3	.948	.859	1.005	.902
			4	.935	.847	.991	.883
			5	.915	.824	.952	.861
2	SROP	M	2	.936	.938	.990	.972
			3	.947	.944	1.004	.994
			4	.935	.931	.990	.972
			5	.914	.906	.951	.947
13	A:S:F	A	2	.912	.824	.954	.854
			3	.912	.825	.951	.860
			4	.915	.823	.960	.856
			5	.915	.823	.952	.861
15	AFS	A	2	.944	.945	.954	.946
			3	.944	.945	.951	.952
			4	.947	.944	.960	.948
			5	.947	.944	.952	.953
16	AS:F	A	2	.912	.913	.954	.946
			3	.912	.914	.951	.952
			4	.915	.912	.960	.948
			5	.915	.912	.952	.953
Standard errors			2	.006	.005	.013	.012
			3	.005	.005	.012	.012
			4	.006	.005	.013	.013
			5	.005	.004	.010	.010

†ROP, current ROP factors; S, sex; A, age of dam; F, feeding system; and ., within.

‡M, multiplicative; A, additive.

Table 14. Estimated age-of-dam by sex-of-calf by feeding system subclass means (kg/day) for preweaning ADG for 1971-1972 data for Herefords

Set	Code†	Type‡	Age of dam (yrs)	Noncreep		Creep	
				Males	Females	Males	Females
0	Unadjusted		2	.749	.699	.793	.725
			3	.805	.745	.854	.788
			4	.853	.782	.906	.817
			5	.889	.810	.939	.849
1	ROP	M	2	.861	.804	.911	.832
			3	.886	.820	.939	.867
			4	.896	.821	.952	.857
			5	.889	.811	.939	.849
2	SROP	M	2	.861	.884	.911	.915
			3	.886	.902	.939	.953
			4	.896	.903	.952	.943
			5	.890	.892	.940	.934
13	A:S:F	A	2	.889	.817	.933	.837
			3	.882	.814	.932	.848
			4	.888	.813	.939	.847
			5	.889	.810	.939	.849
15	AFS	A	2	.954	.962	.933	.933
			3	.947	.959	.932	.944
			4	.953	.958	.939	.943
			5	.954	.955	.939	.945
16	AS:F	A	2	.889	.896	.933	.933
			3	.882	.894	.932	.944
			4	.888	.893	.939	.943
			5	.889	.889	.939	.945
Standard errors			2	.004	.004	.008	.008
			3	.004	.004	.008	.008
			4	.004	.004	.008	.008
			5	.004	.004	.007	.007

†ROP, current ROP factors; S, sex; A, age of dam; F, feeding systems and :, within.

‡M, multiplicative; A, additive.

justments (set 16) could be used to solve this problem.

Statistically, additive adjustments of preweaning ADG records have been shown to be more appropriate than multiplicative adjustments. Practically, either set 15 or 16 is feasible and superior to the current ROP factors.

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