COVARIANCE STRUCTURES IN REPEATED MEASURES OF BODY WEIGHT OF *Bos indicus* BEEF CATTLE IN BRAZIL

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INTRODUCTION

Body weights taken from the same animal and analyzed as repeated measures (RM) are important for estimating growth curves, to compare treatments at specific times or averaged over time and estimate genetic parameters by random regression, because repeated structures analysis considers the trends of genetic and residual variances over time. The term RM used in this paper refers to multiple responses taken sequentially on the same animal. Such as a split-plot, in RM analysis animals are the whole-plot units and responses taken at a particular time are the sub-plot units. An efficient use of repeated measures analysis needs to determinate a covariance structure which refers to variances at individual times and correlation between measures at different times on the same animal. The objective of this work was to select the most appropriate within-subject variance-covariance matrix considering data from nine measures of body weight on the same animal, with three month intervals, from birth to 24 months, obtained from four *Bos Indicus* bovine beef cattle in Brazil: Nelore, Guzerá, Gir and Indubrasil.

MATERIAL AND METHODS

In this study, measures of body weight were analyzed , taken in three months intervals, from birth to 24 months of age of four *Bos indicus* beef cattle, born from 1972 to 1997, originated from several regions of Brazil (Nelore, Guzerá, Gir and Indubrasil,). The data used are held by the National Archive of Brazilian Zebu Breeders Association (ABCZ). The fixed effect of contemporary groups was considered as a variation factor between the animals. Multiple responses taken in sequence on the same animal show a correlation structure within animals that decreases with increasing lag between measures, that is imposed on the e_{ijk}. In the class of linear mixed model $y = X\beta + Zv + \varepsilon$, the standard model for repeated measures (Littell *et al.*, 1998) was used : $y_{ijk} = \mu + \alpha_i + d_{ij} + t_k + (\alpha t)_{ik} + \varepsilon_{ijk}$, where y_{ijk} is the response at time k on animal j in contemporaneous group i, μ is the overall mean, α_i is a fixed effect of contemporary group i, d_{ij} is the random effect of animal j in treatment i, t_k is a fixed effect of time k, $(\alpha t)_{ik}$ is a fixed interaction effect and ε_{ijk} is the random error. The objective function for REML (Wolfinger, 1993) is $-2L_R(\theta/y)=\log|V(\theta)| + [y - Xb(\theta)]'V^{-1}(\theta)\,[y-Xb(\theta)] + \log|X'V^{-1}(\theta)X| + (n-p)\log 2\pi$. The covariance structures considered in this study were : Compound Symmetry Heterogeneous : CSH, Factor-Analytic : FA(1), First-order Autoregressive Moving Average Structure : ARMA(1,1) and Unstructured : UN. The (i,j)th elements for these matrices are : $\sigma_i\sigma_j[\rho\ \mathbf{1}\ (i{\neq}j) + \mathbf{1}(i{=}j)]$ for CSH; $\sum_{k=1}^{\min(i,j,q)} \lambda_{ik}\lambda_{jk} + \sigma^2 \mathbf{1}\,(i{=}j)$ for FAC(1); $\sigma^2[\ \gamma\rho^{|i-j|-1}]$, j > i and σ^2 , j = i for ARMA(1,1) ; and σ_{ij} for UN (Bozdogan, 1987 ; Wolfinger, 1993 ; Littell *et al.*, SAS Institute, 1996). These structures were compared using three goodness of fit criteria provided by PROC MIXED : χ^2-distribution, Akaike's Information Criterion (AIC=-2 L_R + 2q) and Schwarz's Bayesian Criterion [BIC =-2$L_R(\theta/y)$ + qLog (n – p)] where q is the number of covariance parameters, n is the number of observations and p is the rank of matrix X.

RESULTS AND DISCUSSION

Table 1 describes the covariance structures and goodness of fit criteria: χ^2-distribution for the Null Model Likelihood Ratio Test, Akaike's Information Criterion (AIC) and Schwarz's Bayesian Criterion (BIC). In the form printed by PROC MIXED (Littell *et al.*, 1998), if the values are negative for AIC and BIC, the larger the value the better the structure is. On the other hand, if the values printed for AIC and BIC, are positive, the smaller is the better.

Covariance structures provided by Table 1 indicate that correlations tend to decrease with increasing length of time interval (lag) between two measures and the variances tend to increase in function of age or time, exhibiting the variance inflation phenomenon, normally observed in growth curve studies. The only exception was ARMA(1,1) for Nelore, whose diagonal elements were constant. Concerning these comments and the information criteria AIC and BIC, the FA(1) correlation, followed by ARMA(1,1) are the selected covariances for Nelore breed. The best two selected structures for the other breeds shown in Table 1 are UN and CSH for Guzerá, UN and FA(1) for Gir, UN and FA(1) for Indubrasil. Tables 2, 3, 4 and 5, show two covariance matrices for Nelore, Guzerá, Gir and Indubrasil breeds, respectively.

Table 1. Covariance structures and comparisons by goodness of fit criteria printed by PROC MIXED : χ^2 for the null model likelihood ratio test, AIC, and BIC

Breeds	Covariances[A]	χ^2	Pr>χ^2	AIC	BIC
Nelore	FA(1)	7185	<0.0001	362014	362068
	ARMA(1,1)	1681	<0.0001	367505	367523
Guzera	UN	80215	<0.0001	-206428	-206582
	CSH	62511	<0.0001	-215245	-215279
Gir	UN	59498	<0.0001	497196	497484
	FA(1)	8200	<0.0001	548422	548479
Indubrasil	UN	10067	<0.0001	52257	52458
	FA(1)	6891	<0.0001	55342	55407

[A] The best two covariance structures for each breed are showed

Table 2. Covariance for Nelore : FA(1) in the upper triangle and ARMA(1,1) in the lower triangle. W_i refers to body weight from birth (W_0) to 24 months of age

	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8
W_0	**19342**	0	0	0	0	0	0	0	0
	30847	**19347**	48	43	76	114	23	540	410
W_1	7125	**30847**	**19822**	428	768	1146	232	5424	4128
W_2	5406	7125	**30847**	**19722**	683	1020	206	4823	3669
W_3	4102	5406	7125	**30847**	**20569**	1833	369	8673	6598
W_4	3112	4102	5406	7125	**30847**	**22082**	552	12957	9859
W_5	2361	3112	4102	5406	7125	**30847**	**19454**	2611	1986
W_6	1792	2361	3112	4102	5406	7125	**30847**	**80636**	46638
W_7	1359	1792	2361	3112	4102	5406	7125	**30847**	**54827**
W_8	1031	1359	1792	2361	3112	4102	5406	7125	**30847**

Table 3. Covariance for Guzerá : UN in the upper triangle and CHS in the lower triangle. W_i refers to body weight from birth (W_0) to 24 months of age

	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8
W_0	**10**	10	20	26	30	35	43	50	54
	14	**365**	349	300	297	365	384	387	413
W_1	41	**429**	**810**	762	745	846	988	1048	1031
W_2	55	299	**783**	**1292**	1287	1355	1556	1788	1771
W_3	66	362	489	**1147**	**1962**	2045	2157	2451	2553
W_4	81	443	599	725	**1717**	**2951**	2980	3173	3292
W_5	100	545	737	891	1090	**2598**	**3891**	4049	3999
W_6	114	622	841	1017	1244	1531	**3384**	**5039**	5013
W_7	124	787	917	1110	1358	1671	1907	**4031**	**5812**
W_8	140	761	1029	1245	1524	1874	2139	2336	**5072**

Table 4. Covariance for Gir : UN in the upper triangle and FA(1) in the lower triangle. W_i refers to body weight from birth (W_0) to 24 months of age

	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8
W_0	**9**	11	27	-0,9	5	-21	68	-88	-11
	38573	**446**	300	525	590	645	558	743	451
W_1	0	**38577**	**50180**	-3785	787	1913	1164	-579	2560
W_2	0	7	**38587**	**50464**	-3844	4887	221	4163	-985
W_3	0	13	28	**38628**	**49984**	-6265	2010	3212	4983
W_4	0	22	47	92	**38728**	**71521**	-3858	361	7249
W_5	0	82	173	339	572	**40688**	**34736**	-17852	-6467
W_6	0	-76	-160	-315	-532	-1963	**40396**	**33149**	71804
W_7	0	528	1114	2191	3696	13651	-12673	**126706**	**21061**
W_8	0	477	1008	1982	3343	12346	-11462	79711	**110667**

Table 5. Covariance structures for Indubrasil breed: FA(1) in the right corner and UN in the left corner. W_i refers to body weight from birth (W_0) to 24 months of age

	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8
W_0	**600**	2	4	7	10	12	15	17	19
	19	**653**	117	207	310	381	462	523	594
W_1	22	**500**	**857**	455	679	837	1014	1148	1302
W_2	20	432	**964**	**1406**	1204	1484	1798	2036	2309
W_3	13	460	920	**1582**	**2399**	2217	2687	3042	3450
W_4	2	433	917	1572	**2546**	**3331**	3310	3748	4250
W_5	9	448	942	1606	2579	**3391**	**4613**	4543	5152
W_6	18	417	975	1770	2666	3479	**4533**	**5743**	5832
W_7	19	409	964	1864	2815	3540	4656	**5758**	**7214**
W_8	15	486	1092	2038	3171	4005	5038	6089	**7525**

CONCLUSION

The selected covariance of body weight of *Bos indicus* beef cattle in Brazil, analyzed as repeated measures, indicated that the correlation structures associated to the repeated measures taken on a same animal, tend to decrease with time interval (lag) between two measures. Moreover, the variances tend to increase with age or time, exhibiting the variance inflation phenomenon, normally observed in growth curve studies. The best two covariance structures for each breed were : Factor-Analytic : FA(1) and First-Order Autoregressive Moving Average : ARMA(1,1) for Nelore, Unstructured :UN and Compound Symmetry Heterogeneous : CSH for Guzerá, UN and FA(1) for Gir, UN and FA(1) for Indubrasil.

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