Economic evaluation of crossbreeding for dairy production in Kenya

A. K. Kahi[a, b], W. Thorpe[c], G. Nitter[d] and C.F. Gall[a]

[a]Institute of Animal Production in the Tropics and Subtropics, Hohenheim University, 70593 Stuttgart, Germany
[b]Department of Animal Science, Egerton University, P. O. Box 536, Njoro, Kenya
[c]International Livestock Research Institute, P.O. Box 30709, Nairobi, Kenya
[d]Institute of Animal Breeding and Husbandry, Hohenheim University, 70593 Stuttgart, Germany

Abstract

Lifetime data of crosses of Ayrshire (A), Brown Swiss (B), Friesian (F) and Sahiwal (S) cattle collected over a 21-year period from a dairy ranch in the lowland tropics of Kenya were analysed to estimate additive and non-additive genetic effects on economic performance and to predict performance of alternative crossbreeding strategies. Performance was predicted from parameters of a genetic model based on additive-dominance and additive x additive interaction effects for the following: first cross (F x S), two-breed rotation $(AS)_{Rot}$, three-breed rotation $(BFS)_{Rot}$ and two- (F and S), three- (B, F and S) and four (A,B,F and S) -breed synthetic ($_{Syn}$) breeds based on equal and unequal contributions of the foundation breeds. Profit values were calculated for individual animals. For profit per day of herdlife (PLD), the B and F additive breed effects were not significantly different from that of A. The additive breed effect for S was negative and significant (P<0.01) indicating that it was inferior to the *Bos taurus* for PLD. Dominance effects for PLD in the crosses A x S and B x S were substantial and significant (P<0.05). The additive x additive interaction effects were negative and significant in all the crosses. Predicted performance showed that PLD would be lowest in $(ABFS)_{Syn}$ and highest in F x S. The $(3/4F\ 1/4S)_{Syn}$ would be the second-best strategy giving 90 % of the expected F x S profit, while $(FS)_{Syn}$ would give 87 %. However, the costs of maintaining the purebred populations for the F x S strategy were ignored. The absence of a significant difference between the *Bos taurus* breeds for PLD showed that comparable economic benefits were derived by use of either of the breeds for continuous crossbreeding in a production system with management achieving 3000 kg lactation yields and may be expected in production systems achieving lower yields (e.g., in many smallholder units), from the development of either an A-, B- or F-based two-breed synthetic breed.

Key words: Crossbreeding, Dairy cattle, Economic evaluation, Lifetime profit, Tropics.

Introduction

Crossbreeding between highly productive and adapted breeds allows for the use of imported germplasm within the constraints of the slowly changing local farming conditions and results in superior overall performance. The majority of published studies on cattle crossbreeding in the tropics have a biological orientation. That is, comparisons generally are restricted to reproductive and production traits. There have been few economic evaluations of cattle crossbreeding in tropical countries (Madalena, 1989). Some economic evaluation of crossbreeding strategies has been conducted under temperate conditions (McDowell and McDaniel, 1968; Touchberry, 1970; McAllister et al., 1994). Different criteria have been used in economic evaluations, which affects the outcome of a comparison (Kahi et al., 1998). Ram and Singh (1975), Patel et al. (1976), Parmar and Dev (1978) and Kanchan and Tomar (1984) used the cost of production of each litre of milk. These studies only considered returns from sales of milk and manure, while the cost of milk production was considered as the only expense. Reddy and Bassu (1985) and Madalena et al. (1990) used a profit function that, in addition to milk sales, included returns from sales of calves and cull cows. Madalena et al. (1990) concluded that maximum profit was obtained utilising F_1 (Holstein-Friesian x Guzera) females, over a wide range of simulated economic situations, suggesting that organisation of continuous F_1 heifer replacement programmes may have a sound economic basis in Brazil.

Tropical dairy production systems vary widely in their feed availability and level of herd management, therefore information is needed on the expected overall economic performance of the available breeds and their crosses at specific levels of resource availability and management and in discrete climatic conditions. This paper compares economic performance utilising data on accumulated lifetime performance of crosses of Ayrshire (A), Brown Swiss (B), Friesian (F) and Sahiwal (S) cattle from a dairy ranch in the lowland tropics of Kenya. Estimates are given for additive breed, dominance and additive x additive interaction effects and are used to model and compare economic performance of alternative crossbreeding strategies. The genetic performance of these strategies was reported by Kahi et al. (1999b).

Materials and methods

Herd management and breeding

Economic data were made available by a private dairy ranch (Kilifi Plantations) in Coast Province, Kenya. The ranch is located in Kilifi District, 60 km north of Mombasa. Thorpe et al. (1994) and Kahi et al. (1999a) described details of the cow management. Briefly, the herd was established in 1939 from a continuous two-breed rotational crossbreeding system involving the S and A breeds, and was transferred from Machakos in the Eastern Province of Kenya to Kilifi in 1963. The A bulls were mated to cows with breed content of 67% S 33% A and S bulls were mated to 67% A 33% S cows. These cows were sometimes mated back to bulls of the same breed as their sires to produce genotypes of 83% S 17% A or 83% A 17% S. In the mid 1970s, B (USA strain) was introduced to the rotation and first mated to the rotation cows to produce genotypes with breed compositions of 50% B 33% S 17% A or 50% B 33% A 17% S. In accordance with the rotation, these were usually mated to A and S bulls, respectively. However, the rotation was not followed strictly and occasionally B, S or A bulls were used on these crosses. This resulted in the generation of several genotypes with a minimum of 8% and maximum of 83% of any one breed. In the early 1990s a fourth breed, the F (European strain), was introduced and mated to the above genotypes with the aim of replacing the A breed in the crosses. For the present analysis only the first generation crosses of F were available. Table 1 shows the distribution of cows that calved over genetic groups and disposal categories. The frequency of culling in the different age-classes and the culling policy before the introduction of the F breed were described by Thorpe et al. (1994).

Table 1. Estimates (Est.) and standard errors (SE) of individual crossbreeding effects for the economic traits[a]

Parameter	FCD		HCD		RCD		IMD		PLD	
Phenotype[b]										
Mean	37.78		3.99		0.72		33.62		31.34	
SD	15.94		2.20		0.40		24.46		26.27	
CV	0.42		0.55		0.55		0.73		0.84	
Effects[c]	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
m	17.88	4.07	4.15	0.55	1.12	0.09	79.09	4.97	88.34	5.13
g_B	8.86*	3.71	3.05***	0.50	0.21**	0.08	-4.12	4.54	-0.83	4.68
g_F	20.56**	6.30	5.71***	0.48	0.74***	0.14	-4.89	7.68	1.24	7.94
g_S	-12.84***	3.55	-2.47**	0.85	-0.67***	0.08	-5.96	4.33	-12.09**	4.47
d_{AB}	-20.93**	7.37	2.82**	0.99	0.32*	0.18	4.21	7.24	9.24	7.48
d_{AS}	-15.08*	5.93	1.06	0.80	0.28*	0.13	16.16†	9.00	22.32*	9.29
d_{BS}	-3.06	6.38	-3.54***	0.86	-0.35**	0.14	12.82	7.79	25.00**	8.05
aa_{AB}	32.38*	14.10	-2.88	1.91	-0.16	0.30	-44.31*	17.22	-56.48**	17.77
aa_{AS}	39.15***	9.60	-1.91	1.29	-0.70***	0.20	-45.86**	16.91	-55.64**	17.47
aa_{BS}	28.52*	13.85	0.72	1.87	-0.35	0.30	-24.52*	11.73	-24.18*	12.11
heterosis effects										
h_{AB}	-4.74		1.38		0.24		-17.95		-19.00	
h_{AS}	4.50		0.11		-0.07		-6.77		-5.50	
h_{BS}	11.20		-3.18		-0.53		0.56		12.91	

[a]All variables are expressed in Kenya Shillings (KSh) per day of productive herdlife. 1 US dollar = 60 KSh. FCD = Feed costs; HCD = Health costs; RCD = Reproduction costs; IMD = Income from milk minus feed, reproduction and health costs; PLD = Profit.

[b]The number of records for all the traits was 2255.

[c]m is the mean performance of the A breed; g_B, g_F and g_S are the additive breed effects for Brown Swiss (B), Friesian (F) and Sahiwal (S), respectively; d_{AB}, d_{AS}, d_{BS}, aa_{AB}, aa_{AS}, aa_{BS}, h_{AB}, h_{AS} and h_{BS} are the dominance (d), additive x additive interaction (aa) and heterosis (h) effects between A and B, between A and S, and between B and S, respectively. Heterosis effects were derived as half the additive x additive interaction effect plus the dominance effect (Dickerson, 1993).

†P<0.10; *P<0.05; **P<0.01; ***P<0.001.

Generally the matings were by artificial insemination (AI) and were not influenced by relative body size of the breed. The A, F and S semen was provided by the Kenya National AI service, while B semen was imported from the USA. In cases where the cows did not conceive after two AI services, they were grazed together with crossbred bulls for at least two natural matings. These bulls were bred in the Kilifi herd and belonged to any of the above genotypes apart from the F crosses.

The cows were grazed rotationally on natural pastures. The predominant grass species was *Panicum infesticum*. During the dry period (generally January-March), approximately 20 kg fresh weight natural pasture silage was offered per cow per day. Mineral licks were always on offer. Milking was by hand twice daily; milk yield was recorded at each milking. During each milking, concentrate feed was offered for *ad libitum* intake. However, the actual level of concentrate consumption was determined by the time it took to milk the cow i.e., higher/longer milkers ate more concentrates. Cows were sprayed weekly with acaricide and given prophylactic treatment for trypanosomosis during pregnancy. At month 7 of pregnancy, cows were dried off and taken to 'pre-calving paddocks'. Calf management was described in detail by Kahi et al. (1995).

Data measurements and calculations

Data were collected for cows born in the period 1973 through 1994 and which calved for the first time between 1976 and 1996. Individual milk yield was measured at each milking and then summed at the end of the lactation to calculate the lactation milk yield. Fat content of the milk was tested on a sample of cows at four-week intervals commencing with parturition. Cows were weighed at three months interval for the purpose of determining the exact dosage of drugs to be used in the case of sickness. All AI events, details of all veterinary interventions from birth and the reason and dates of disposal were recorded

The length of productive herdlife (PL) was defined as the interval between first calving and disposal for cows that died, were culled or sold for dairy. For cows that stayed in the herd, it was assumed that they left the herd at the end of the last recorded lactation. For these cows, PL was defined as the interval between first calving and end of the last recorded full lactation. Lifetime yields were calculated for all cows initiating a first lactation. All available records were included irrespective of lactation length, PL, or any other performance trait. Lifetime milk revenue was based on fluid milk price because the pricing system does not depend on the milk composition. Therefore, the milk revenue is represented by milk price per kg x kilogram of lifetime milk yield.

Profit per day of productive herdlife (PLD) per cow was used as the criterion for the economic comparison of the genetic groups and for evaluation of crossbreeding strategies (Balaine et al., 1981). The PLD was calculated for each cow with a recorded first calving and included all estimated costs and revenues for the whole herdlife i.e., from birth to disposal or for cows still in the herd, from birth to end of the last recorded lactation. It was assumed that all cow cost and revenue were spread evenly over each day of PL and therefore revenue and costs were discounted back to birth using a daily discount rate (0.04 %) that was equal to the inflation-corrected savings account rate estimated for Kenya by Kimura (1997). Revenue was based on the value of milk, calves and the disposal value (DV) of the cow while costs included fixed costs and those incurred for feed, health, reproduction, marketing and heifer rearing.

The DV was equal to the carcass value for the culled cows (i.e., live weight, LW x price per kg LW). For cows sold for dairy and those that stayed in the herd, the DV was equal to their carcass value plus a price differential that was based on number of calvings. This price differential was calculated from prices of cows sold for dairy in each of the first four lactations. For cows in lactations greater than four, this price differential was assumed to be zero (i.e., their DV were equal to their carcass values). Cows, which died in the herd, had a zero DV.

Feed costs during the productive herdlife (FC) were estimated using feeding equations (Korver, 1982). Health costs for the cows (HC) were determined from the disease events and included the cost of discarded milk, drugs and labour. Reproduction costs were determined from the AI services and also included the cost of labour. The marketing cost per kg milk included costs incurred in recording, weighing and transportation.

Marketing costs of disposed cows were equivalent to 5 % of the DV because sale of animals was done on-farm. This cost was not charged to cows that were still in the herd at the time of data collection. Milking labour costs were not included. Milking labour costs are dependent on herd size and management practise. With variation in herd size, the milking labour cost would marginally change. The rearing costs of heifers until first calving included the value of the calf, the heifer feed, health, reproduction, labour and fixed costs and was different for all the genetic groups. The fixed costs included direct costs that are attributable to equipment, machines and farm structures. Detailed calculation of prices and costs are given by Kahi et al. (1999c).

Along with profit per day of PL (PLD), the following economic traits (all expressed per day of PL) were considered for analysis: Feed costs (FCD); health costs (HCD); income from milk minus feed, reproduction and health costs (IMD) and reproduction costs (RCD).

Statistical analyses
A total of 2255 records were used. There were two main components of analysis: first, estimation of the fixed effects of genetic group and separation of the additive genetic contribution of the four component breeds from the non-additive effects from crossing them; and second prediction and comparison of economic performance of alternative crossbreeding strategies. To achieve this, a two-step procedure was used. First, an individual animal model that accounted for all additive genetic relationships between animals was used to estimate the mean values of the genetic groups using the DFREML program (Meyer, 1991). The model fitted the animals' additive genetic effects as random effects. The fixed effects fitted were: Genetic group of the cow, which consisted of 25 classes with different sire and dam combinations and hence different breed and heterosis contributions; year-season of first calving, where each year from 1976 to 1996 has four seasons; January to March for the first dry season; April to June for the main wet season; July to September and October to December as the secondary dry and wet seasons, respectively.

Second, the crossbreeding effects were estimated by regressing the genetic group means on covariables for breed additive and non-additive effects in a weighted least squares (WLS) genetic model that included additive, dominance and additive x additive interaction effects. The coefficients of dominance (d_{ij}) and additive x additive interaction effects were calculated as $p_i^f p_j^m + p_i^m p_j^f$ and $\frac{1}{2}(d_{ij} + p_i^f p_j^f + p_i^m p_j^m)$, respectively, where p_i^f and p_i^m denote the gene proportion of breed i in the sire and dam, respectively (Akbas et al., 1993). To predict performance of alternative crossbreeding strategies, the A mean, the additive breed, dominance and additive x additive interaction effects estimated and the coefficients for a particular crossbreeding strategy were substituted in the genetic model as described by Kahi et al. (1999b). The number of crosses with F genes was insufficient to allow estimation of dominance and additive x additive interaction effects that result from A x F, B x F or F x S crosses.

Results

Fixed effects
Means and standard deviations of the traits studied are shown in Table 1. The coefficients of variation for most traits were high, which is not surprising because these data represent all females that had a first calving and at least a milk yield recorded and not simply those that

survived to complete a first lactation. Data were collected over a long period of time and in this type of data, many factors affect both biological and economic traits.

Additive breed effects

Estimates of additive breed, dominance and epistasis effects are presented in Table 1. The B and F additive breed effects were unfavourable and significant (P<0.05) for FCD, HCD and RCD with F having higher values than B. The S additive breed effect was the lowest for HCD. Differences in additive breed effects were negative but non-significant for IMD. The B and F additive breed effects for PLD were not significant indicating that A, B and F were similar for PLD. As was expected, S additive breed effect for this trait was unfavourable and significant (P<0.01).

Dominance and epistasis effects

Dominance effects for FCD in all the crosses were negative and only significant in the A x B and A x S crosses (Table 1). The corresponding estimates of additive x additive interaction effects were positive and significant in all the crosses. This translated to a negative estimate of heterosis (estimated as $d_{ij} + \frac{a_{ij}}{2}$) in the A x B cross but positive estimates in the other crosses, with the cross B x S having the highest estimate of KSh 11.20. Crossbreeding A with B produced a significant (P<0.01) positive dominance effect for HCD. For this trait, the dominance effect in the B x S cross was negative and significant, which when coupled with the positive estimate of additive x additive interaction effects resulted in a negative estimate of heterosis. Similar signs were observed on the estimates of dominance effects in all crosses for RCD. However in the B x S cross, the estimate of additive x additive interaction effect was negative, which together with the negative estimate of dominance effects translated to negative estimates of heterosis in this cross (KSh -0.53). Significant and negative additive x additive interaction effects were present for IMD in all the crosses. The dominance effect for PLD in A x S (KSh 22.32) and B x S (KSh 25.00) crosses were positive, substantial and significant (P<0.05). The additive x additive interaction effects were negative for PLD in all the crosses, the estimate in A x B cross being the highest (KSh –56.48). It was estimated that the B x S cross had KSh 12.91 (15.8 %) higher PLD than the mean of the parental breeds.

Crossbreeding strategies

The predicted economic performances as shown in Table 2 indicate that PLD would be lowest in $(ABFS)_{Syn}$ and highest in F x S. The $(3/4F\ 1/4S)_{Syn}$ would be the second-best strategy giving 90 % of the expected F x S profit, while $(FS)_{Syn}$ would give 87 %. The $(BFS)_{Rot}$ would attain higher PLD than in the four synthetic breeds that involve the B breed.

Table 2. Predicted PLD for the crossbreeding strategies using parameters from analysis of the data

Abbreviation[a]	Crossbreeding strategy	Breed contribution (%)				Predicted PLD[b]
		A	B	F	S	
F x S	First cross			50	50	95.83
$(AS)_{Rot}$	Two-breed rotation	50			50	72.42
$(BFS)_{Rot}$	Three-breed rotation		33.3	33.3	33.3	81.51
$(FS)_{Syn}$	Two-breed synthetic (equal contribution)			50	50	83.33
$(3/4F\ 1/4S)_{Syn}$	Two-breed synthetic (unequal contribution)			75	25	86.56
$(BFS)_{Syn}$	Three-breed synthetic (equal contribution)		33.3	33.3	33.3	74.36
$(3/8B\ 3/8F\ 1/4S)_{Syn}$	Three-breed synthetic (unequal contribution)		37.5	37.5	25	72.51
$(ABFS)_{Syn}$	Four-breed synthetic (equal contribution)	25	25	25	25	63.75
$(1/8A\ 1/4B\ 1/2F\ 1/8S)_{Syn}$	Four-breed synthetic (unequal contribution)	12.5	25	50	12.5	65.67

[a]See footnotes in Table 1 for description of breeds.
[b]Expressed in Kenya Shilling. 1 US dollar = 60 KSh

Discussion

Additive breed effects

The higher F additive breed effect for FCD than in the other breeds was expected due to its heavier body weight. In the present study, the amount of silage consumed per day during lactation was assumed to be the same for all the genetic groups while that of concentrates was determined by the time it took to milk the cow, i.e., higher/longer milkers ate more concentrates. Given the feeding equation (Korver, 1982), roughage costs are expected to be less in lighter and lower yielding cows. The weights used in this study were adjusted for the effect of age, parity and physiological state (Kahi et al., 1999a) indicating that the differences in FCD can fully be attributed to the production level and the feed intake capacity of the respective breeds.

Health costs indirectly measure the ability of an animal to cope with a certain environment. Higher health costs reflect a lower ability to cope with the environment. Therefore, the lower S additive breed effects for HCD compared to that of the *B. taurus* breeds is in accordance with the fact that S is more adapted to the tropical stress of poor nutrition, disease challenge and heat stress than the *B. taurus* cattle, hence its recommendation for use in crossbreeding in the tropics (Cunningham and Syrstad, 1987). The F had the highest additive effects for FCD, RCD and HCD. The combined effects of these traits may have resulted in the non significant effect of additive breed effects for PLD.

The high income from milk yield of the F breed did not compensate for its high additive value for FCD, RCD and HCD, at least when milk price is determined by volume, not composition. Milk yield is normally a direct indicator of profit (Gill and Allaire, 1976; Allaire and Gibson, 1992). Therefore, the lack of a significant difference between the *B. taurus* breeds for PLD was rather surprising given the differences in genetic potentials for milk yield for these breeds (Felius, 1985). The superior biological performance of the F when compared to A and B reported by Kahi et al. (1999a) and the lack of significant difference in PLD between these breeds suggest that in the tropics superior biological efficiency does not necessarily lead to superior economic efficiency.

Given the generally low level of feeding in the smallholder dairy production sub-sector in the tropics and the positive relationship between feed intake and live weight, use of larger breeds is not advisable because they would be less able to meet their feed intake capacity than smaller breeds and become less efficient. Reducing HCD and RCD may help to improve dairy farm profits and also influence the choice of breeds for use in crossbreeding given the harsh tropical conditions of poor nutrition, heat and disease challenge. In some temperate countries, the importance of these costs is shown by the inclusion of some health and fertility traits as breeding objectives in selection programmes, to counter the deterioration in health and fertility due to selection for increased milk yields (Eriksson and Wretler, 1990; Solbu and Lie, 1990).

Dominance and epistasis effects

Dickerson (1969 and 1973) presented a genetic model that accounts for heterosis and epistasis interactions expressing the loss of favourable genetic interaction within gametes. Heterosis in this model includes a part of the additive x additive epistasis in addition to dominance. From the results of the model used in the present study, heterosis effects can be estimated as half of the additive x additive effect plus the dominance effect (Dickerson, 1993).

For FCD, HCD and RCD, these results are, to the best of our knowledge, the first values published for dairy crosses of *B. taurus* and *B. indicus* in the tropics. The positive, i.e., unfavourable heterosis estimate (KSh 11.20) in the B x S cross for FCD was expected and could be a result of the positive heterosis estimate obtained for milk yield and LW (Kahi et al., 1999a). The negative and significant dominance effect for HCD in the B x S cross which also resulted in a favourable estimate of heterosis, was interesting. Assuming that HCD is an indirect indicator of incidence of diseases, crossbreeding *B. taurus* with *B. indicus* should result in increased adaptation as measured by disease incidence.

The dominance effects for PLD in A x S and B x S were positive and significant which when coupled with the negative additive x additive interaction effects, resulted in positive and substantial heterosis (15.8 %) in the B x S cross. In India, Ram and Singh (1975), Parmar and Dev (1978) and Kanchan and Tomar (1984) concluded that F_1 *B. taurus* x *B. indicus* crossbreds were more profitable than *B. taurus* pure-breds, grades above 1/2 *B. taurus* being preferable to those below that fraction. In Brazil, Madalena et al. (1990) reached a similar conclusion in their study with Holstein-Friesian x Guzera crossbreds. The 15.8 % heterosis for PLD in the B x S cross is less than reported elsewhere in the literature. Parmer and Dev (1978) reported 28 % heterosis for first lactation profit. Touchberry (1992) and McAllister et al. (1994) reported estimates of 21.7 % and 20.6 %, respectively.

To the best of our knowledge, the present study seems to be the first to report on additive x additive interactions for profit. The negative estimates of additive x additive interaction for PLD in all the crosses were in accordance with the theory that during meiosis favourable epistatic interactions between genes in the parental purebreds are being lost due to the free recombination process. This loss is expected to be big when two breeds that have been subjected to decades of selection are crossed and particularly so for an aggregate trait such as PLD for which genes at very many loci are responsible. Hence the substantial estimate of additive x additive interaction in the *B. taurus* x *B. taurus* cross.

Crossbreeding strategies

The estimates of additive and nonadditive genetic effects were used to predict economic performance of crossbreeding strategies. The ranking of strategies according to PLD was quite different from their genetic ranking reported by Kahi et al. (1999b). For example, in that study, F x S was ranked slightly inferior to the $(3/4F\ 1/4S)_{Syn}$ and to the $(BFS)_{Rot}$ in milk yield at both the cow and production systems levels, respectively, but was superior in PLD in the present study. This shows that breeding recommendations for increased lifetime productivity should not be solely based on lactation and reproductive performance. It should be noted that the comparison of strategies is based on the final product. Kahi et al. (1999c) compared profit at the production systems level and reported that on average production systems that are based on F x S cows would be superior to those based on the two-breed synthetics only at a NL higher than 4. In most of the tropics, given the overall mean performance of the cow, the management levels and culling policies, rarely does NL exceed the value of 4 (Amble and Jain, 1967; Madalena et al., 1990; Thorpe et al., 1994).

Given the differences in the ecological and socio-economic characteristics of production systems, some of the crossbreeding strategies considered in the analyses are being practised commercially to some extent and have their own niches. For example, because of the level of management (nutrition, disease control), there is use of $(AS)_{Rot}$ and $(ABS)_{Rot}$ for milk production at Kilifi Plantations. As seen in the present study, inclusion of the F breed in these rotations has had little effect on profitability. While the F_1 (exemplified by the F x S strategy in this study) ranked superior for profitability, the basic problem has been how to breed the next generation. Teodoro et al. (1996) explored from published information the economics of F_1 females over those from continuous purebreeding or crossbreeding systems and estimated the break-even cost of producing F_1 females by embryo transfer. In that study, it was concluded that the economic superiority of the F_1 systems seemed to justify the extra costs incurred in their production, but this would depend on whether efficient *in vitro* fertilisation methods are developed. Kahi et al. (1999b) have discussed the limitations of utilisation of the F_1 strategy in smallholder farms in the tropics.

For most smallholder farms in Kenya, and especially for those in the humid coastal lowlands, the synthetic breed strategy might be a viable option because of its organisational simplicity (Syrstad, 1996). Under such harsh humid conditions, more attention should be given to raising animal productivity from low to intermediate rather than to providing genetic potential for productivity that cannot be supported economically by the production environment (McDowell, 1985). A problem to be addressed is the need for an efficient selection scheme in the synthetic breed, which may be difficult because of the fact that a sufficient size of the breeding population is necessary and that it is difficult to establish a large-scale field-recording scheme. For the specific situation in developing countries, open nucleus breeding schemes have been proposed (Cunningham, 1980; Smith, 1988; Bondoc and Smith, 1993) to offset lack of money, expertise and the infrastructure required for operating an efficient improvement program based on AI and field recording.

Conclusions

Evidence was presented for the presence of additive breed effects for the variable costs and of dominance and additive x additive interaction effects for feed costs and profitability. There was an absence of significant differences in the additive breed effects of the *B. taurus* breeds for profitability indicating that greater genetic differences among breeds does not necessarily lead to greater economic benefits. Therefore breeding decisions aiming to increase herd production efficiency should not solely be based on lactation and reproductive performances of cows but also on their relative economic efficiency. This study showed that comparable economic benefits were derived by use of any of the three *B. taurus* breeds for continuous crossbreeding in a production system with management achieving 3000 kg lactation yields. Similar benefits may be expected in production systems achieving lower yields (e.g., in many smallholder units), from the development of either an A-, B- or F-based synthetic breed. Synthetic breeds would seem to fulfil the desire of smallholder cattle owners in the humid coastal lowlands for a breed combining higher performance and adaptation.

Acknowledgements

We thank C.D. Wilson of Kilifi Plantations, for permission to use the records from the herd, the German Academic Exchange Service (DAAD, Bonn, Germany) and Hohenheim University (Stuttgart, Germany) for funding the work, and the International Livestock Research Institute (ILRI, Nairobi, Kenya) for provision of facilities. Special gratitude is extended to Dr. Steve Staal (ILRI) for his suggestions on economic calculations. This paper was written when the first author was on leave from Egerton University (Njoro, Kenya).

References

Akbas, Y., Brotherstone, S. and Hill W. G., (1993). Animal model estimation of nonadditive genetic parameters in dairy cattle, and their effect on heritability estimation and breeding value prediction. Journal of Animal Breeding and Genetics. 110: 105-113.

Allaire, F. R. and Gibson, J. P., (1992). Genetic value of herd life adjusted for milk production. Journal of Dairy Science. 75: 1349-1356.

Balaine, D. S., Pearson, R. E. and Miller, R. H., (1981). Profit functions in dairy cattle and effect of measure of efficiency and prices. Journal of Dairy Science. 64: 87-95.

Bondoc, O. L. and Smith, C. (1993). Deterministic genetic analysis of open nucleus breeding schemes for dairy cattle in developing countries. Journal of Animal Breeding and Genetics. 110: 194-208.

Cunningham, E. P., (1980). Methods for recording, evaluation and selection in adverse environments. FAO/UNEP Technical Consultation on Animal Genetic Resources, Conservation and Management, Rome 12pp.

Cunningham, E.P. and Syrstad, O., (1987). Crossbreeding *Bos indicus* and *Bos taurus* for milk production in the tropics. FAO Animal Production and Health Paper No. 68.

Dickerson, G. E., (1969). Experimental approaches in utilising breed resources. Animal Breeding Abstract. 37: 191-202.

Dickerson, G.E., (1973). Inbreeding and heterosis in animals . In: Proc. Animal Breeding Symposium in Honour of Jay Lush. Amer. Soc. Anim. Sci. and Amer. Dairy Sci. Assoc., Champaign, IL. pp 54-77.

Dickerson, G. E., (1993). Evaluation of breeds and crosses of domestic animals. FAO Animal. Production and Health paper 108. Food and Agriculture Organisation of the United Nations, Rome.

Eriksson, J. A. and Wretler, E., (1990). Sire evaluation for diseases in Sweden. World Animal Review. 25: 29-32.

Felius, M., (1985). Genus *Bos:* Cattle Breeds of the World. March and Co., Inc.

Gill, G. S., and Allaire, F. R., (1976). Genetic and phenotypic parameters for a profit function and selection method for optimising profit in dairy cattle. Journal of Dairy Science. 59: 1325-1333.

Kahi, A.K., Mackinnon, M. J., Thorpe, W., Baker, R. L. and Njubi, D., (1995). Estimation of individual and maternal additive genetic and heterotic effects for preweaning traits of crosses of Ayrshire, Brown Swiss and Sahiwal cattle in the lowland tropics of Kenya. Livestock Production Science. 44: 139-146.

Kahi, A. K., Kosgey, I. S., Cardoso, V. L. and Van Arendonk, J. A. M., (1998). Influence of production circumstance and economic evaluation criteria on economic comparison of breeds and breed crosses. Journal of Dairy Science. 81: 2271-2279.

Kahi, A. K., Thorpe, W., Nitter, G. and Baker, R. L., (1999a). Crossbreeding for dairy production in the lowland tropics of Kenya. I. Estimation of individual crossbreeding effects on milk production traits and cow live weight. Livestock Production Science. (in press).

Kahi, A. K., Nitter, G., Thorpe, W. and Gall, C. F., (1999b). Crossbreeding for dairy production in the lowland tropics of Kenya. II. Prediction of performance of alternative crossbreeding strategies. Livestock Production Science. (in press).

Kahi, A. K., Thorpe, W., Nitter, G. and Gall, C. F., (1999c). Economic evaluation of crossbreeding for dairy production in a pasture based production system in Kenya. Livestock Production Science. (in press).

Kanchan, D.K. and Tomar, N.S., (1984). The economics of cattle and buffalo breeding for milk production. Indian Veterinary Journal. 61: 1044-1049.

Kimura, J. H., (1997). Interest rates in Kenya. Report of a joint IPAR/ICPAK seminar held in Nairobi, Kenya.

Korver, S., (1982). Feed intake and production in dairy breeds dependent on the ration. Ph.D.-Diss., Wageningen Agric. Uni., Wageningen, The Netherlands.

Madalena, F. E., (1989). Cattle breed resource utilisation for dairy production in Brazil. Brazilian Journal of Genetics 12,3-Supplement, 183-220.

Madalena, F.E., Teodoro, R. L., Lemos, A. M., Monteiro, J. B. N. and Barbosa, R. T., (1990). Evaluation of strategies for crossbreeding dairy cattle in Brazil. Journal of Dairy Science. 73: 1887-1901.

McAllister, A. J., Lee, A. J., Batra, T. R., Lin, C. Y., Roy, G. L., Vesely, J. A., Wauthy, J. M. and Winter, K. A., (1994). The influence of additive and nonadditive gene action on lifetime yields and profitability of dairy cattle. Journal of Dairy Science. 77: 2400-2414.

McDowell, R. E. and McDaniel, B. T., (1968). Interbreed matings in dairy cattle. III. Economic aspects. Journal of Dairy Science. 51: 1649-1658.

McDowell, R.E., (1985). Crossbreeding in tropical areas with emphasis on milk, health and fitness. Journal of Dairy Science. 68: 2418-2435.

Meyer, K., (1991). DFREML- a set of programs to estimate variance components by restricted maximum likelihood using a derivative-free algorithm. User notes, version 2.0. Animal Genetics and Breeding Unit, University of New England, Armidale. Mimeo.

Parmar, O.S. and Dev, D.S., (1978). Additive and non-additive genetic effects for some economic traits in Holstein-Friesian x Sahiwal crosses. Indian Journal of Dairy Science. 31: 316-320.

Patel, R. K., Kumar, P., Gangadharan, T. P., Dhaka, J. P., Voegele, K., Sukumaran Nair, R. and Sreekumaran Nair, G., (1976). Economic of crossbred cattle. National Dairy Cattle Research Institute, Karnal, 161 pp.

Ram, K, and Singh, K., (1975). A note on comparative economic efficiency of crossbred and purebred cows in different lactations. Indian Journal of Animal Science. 45: 792-794.

Reddy, C. O. and Bassu, S. B., (1985). Factors affecting profit function and production traits in crossbred cattle. Indian Journal of Animal Science. 55: 477-484.

Smith, C., (1988). Genetic improvement of livestock, using nucleus breeding units. World Animal. Review. 65: 2-10.

Solbu, H. and Lie, O., (1990). Selection for disease resistance in dairy cattle. Proc. 4th World Congr. Genet. Appl. Livest Prod., XVI: 445-448.

Syrstad, O., (1996). Dairy cattle crossbreeding in the tropics: Choice of crossbreeding strategy. Tropical Animal Health and Production. 28: 223-229.

Teodoro, R. L., Madalena , F. E. and Smith, C., (1996). The value of F_1 dairy *Bos taurus-Bos indicus* embryos for milk production in poor environments. Journal of Animal Breeding and Genetics. 113: 471-481.

Thorpe, W., Morris, C. A. and Kang'ethe, P., (1994). Crossbreeding of Ayrshire, Brown Swiss, and Sahiwal cattle for annual and lifetime milk yield in the lowland tropics of Kenya. Journal of Dairy Science. 77: 2415-2327.

Touchberry, R. W., (1970). A comparison of the general merits of purebred and crossbred dairy cattle resulting from twenty years (four generations of crossbreeding). In: Jasiorowski, H. and Rudzka, J. (Eds), Optimum Methods in Cattle Breeding for Increasing Meat and dairy Production, Warsaw Agric. Univ. pp 107-140.

Touchberry, R. W., (1992). Crossbreeding effects in dairy cattle: the Illinois experiment, 1949 to 1969. Journal of Dairy Science. 75: 640-667.