Evaluation of Strategies for Crossbreeding of Dairy Cattle in Brazil

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ABSTRACT

To compare breeding strategies, economic performance was calculated for 376 cows of six red and white Holstein-Friesian × Guzera crossbred groups (1/4 to ≥31/32 European grades), based on their accumulated dairy production (914 lactations on 60 farms) and on culling or death observations of 87 nonfreshening heifers. Performance was predicted from a genetic model based on additive-dominance and inter se mating effects for the following: utilization of F1 females, upgrading to Holstein-Friesian, new synthetic breed, crisscrossing, and modified crisscrossing (of Holstein-Friesian sires for two generations and zebu sires for one generation). On the better-managed farms, profit per day of herd life for those strategies, was equivalent to, respectively, 1.82, 1.36, –.33, .75, and 1.36 kg of milk, whereas corresponding equivalence on low management level farms was 4.64, –.95, 1.37, 2.72, and 2.23 kg. Differences between groups in culling and mortality rates were considerable in the low management level, influencing herd life and heifer cost and reducing profit of high European grades. Important economic gains may accrue from choice of a breeding strategy to match the appropriate animal genetic resources to husbandry practices. Continuous F1 heifer replacement programs may have sound economic basis, particularly for low management level farms. Crisscrossing was the second best alternative for those farms. On the better-managed farms, modified crisscrossing and upgrading had similar performance under present prices, but the former would be more profitable under higher pricing of fat and protein.
(**Key words**: Zebu crosses, Brazil, breeding strategies)

INTRODUCTION

It is generally accepted that European cattle breeds may be profitably utilized only in the more intensive tropical dairy production systems, where they may express their high genetic production potential, particularly when heat stress is attenuated by high altitude or other factors (12, 30). European breeds, however, cannot sustain adequate performance in the harsher environments, where local or naturalized breeds may be preferred because of their heat tolerance, low metabolic rate, disease and parasite resistance, or other factors (12, 13). For a range of intermediate environments, heterosis and complementarity between highly productive and adapted breeds may result in superior overall performance of crossbreds (4, 13). Because of the strong genotype × environment interaction, choosing the cattle type to match other inputs becomes an important economic decision when defining tropical dairy production systems (16).

When the National Dairy Cattle Research Centre of Brazil initiated activities in 1975, no experimental evidence was available to formulate breeding recommendations for the Southeast Region of Brazil (states of Sao Paulo, Minas Gerais, Rio de Janeiro, and Espirito Santo), which produced more than 5.2 million tons of milk/yr (57% of the country's total production) with 7.5 million cows milked. As discussed by Madalena (14), most dairy farmers kept their herds intermediate between purebred Holstein-Friesian and purebred Zebu but did

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TABLE 1. Strategies for the utilization of Holstein-Friesian (HF) and Guzera (Gu) breed resources. Expected fraction of HF genes (q) and of loci with one gene of each breed (z), for the genotypes theoretically generated by each scheme and for the actual experimental animals.

	Sire breed	Theoretical		Experimental	
		q	z	q	z
Upgrading to Holstein-Friesian	HF	1	0	≥31/32[1]	≤31/32[1]
New breed	New	5/8[2]	30/64[2]	5/8	30/64
Crisscrossing	HF	2/3	2/3	3/4	1/2
	Gu	1/3	2/3	1/4	1/2
Rotation cycle mean	. . .	1/2	2/3		
Modified crisscrossing	HF	5/7	4/7	3/4	1/2
	HF	6/7	2/7	7/8	1/4
	Gu	3/7	6/7	1/2	1
Rotation cycle mean	. . .	2/3	4/7		

[1] q = 1, z = 0 assumed for genetic models.

[2] No a priori theoretical fraction for this strategy, new breed assumed to be 5/8 HF × 3/8 Gu inter se.

not follow a defined breeding program. Several untested recommendations were being suggested by extension and technical organizations, such as: development, at individual farm level, of cattle of 5/8 Holstein-Friesian × 3/8 Zebu breeding; creation of new breeds from European × Zebu crosses; and use of purebred Holstein-Friesians under improved management systems. Given the importance of the milk industry and the potential economic impact of breeding strategy, it was deemed necessary to obtain experimental evidence for recommendations concerning the different dairy production technologies coexisting in the region.

The trial described in this paper was to compare those strategies, utilizing data on the accumulated life performance of six Holstein-Friesian × Zebu crossbred groups at commercial and experimental farms of varying management levels (16). Results for the first 8 yr are presented here. Genetic models based on breed additive differences and heterosis (5) are developed to predict and compare economic performance of alternative breeding strategies.

MATERIALS AND METHODS

Strategies Compared

Life performance (accumulated up to August 31, 1985) and disposal records were kept for red and white Holstein-Friesian (HF) × Guzera (Gu) females (376 cows and 87 nonfreshening heifers) born between 1977 and 1980. The main purpose of the investigation was to compare the following four crossbreeding strategies: 1) grading up to HF; 2) forming a new breed from HF × Zebu foundation; 3) crisscrossing HF × Zebu; or 4) modified crisscrossing, repeating the HF sire breed for two generations followed by one generation of Zebu sires. The latter procedure was suggested by Madalena (14) to maintain the crossbred herd at higher European gene fractions than those possible under crisscrossing, with small decrease of heterozygosity.

To evaluate these four strategies, batches of contemporary heifers of six HF × Gu genotypes were obtained, utilizing crossbred dams available from a previous project. The six genotypes were similar to those that would be generated by each strategy (Table 1). Thus, grading up was represented by an experimental group of registered females; the new synthetic breed was represented by 5/8 HF inter se females; the two HF grades in alternative generations of crisscrossing were approximated by the reciprocal first backcrosses (3/4 and 1/4 HF); and the three modified crisscross grades by F1, first, and second (7/8) backcrosses to HF. Expected performance under each strategy was interpolated by standard regression methods using a genetic model described herein.

Management

Females were raised at an experimental farm and distributed at mean age 22 mo to commercial cooperator farms, for further performance recording. Farms were grouped in two classes: high and low management level (HML and LML) (18). With few exceptions, each cooperator farm received a batch of six contemporary heifers, one of each crossbred group. In addition, 86 and 20 heifers were kept in two experimental farms, representing HML and LML. Genetic background, climate, management, and recording were described by Madalena (16) and Madalena et al. (18).

Females born after 1980 were not included in this study, so that the minimum age at last recording day would be 56 mo. Number of farms and females and birth date distribution are in Table 2 along with number of lactations and sires.

Amount and ingredient composition of concentrate feeds were recorded for 9750 cow/d (83% of milk records). Cows not fed according to an individual schedule (as usual in the LML) were assigned the average herd ingredient consumption on recording day.

Experimental animals and half their progeny remained the property of the research centre and were sold locally at prevailing commercial prices by a small team of supervisor technicians. Farmers agreed not to cull on yield before 7.5 yr of age, but they were encouraged to declare intention to cull. Otherwise, they made their own (supervised) culling decisions. On the experimental farms, 19% of the herd was culled on production soon after age 7.5 yr, and 5% annually thereafter. The distribution of crossbred groups by animal categories is in Table 3.

Biological Traits

Milk, fat, and protein yield were accumulated for each cow during its current herd life, defined as the time interval between first calving and end of last recorded lactation. Lactations in progress were not considered. Cows were assumed to leave the herd at the end of lactation. Intention to cull was treated as actual culling, i.e., performance was disregarded after the end of lactation when culling intention was reported, or after the end of previous lactation if cow was dry at the time. Intended culls were 33% of total (intended plus actual) culls. As discussed elsewhere (18), all available records were included irrespective of lactation length, cause of terminating record, or any other performance trait. The following production traits were considered: total number of calvings; age at first calving; milk, fat, and protein yields per day of current herd life. Fat and protein percentages were calculated from total accumulated milk and component yields.

Economic Variables

Based on work by Balaine et al. (2), profit per day (PPD), was used as the economic evaluation criterion, and calculated for each cow freshening, PPD = (income − expense)/current herd life. Profit components were income and expense. Income = total milk produced × milk price + total 10-d-old calves produced × price of calves + final cow value + expected value of cull heifer fraction associated with each cow entering herd. Dead animals had zero value. Expense = concentrates + milking labor + milk transport + heifer cost up to first calving + expected cost of (cull + dead) heifer fraction associated with each cow entering herd + other miscellaneous costs. Income and expense items were discounted to age 30 mo at 6% annual interest rate (the inflation-corrected savings account rate).

All prices were expressed relative to quota base (3.3% fat) milk price paid to farmers and averaged over 63 mo between June 1980 and August 1985, when lactations occurred. Price of 1 kg of quota base milk will be referred to as

TABLE 2. Numbers of farms, experimental heifers distributed, lactations, and sires; birth date distribution and mean recording period.

	Management level	
	High	Low
Farms	6	54
Heifers	116	347
Birth date, mo/yr		
March 1977 to August 1977	56	26
September 1977 to August 1978	60	114
September 1978 to August 1979	. . .	107
September 1979 to December 1980	. . .	100
Potential recording period, yr[1]	7.9	6.6
Lactations	403	511
Sires		
Holstein-Friesian	11	25
5/8	1	8
Guzera	6	15

[1]Mean time interval between birth and last recording, including dead and live animals.

TABLE 3. Distribution of female numbers over crossbred groups and animal categories.

	Crossbred group (HF fraction)						
	1/4	1/2	5/8	3/4	7/8	HF	Total
	High management level						
Total	26	21	14	16	24	15	116
Freshened	25	20	14	14	23	14	110
Stayed in herd	5	16	4	13	15	12	65
Culled	19	4	10	...	7	1	41
Died	1	...	...	1	1	1	4
Not freshened	1	1	...	2	1	1	6
Stayed in herd	...	...	...	...	...	...	...
Culled	...	1	...	1	1	1	4
Died	1	...	...	1	...	...	2
	Low management level						
Total	60	59	58	58	54	58	347
Freshened	48	54	38	46	43	37	266
Stayed in herd	37	51	28	38	30	22	206
Culled	9	...	4	4	6	7	30
Died	2	3	6	4	7	8	30
Not freshened	12	5	20	12	11	21	81
Stayed in herd	5	2	6	3	3	2	21
Culled	5	2	8	1	...	3	19
Died	2	1	6	8	8	16	41

1 milk equivalent (ME). Average value of 1 ME was US$.16. Quota is the average milk sold in June, July, and August (the driest months). Only fat differential is paid in Brazil. Average price was 1 + .0415 (fat percentage – 3.3) ME/kg.

Prices of calves and cull cows were from experimental animals sold and milking labor from a study on milking time (19). All other prices were from regional statistics (16). A price differential based on milk yield was calculated from prices of cows yielding <5, 5 to 10, and >10 kg/d. Initial (30 mo age) heifer price (724 ME) was assumed equal for all heifers.

The PPD calculations were based on individual measurements for traits recorded on all animals. For traits estimated from samples, each animal was assigned the mean value of its crossbred group × management level class.

Income and expense components were calculated for each cow freshening:

1. Income from milk. Individual total milk produced × milk price, based on individual fat test.
2. Final cow value. This was the sum of beef value + milk yield price differential for cows staying in herd, and beef value only for cull cows. Beef value was the group mean cull price adjusted for individual final age (Table 4). Cow price yield differential was assigned according to individual milk yield per day of last lactation.
3. Calf value. Mean prices for 10-d-old males and females were 65 and 68 ME. No influence of dam genotype on calf price was detected (16).
4. Concentrate cost. Cows were charged the mean concentrate cost per kg milk yield of their management level × crossbred group class, (Table 4).
5. Milking labor cost. Management level × crossbred group means were used (Table 4).
6. Transport costs. A fixed .06 ME/kg of milk was charged to each cow (15).
7. Heifer cost up to first freshening. The sum of initial 30-mo-old heifer price + individual number of days from 30 mo to first freshening × heifer cost per day (.978 and .470 ME/d in the HML and the LML).
8. Overhead heifer cost. This was the net *difference between loss from dead heifers* minus profit from cull heifers, associated with each cow freshening. It was charged

TABLE 4. Group mean costs and prices, in milk equivalents (ME),[1] for high (HML) and low (LML) management levels.[2]

Crossbred group	Concentrate cost[3]		Milking labor cost		Cull animal base price[4]		Overhead heifer cost[5]	
	HML	LML	HML	LML	HML	LML	HML	LML
	ME/kg milk yield				ME			
1/4	.593	.159	.053	.072	1421	1169	18	6
1/2	.458	.150	.033	.052	1421	1326	18	−6
5/8	.471	.189	.039	.058	1421	1069	18	130
3/4	.446	.200	.033	.051	1421	782	18	190
7/8	.446	.190	.032	.050	1421	799	18	197
HF	.447	.219	.034	.049	1421	739	18	461
Mean	.464	.180	.037	.055	1421	981	18	163

[1]1 ME = price of 1 kg of milk.

[2]For details see the study by Madalena (16).

[3]Mean cost of most common feeds were (ME/kg): commercial ration, .92; corn grain, .63; wheat bran, .46; cottonseed meal, .69.

[4]At mean ages 2101.5 d (HML) and 1814.5 d (LML). Linear regressions of price on age were .9367 and .4370 ME/d, within the HML and the LML, respectively.

[5]Losses from dead heifers minus profit or losses from culled heifers, per cow freshening (minus sign indicates profit).

to each cow according to its management level and crossbred group (Table 4).

9. Miscellaneous costs. Variable and fixed costs per day, other than those described were adapted from budget case studies (16). Costs per day of 3.48 and 1.63 ME for HML and LML were assumed for all crossbred groups.

Further details on economic calculations were given by Madalena (16).

The following income and cost components, per day of current herd life, were considered for analysis along with profit per day: income from milk over cost of concentrates, milking labor and transport; final cow value; calf value; heifer cost (including initial and overhead cost plus cost up to first freshening) and miscellaneous costs.

Statistical Analysis

Models were developed to predict performance under the alternative breeding strategies studied. Separate analyses were performed for each management class because interactions of crossbred group × management level had been previously shown in components of total economic performance (18).

Animals kept on experimental farms were grouped in contemporary batches (this was not necessary for animals distributed to cooperator farms). Thus, farm-batches included the effects of farms where performance was recorded, birth season and length of recording period (since performance was recorded up to a fixed date).

Data were analyzed by least squares techniques using procedure GLM of SAS (26). The following models were utilized:

$$Y_{ijkl} = b_0 + M_i + g1 \cdot q_j + h1 \cdot z_j + FB_k + e_{ijkl} \quad [1]$$

$$Y_{j'kl} = b_0 + G_{j'} + FB_k + e_{j'kl} \quad [2]$$

where:

Y_{ijkl}(or $Y_{j'kl}$) = trait of cow ijkl (or j'kl),
b_0 = intercept,
M_i = effect of the mating type i (i = 1 for F1 or backcross, i = 2 for 5/8 inter se),
g1 = breed additive difference (HF-Gu) within F1 and backcrosses,
q_j = expected proportion of HF genes in individuals of crossbred group j within F1 and backcrosses (j = 1,...,5),
h1 = heterosis effect within F1 and backcrosses,

z_j = expected proportion of loci with one gene of each breed, in individuals of the crossbred group j,

FB_k = effect of the farm-period of birth class k,

e_{ijkl} (or $e_{j'kl}$), = random residual, assumed normally and independently distributed with mean zero and variance σ^2

$G_{j'}$ = classification effect of the crossbred group j′, (all groups included, j′ = 1,...,6).

All effects were considered fixed. Values of q_j and z_j are shown in Table 1; these were set to zero for the 5/8 to run model 1.

The g1 parameter corresponds to Dickerson's (5) average direct individual gene effects for each breed, measured from the Gu breed. A linear restriction has to be imposed to estimate breed additive effects, because the HF and Gu gene proportions add up to 1. The h1 parameter measures individual heterosis effects, including dominance and epistatic effects (5), which are confounded in data sets containing only F1 and backcross information (7, 10).

Before adopting model 1, two other more conventional models were tested ignoring mating type (i.e., dropping the M_i term): the additive-dominance or g-h model,

$$Y_{j'kl} = b_0 + g \cdot q_{j'} + h \cdot z_{j'} + FB_k + e_{j'kl},$$

where direct gene and heterosis parameters g and h were fitted irrespective of mating type (j′ = 1,...,6); and the g-h-gg model, in which a term $gg \cdot w_{j'}$ was added to the above model, gg representing the additive × additive nonallelic interactions and $w_{j'}$ representing the expected proportion of two loci gene combinations present in parental breeds that are recovered in the crossbred group j (10). Values of $w_{j'}$ for groups 1/4, 1/2, 5/8, 3/4, 7/8, and HF were, respectively, 5/8, 1/2, 34/64, 5/8, 50/64, and 1.

Additive × dominance and dominance × dominance deviations (7, 10) could not be explicitly included in the models because their coefficients were highly correlated with q and z. Expected additive maternal HF gene proportions equaled $1 - z_j$ for all crossbred groups except for the 5/8, and because of this partial confounding, heterosis estimates are valid only on the assumption of no maternal effects. Sire effects were not included in models because they were partly confounded with the environmental effects. Goodness-of-fit of a given genetic model was assessed by *F* tests on the extra variation due to fitting model 2 after it (25).

Performance under the breeding strategies studied was predicted from model 1 utilizing the theoretical q and z values of Table 1 (the new breed was assumed to be an inter se of 5/8 HF × 3/8 Gu). Error in prediction of 5/8 inter se performance from the additive-dominance model was estimated by $\hat{b} = \hat{M}_1 + 5/8\ \hat{g}1 + 30/64\ \hat{h}1 - \hat{M}_2$.

RESULTS

Crossbred Group Performance

The F-values for model 2 analyses of variance are in Table 5. Crossbred groups significantly affected all traits in both management levels, with the exception of final cow value ($P<.05$).

Crossbred group least squares means are shown in Table 6. Because animals in the HML were born earlier than those in the LML, they could accumulate production longer, so performance should not be compared between levels. However, because animals in the same farm-batch class were contemporary, crossbred group comparisons were not affected by the length of recording period.

In both management levels, the F1 had longer current herd life and better productive and reproductive performance than the other groups, although their superiority over HF backcrosses was more marked in the LML. Groups 1/4 and 5/8 had short current herd life and low accumulated milk and component yield in the HML, and their very low income over cost resulted in negative profit. Differences between groups in the HML were larger for income over cost and heifer cost than for final cow value, calf value, and miscellaneous costs. Crossbred groups with higher final cow value in the HML had longer current herd life, so final cow value group means were similar for this trait. Differences between groups in heifer cost were caused mainly by differences in age

TABLE 5. The *F* values and residual standard deviations for Model [2] analyses of variance.

Source	df	NC[1]	A1C	CHL	MYD	FYD	PYD	PPD	IMD	FVD	CVD	MCD	HCD
	High management level												
Crossbred group	5	3.96***	2.96*	5.53***	21.58***	18.24***	17.70***	46.18***	39.73***	.22	7.41***	5.02***	3.21*
Farm-batch	9	1.69	2.96***	2.11*	.37	1.54	.49	1.08	.61	2.41*	1.95	1.85	1.10
	Low management level												
Crossbred group	5	6.08***	8.21***	8.05***	19.99***	20.65***	18.48***	24.56***	25.12***	1.89	4.76***	2.63*	8.83***
Farm-batch	52	6.62***	2.47***	5.02***	2.58***	2.73***	2.70***	1.98***	2.86***	2.54***	1.45*	6.01***	1.43*
	Residual standard deviations												
			(d)		(kg/d)	(g/d)		Milk equivalents (kg/d)[2]					
Management level													
High	95	.913	133	335	1.672	65	50	.798	.645	.524	.025	.138	.635
Low	208	.705	188	333	1.664	72	52	2.496	1.089	2.200	.136	.069	3.060

[1]NC = Mean number of calvings per cow, A1C = age at first calving, CHL = current herd life. Other traits are expressed per day of CHL: MYD = milk yield, FYD = fat yield, PYD = protein yield, PPD = profit per day, IMD = income from milk over concentrates, milking labor, and transport costs, FVD = final cow value, CVD = calf value, MCD = miscellaneous costs, HCD = heifer cost.

[2]One milk equivalent = price of 1 kg milk.

*$P<.05$.

***$P<.005$.

TABLE 6. Model [2] least squares means.

Crossbred group	NC[1]	A1C	CHL	MYD	FYD	PYD	PPD	IMD	FVD	CVD	MCD	HCD	DIV[2]
	(d)			(kg/d)	(g/d)		Milk equivalents (kg/d)[3]						
	High management level												
1/4	3.20	1203	1092	4.259	173	146	–1.18	1.22	1.44	.18	2.80	1.23	4.67
1/2	4.41	1091	1552	8.314	333	264	1.79	3.44	1.47	.17	2.64	.64	4.27
5/8	3.40	1149	1090	5.307	183	166	–.32	2.06	1.39	.20	2.82	1.14	3.57
3/4	3.66	1113	1364	8.155	305	253	1.67	3.41	1.48	.16	2.71	.67	3.61
7/8	3.76	1145	1400	8.230	283	243	1.51	3.34	1.35	.16	2.68	.65	4.34
HF	3.59	1244	1394	7.942	260	227	1.31	3.10	1.50	.15	2.64	.81	3.61
Mean	3.67	1157	1315	7.035	256	217	.80	2.76	1.44	.17	2.72	.86	9.03
	Low management level												
1/4	2.02	1351	702	3.359	148	109	1.67	2.23	2.78	.20	1.40	2.15	6.77
1/2	2.20	1176	908	6.387	274	197	4.43	4.44	2.51	.16	1.39	1.30	7.25
5/8	1.55	1375	547	4.391	174	135	1.38	2.80	3.21	.23	1.43	3.44	5.90
3/4	1.95	1281	825	5.698	231	173	2.37	3.59	1.84	.15	1.39	1.83	6.48
7/8	1.60	1384	607	5.019	189	146	.49	3.20	2.18	.24	1.41	3.72	6.34
HF	1.60	1347	576	4.252	159	122	–1.31	2.59	2.47	.27	1.43	5.21	5.79
Mean	1.82	1319	694	4.851	196	147	1.50	3.14	2.50	.21	1.41	2.94	15.09

[1]NC = Mean number of calvings per cow, A1C = age at first calving, CHL = current herd life. Other traits are expressed per day of CHL: MYD = milk yield, FYD = fat yield, PYD = protein yield, PPD = profit per day, IMD = income from milk over concentrates, milking labor, and transport costs, FVD = final cow value, CVD = calf value, MCD = miscellaneous costs, HCD = heifer cost.

[2]Standard error of means = residual standard deviations (Table 5)/DIV, where DIV is a coefficient indicating the magnitude of residual standard deviation relative to standard error.

[3]One milk equivalent = price of 1 kg milk.

at first calving and current herd life, overhead heifer cost being only 1.5 to 2.0% of mean group heifer cost. Variation between groups in miscellaneous costs reflected effects of discounting associated with current herd life differences.

Differences between groups in calf value and miscellaneous costs were not very important in the LML either. Although not measured, there were obvious differences between groups in cull cow condition, reflected in prices shown in Table 4. Overhead heifer costs were very important for groups with high heifer mortality, accounting, respectively, for 1.6, –1.2, 11.0, 15.3, 16.6, and 32.7% of heifer cost of groups 1/4, 1/2, 5/8, 3/4, 7/8, and HF. High heifer cost and low income over cost resulted in very low or negative profit per day for the 7/8 and HF groups. The 5/8 had poor performance in the LML also with some compensation in profit per day from higher final cow value.

Genetic Models

As may be seen in Table 7, neither the additive-dominance model, ignoring mating type, nor the model also including additive × additive deviations, fitted the HML data for traits directly dependent on milk yield (milk, fat, and protein yields; income over cost; and profit per day). In the LML, however, the additive-dominance model sufficed to explain variation between all crossbred groups for the milk yield based traits, but not for number of calvings, age at first calving, and current herd life. However, exclusion of the 5/8 inter se observations from the data set resulted in generally good fit of the additive-dominance model, i.e., *F*-values for the extra variation due to fitting crossbred group classification after g1 and h1 were not significant for any trait, except for calf value and heifer cost in the LML (*P*>.05). This result led to Model [1], which also accounted for variation between crossbred groups for the same traits (Table 7).

The fact that the additive-dominance model fitted F1 and backcross data, but not inter se data, as well as Model [2], indicates that other genetic effects, in addition to direct gene effects and heterosis were present, but could not be detected and must, therefore, have been confounded with g1 and h1 in the F1 and backcross data subset. Errors in prediction of inter

TABLE 7. Goodness-of-fit of genetic models. The *F* values for extra variation due to fitting crossbred group classification after genetic parameters shown.[1]

Parameters[2]	df	NC[3]	A1C	CHL	MYD	FYD	PYD	PPD	IMD	FVD	CVD	MCD	HCD
High management level													
g-h	3	.79	.98	2.29	4.30**	5.57***	4.32**	7.59***	4.53**	.36	5.81***	3.39*	.99
g-h-gg	2	.30	.75	.47	3.03	4.16*	3.58*	5.77***	4.33*	.38	3.49*	.17	1.04
M-g1-h1	2	.69	1.44	.49	.08	.08	.15	1.14	.39	.48	.06	1.32	.18
Low management level													
g-h	3	2.98*	2.61*	4.02**	1.18	1.39	1.08	1.12	1.15	2.26	2.26	2.46	2.67*
g-h-gg	2	2.26	1.46	4.50*	1.73	1.78	1.62	1.47	1.27	3.22*	3.97*	3.55*	3.90*
M-g1-h1	2	.88	2.20	1.71	.79	.59	.92	1.54	.26	1.30	3.15*	1.58	3.13*

[1]Residual variation and df in Table 5.

[2]g = direct gene effects, h = heterosis, gg = additive × additive interactions, M = effect of mating type (inter se or not), g1 and h1 = same as g and h but restricted to F1 and backcrosses.

[3]NC = Mean number of calvings per cow, A1C = age at first calving, CHL = current herd life. Other traits are expressed per day of CHL: MYD = milk yield, FYD = fat yield, PYD = protein yield, PPD = profit per day, IMD = income from milk over concentrates, milking labor, and transport costs, FVD = final cow value, CVD = calf value, MCD = miscellaneous costs, HCD = heifer cost.

**P*<.05.

***P*<.01.

****P*<.005.

se performance from the g1-h1 model are shown in Table 8.

Because of its general validity over traits and management levels, model 1 was adopted to predict performance under alternative breeding strategies. Genetic parameters for this model are in Table 8. In the HML, g1 estimates were favorable to HF (i.e., the HF genes increased product or decreased costs) but were not significant for age at first calving and final cow value, and heterosis was favorable for all traits except final cow value and calf value. In the LML, g1 estimates were favorable to HF, and significant, for age at first calving; milk, fat, and protein yields; and income over cost. Estimates were unfavorable, although not significantly so, for final cow value and heifer cost. Net breed additive difference for PPD was small and not significant. Heterosis estimates were favorable and significant for all traits in the LML except final cow value and miscellaneous costs (Table 8). For most traits, h1 estimates were larger, relative to g1, in the LML than in the HML. Negative g1 estimates were found for accumulated fat and protein percentages in both management levels, and positive heterosis was detected for fat percentage in the HML. Estimates for these parameters were similar to those previously reported for single lactations (18) and need not be repeated here.

Breeding Strategies

Predicted performance under Model [1] is shown in Table 9 for each of the strategies studied. Predicted F1 performance is also shown for comparison, since it would be the most profitable genotype. Performance for rotational crossing in Table 9 corresponds to the mean of the generations involved in one rotation cycle, predicted from mean q and z values in Table 1.

The F1 would excel in both management levels in most traits (its PPD difference with upgrading in the HML had $P<.09$). In the HML, grading up to HF and the HF-HF-Gu rotation would result in the same profit per day, but this would only be .75 of the F1 profit per day. Profitability would be low for the HF-Gu crisscrossing in the HML, mainly because of the low milk yield and income over cost expected for the Gu-sired, 1/3 HF generation. The new breed would result in negative profit in the HML due to its low expected milk and fat yield and short herd life.

In the LML, HF-Gu crisscrossing would be the second-best strategy, but this would attain only .59 of the expected F1 profit per day. Both rotational crossing schemes would be very similar in all traits except heifer cost.

DISCUSSION

Results for accumulated yield and reproductive traits broadly agree with literature reports (9, 21, 23, 24), although present crossbred group effects are generally larger, which may be due to our use of unselected data in addition to other genetic and environmental differences. No consistent group effects on herd life have been reported (8, 9, 24). High rates of culling and mortality, both for heifers and adult cows, have been reported by Amble and Jain (1) and Madsen and Vinther (20), who also found higher F1 survival, as in the LML. Although diverse methods have been used for economic evaluation of tropical dairy crosses, the general conclusion has been that European × Zebu crossbreds were more profitable than purebreds, grades above 1/2 European being preferable to those below that fraction. In one study, heterosis for first lactation profit was 28% of parental mean, the maximum profit corresponding to the F1 (15).

Drift may not be ruled out as a cause of the relative poor performance of the 5/8, particularly in the HML, where only one sire was represented (16). However, low performance of inter se animals has been reported for several important traits (4, 13).

Roughage cost should be lower in lower yielding groups, but this would appear to have only small effects on the profit per day comparison (3, 22). Veterinary costs were, respectively, 10.3 and 4.8% of mean miscellaneous costs in the HML and the LML, so group differences in this item would not appear to be important either, although genetic differences in disease and parasite resistance may have affected performance. Field tick burdens increased exponentially with q (11), but even under heavy infestation, burdens of 1/4 and F1 heifers were below accepted damaging levels. Although the value of tick resistance depends on control policy (15), this trait may influence choice of cattle genotypes in regional planning consider-

TABLE 8. Estimates of breed additive differences (g1, HF-Gu) and heterosis (h1) within F1 and backcrosses, and errors in prediction of inter se performance from the additive-dominance model (b).

Parameter	NC[1]	A1C	CHL	MYD	FYD	PYD	PPD	IMD	FVD	CVD	MCD	HCD
		(d)	(d)	(kg/d)	(g/d)	(g/d)	Milk equivalents (kg/d)[2]					
	High management level											
g1	1.456***	-126	701***	7.861***	254***	206***	5.54***	4.23***	.00	-.04***	-.26***	-1.10***
(SE)	(.443)	(65)	(162)	(.807)	(31)	(24)	(.39)	(.31)	(.25)	(.01)	(.07)	(.31)
h1	1.539***	-192***	517***	4.213***	199***	138***	3.22***	2.39***	.03	-.00	-.14*	-.66*
(SE)	(.386)	(56)	(139)	(.693)	(27)	(21)	(.33)	(.27)	(.22)	(.01)	(.06)	(.26)
b	.268	8	241*	1.771***	79***	53***	1.12***	.68***	.05	-.03***	-.11**	-.30
(SE)	(.270)	(40)	(99)	(.491)	(19)	(15)	(.23)	(.19)	(.15)	(.01)	(.04)	(.19)
	Low management level											
g1	-.283	-132*	95	4.220***	144***	111***	.36	2.68***	-1.05	-.00	.01	1.26
(SE)	(.235)	(63)	(112)	(.555)	(24)	(18)	(.84)	(.36)	(.74)	(.05)	(.02)	(1.03)
h1	.512**	-269***	402***	4.152***	187***	129***	5.77***	3.13***	-.36	-.11***	-.03	-3.08***
(SE)	(.186)	(50)	(88)	(.438)	(19)	(14)	(.66)	(.29)	(.58)	(.04)	(.02)	(.81)
b	.344**	-63	178***	.425	23	11	.25	.34	-.82*	-.03	-.03*	-.73
(SE)	.123	34	(61)	(.303)	(13)	(10)	(.46)	(.20)	(.40)	(.02)	(.01)	(.56)

[1]NC = Mean number of calvings per cow, A1C = age at first calving, CHL = current herd life. Other traits are expressed per day of CHL: MYD = milk yield, FYD = fat yield, PYD = protein yield, PPD = profit per day, IMD = income from milk over concentrates, milking labor, and transport costs, FVD = final cow value, CVD = calf value, MCD = miscellaneous costs, HCD = heifer cost.

[2]One milk equivalent = price of 1 kg milk.

*$P<.05$.

**$P<.01$.

***$P<.005$.

TABLE 9. Expected performance under alternative breeding strategies (Model [1] predicted values).

Strategy	NC[1]	A1C	CHL	MYD	FYD	PYD	PPD	IMD	FVD	CVD	MCD	HCD
		(d)	(d)	(kg/d)	(g/d)	(g/d)	Milk equivalents (kg/d)[2]					
	High management level											
F1	4.33	1075	1524^a	8.329^a	336	267	1.82^a	3.48^a	1.46	$.17^a$	2.66^a	$.63^a$
Rotational crossing[3]												
HF-HF-Gu	3.91^a	1136^a	1419^b	7.833^b	293^a	242^a	1.36^b	3.16^b	1.45	$.16^b$	2.68^a	$.73^a$
HF-Gu	3.81^{ac}	1139^a	1351^c	6.924^c	269^b	221^b	$.75^c$	2.68^c	1.45	$.17^a$	2.71^b	$.85^b$
Grading up to HF	3.51^{bc}	1204^b	1357^{abc}	8.046^{ab}	264^{bc}	231^{ab}	1.36^{ab}	3.21^{ab}	1.43	$.15^c$	2.68^{ab}	$.74^{ab}$
New breed (5/8)	3.42^{abc}	1153^{ab}	1096^d	5.302^d	183^d	166^c	$-.33^d$	2.05^d	1.39	$.20^d$	2.82^c	1.14^b
	Low management level											
F1	2.20	1184	927	6.488	278	201	4.64	4.47	2.34^{ab}	.14	1.38^a	.93
Rotational crossing[3]												
HF-HF-Gu	1.94^a	1277^a	771^a	5.412^a	222^a	164^a	2.23^a	3.57^a	2.32^a	$.19^{ac}$	1.40^b	2.46^a
HF-Gu	2.03^b	1274^a	793^a	5.104^b	216^a	158^b	2.72^b	3.42^b	2.46^{ab}	$.18^a$	1.39^{ab}	1.96^b
Grading up to HF	1.55^c	1387^b	573^b	4.446^c	163^b	127^c	$-.95^c$	2.67^c	2.18^a	$.25^b$	1.42^c	4.64^c
New breed (5/8)	1.55^c	1373^b	547^b	4.385^c	174^b	135^c	1.37^d	2.80^c	3.22^b	$.23^{bc}$	1.43^c	3.46^{ac}

[a,b,c,d]Within management levels, means within column with different superscript differ significantly ($P<.05$).

[1]NC = Mean number of calvings per cow, A1C = age at first calving, CHL = current herd life. Other traits are expressed per day of CHL: MYD = milk yield, FYD = fat yield, PYD = protein yield, PPD = profit per day, IMD = income from milk over concentrates, milking labor, and transport costs, FVD = final cow value, CVD = calf value, MCD = miscellaneous costs, HCD = heifer cost.

[2]One milk equivalent = price of 1 kg milk.

[3]Mean performance over one rotation cycle; HF = Holstein-Friesian, Gu = Guzera breed.

ations broader than the farm profit approach. Genetic effects on temperament might influence labor other than milking. The HF direct gene effects and heterosis favored docility, but only the 1/4 were considered hard to deal with by farm milkers (19).

The constant initial heifer cost does not reflect likely differences in calf survival, which has been generally higher for the F1 (4, 12, 13, 29). Consideration of male traits important for beef production would probably have also enhanced the value of intermediate crosses (16).

Breeding strategies were also compared using 15 other profit functions, representing all combinations of four milk pricing systems × two ratios of beef animal:milk prices × two relative costs of concentrates. Although not reported in detail here, the results showed that the differences between strategies over most cost-price structures were consistent with those described. In the HML, profit per day for the HF-HF-Gu rotation became higher than that for grading up when protein was paid along with fat at three times the present fat differential, a fairer price for farmers (15). In the LML, doubling beef value of animals increased profit per day for the new breed more than for the HF-HF-Gu rotation, but the F1 and crisscrossing continued to be more profitable. Halving the cost of concentrates had little effect on the relative profit per day for the various strategies, as did varying the annual interest rate from 3 to 9% (17).

Cooperator farms were chosen among those milking twice daily, so the LML class is not representative of farms in the lowest management level (14), which may cast some doubt as to whether results would also apply to the latter (13, 22). Otherwise, F1 superiority was sustained over a wide range of circumstances, which indicates that this genotype should be considered as a major option for breed resource utilization. McDowell (13) stated that "the real challenge is to establish breeding programs that retain merits of the first cross." An obvious plan would be the continuous replacement with F1 heifers. Ranching production of F1 dairy heifers may have some drawbacks on a regional scale, such as health control, transport costs, and low productivity of purebred Zebus (14). However, the main conclusion from the present study is that the large observed superiority of the F1 may justify an increased cost of replacement heifers. In the Brazilian context, supply of F1 heifers could be organized through the existing dairy cooperatives, just as presently done for other farm inputs. F1 heifer production by embryo transfer from selected donors may also be a feasible alternative, depending on the field economic efficiency of the technique.

Crisscrossing would be the second best strategy for the LML, but it requires controlled mating, which is not practiced in many farms. Crossbred bulls might be preferable for natural service due to their higher reproductive efficiency (27). However, there are no ready sources of improver crossbred bulls in spite of the potential need for them (13, 16). Advantages of a synthetic breed might then transcend disappointing results in the initial inter se generations, which may be counteracted by selection, at least for lactation length and yield (6). However, selection may also be superimposed to the other crossbreeding schemes.

The 5/8 group provided a convenient source of advanced generations of inter se matings for the present trial, although a new breed should not necessarily be of that composition (12). In fact, it need not be developed from any strict gene fraction nor should germoplasm sources be restricted only to two breeds (16).

In the HML, improved management, particularly in heifer raising and roughage and pasture quality, might remove limitations for HF performance (3). Thus, each breeding strategy must be considered in relation to the ecological and socioeconomic characteristics of any given situation, and different breeding programs might be required according to the specific circumstances involved (13, 16, 28). In Brazil, because of wide variation among farms in milk production technology, each of the strategies considered has its own niche and is being practiced commercially to some extent, although most crossing is unplanned. However, present results indicate that the crossbreeding plan may have important effects on economic performance.

CONCLUSIONS

Maximum profit was obtained utilizing F1 females, over a wide range of simulated economic situations, particularly for the farms with LML in this study, suggesting that organization of continuous F1 heifer replacement programs may have sound economic basis.

The second best alternative, after the F1, for the better-managed farms in this study, would be either a modified crisscrossing of HF sires for two generations and Zebu sires for one generation or upgrading to HF. Both had the same expected profit per day of herd life.

On the LML farms, crisscrossing would be the second best option, whereas grading up to HF would result in economic loss.

Poor results were obtained with inter se matings, which does not invalidate development of new synthetic breeds but indicates that strong selection should be practiced to counteract loss of heterosis. Use of unselected crossbred bulls is not warranted.

Important economic gains may accrue from the choice of a breeding strategy to match the appropriate animal genetic resources to the husbandry practices used.

The additive-dominance genetic model accounted for variation between F1 and backcrosses. However, it was not adequate to explain heterosis breakdown in inter se animals for several components of profit per day of herd life.

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