Statistical Genetic Studies on Cattle Breeding for Dairy Productivity in Bangladesh: II. Estimation of Reciprocal and Heterosis Effects and Optimum Crossbreeding System between the Local Breeds and Exotic Breeds for Milk Performance

K. B. Hossain, S. Takayanagi, T. Miyake, A. K. F. H. Bhuiyan[1] and Y. Sasaki*
Laboratory of Animal Breeding and Genetics, Division of Applied Biosciences, Graduate School of Agriculture
Kyoto University, Kyoto 606-8502, Japan

ABSTRACT : Reciprocal effects among local breeds and additive and heterosis effects were estimated for total milk production per lactation (TLP), lactation length (LL) and daily milk yield (DMY). Procedures for an optimum crossbreeding system were examined by comparing various crossbred combinations. Three data sets were chosen from the total records collected from 1962 to 1997. Data set I with a total of 5,938 records composed of 9 breed groups for reciprocal crosses, data set II with a total of 6,064 records composed of 5 breed groups for additive and heterosis effects and data set III with a total of 10,319 records composed of 42 breed groups for optimum crossbreeding system were analyzed. The least squares ANOVA was used. The reciprocal crosses between Red Sindhi and the Bangladeshi Local showed significant difference. When the Red Sindhi was used as cow, the cross was superior to the opposite in terms of the three performance traits. The results showed that additive breed effects on both TLP and DMY were positive and highly significant between *Bos indicus* and *Bos taurus*, whereas the individual heterosis effects were not significant. In general, any local breeds were improved two to three times by crossing with the Friesian once or twice. However, the effect was reduced when the grading up with the Friesian was repeated more than twice. On the other hand, when the local breed was crossed with the other breeds such as Holstein and Jersey, the improvement of TLP was less. Crossing the F_1 cows with the Friesian bull gave further improvement. Almost the same trends were found also for LL and DMY. The local breeds and their crosses are raised mainly for draft animals, then it is recommended that the crossbreds between the local cows and Friesian are used for dairy purposes and more than 75% Friesian blood is used for beef. ***(Asian-Aust. J. Anim. Sci. 2002. Vol 15, No. 6 : 777-782)***

Key Words : Bangladeshi Cattle, Reciprocal Effects, Heterosis, Optimum Crossbreeding System

INTRODUCTION

In Bangladesh, the native local breed is mostly of indigenous type (*Bos indicus*). They seem to be late maturing animals with short lactation length and their milk production is low. Sahiwal and Red Sindhi breeds were imported considering the good adaptability of these breeds under our tropical situation.

Selection breeding within a breed was investigated for Bangladeshi Local, Red Sindhi and Sahiwal breeds. Some progress will be made, but it is difficult to improve the local breeds by only selection within each breed. As another breeding strategy, crossbreeding between *Bos indicus* and *Bos taurus* species has been widely undertaken in the Central Cattle Breeding Station (CCBS) for improving the milk production potential of cattle in Bangladesh.

Heterosis effects for both individual and maternal traits were reported for Brahman-Shorthorn crossbred raised in Florida (Koger et al., 1975), for Brahman-Hereford crossbred (Cartwright et al., 1964), for Friesian-Sahiwal crossbred raised in India (Sarma and Pirchner, 1991) and for Red Danish-Native cattle raised in Thailand (Madsen & Vinther, 1975). In Bangladesh, additive and heterosis effects for birth weight and daily milk yield for Holstein-Local crossbred were reported (Hirooka and Bhuiyan, 1995).

The objectives of this study are to estimate heterosis and reciprocal effects among local breeds for milk performance. Secondly to estimate additive and heterosis effects on dairy performance traits using performance records obtained from various grade of crossbreds between the Bangladeshi Local and the Friesian. Finally to determine an optimum crossbreeding system, various crossbred combinations were compared by the least squares means of dairy performance traits.

MATERIALS AND METHODS

Data

Data on the productive performance of pure breed (5 breeds) and crossbred (43 combinations) cows were chosen from the total records (Hossain et al., 2002) accumulated in the CCBS, Bangladesh, for this study. Three data sets covering the period of 36 years from 1962 to 1997 were

* Address reprint request to Y. Sasaki. Tel: +81-75-753-6322, Fax: +81-75-753-6340, E-mail: sasaki@kais.kyoto-u.ac.jp
[1] Bangladesh Agricultural University, Bangladesh.
Received March 26, 2001; Accepted December 24, 2001

used in this study. Data set I with a total of 5,938 milk performance records composed of nine genetic groups, i.e., L, R, S, L×R, R×L, L×S, S×L, R×S and S×R, was used for analysis of reciprocal effects, data set II with a total of 6,064 milk production records composed of five genetic groups for heterosis effects, and data set III with a total of 10,319 records for 42 types of breed groups for the comparison of various breed groups to find out the optimum crossbreeding system for Bangladesh. The year is delineated into four main seasons, viz summer (March, April, May), rainy summer (June, July, August), autumn (September, October, November) and winter (December, January, February). The productive traits considered for three kinds of data sets were TLP, LL and DMY.

The cows were kept under a stall feeding system and supplied with green grass and concentrate (wheat bran, rice polish, khesary bran, oil cake etc.) according to their body requirements as per DLS (Directorate of Livestock Services) recommendations.

Model for estimation of reciprocal effects

Data set I was used for the analysis of reciprocal effects. The statistical model for TLP, LL and DMY was as follows:

$$Y_{ijklm}=\mu+P_i+N_j+S_k+B_l+e_{ijklm}$$

where, Y_{ijklm}: an observed trait value, μ: overall mean, P_i: the fixed effect of i^{th} parity (1 to 12), N_j: the fixed effect of j^{th} calving year (1962 to 1997), S_k: the fixed effect of k^{th} season (summer, rainy summer, autumn and winter), B_l: the fixed effect of l^{th} breed group (9 breed groups), e_{ijklm}: random residual effect.

Model for estimation of heterosis effects

Data set II was analyzed for estimation of the contribution of breed additive genetic, breed maternal, individual heterosis and maternal heterosis effects. The statistical model was as follows:

$$Y_{ijklm}=\mu+P_i+N_j+S_k+g_I X_1+h_I X_2+g_M X_3+h_M X_4+e_{ijklm}$$

where, Y_{ijklm}: an observed trait value, μ: overall mean, g_I: breed additive effect, expressed as a deviation from local breed, g_M: breed maternal effect, h_I: the individual heterosis effect, h_M: the maternal heterosis effect, P_i: the fixed effect due to i^{th} parity (1 to 12), N_j: the fixed effect due to j^{th} calving year (1962 to 1997), S_k: the fixed effect due to k^{th} season (summer, rainy summer, autumn and winter), X_1: proportion of genes contributed by Friesian, X_2: proportion of loci occupied by genes from Friesian, X_3: proportion of genes in dam from Friesian, X_4: proportion of loci in dam from Friesian, e_{ijklm}: random residual effect.

The fractions of the additive, heterozygotic, maternal heterosis and maternal breed effects (i.e. X_1 to X_4) were considered as continuous variable and calculated as deviation of the proportion of Friesian genes from proportion of Local breed genes (Ahlbornbreier and Hohenboken, 1991; Hirooka and Bhuiyan, 1995). The coefficients for genetic effects of each breed group are presented in table 1.

Model for estimation of optimum crossbreeding system

According to the combination of breeds, the total 42 genetic groups were divided into three broad groups which were Bangladeshi Local breed combinations (23), Red Sindhi breed combinations (12), and Sahiwal breed combinations (11) including two pure breeds. The model and method for the analysis were the same as those for reciprocal effects.

Statistical analysis

Least squares analysis of variance (Harvey, 1985) was performed using the General Linear Model (GLM) of SAS (1990a,b). Least squares means were derived and tested using PDIFF option.

RESULTS

From results of analysis of variance using the data set I, effects of parity, year of calving and breed group were highly significant on TLP, LL and DMY. Effect of season of calving was significant on LL ($p<0.05$), but highly significant on TLP and DMY ($p<0.01$).

Table 2 shows the least-squares means for dairy productive traits of the Bangladeshi Local, Red Sindhi and Sahiwal breeds and the reciprocal crosses among them. The dairy production performance of the Bangladeshi Local was significantly lower than that of either the Red Sindhi or

Table 1. Coefficients for genetic effects in breed groups for the crossbred between the Bangladeshi Local (L) and the Friesian (F)

Breed groups	Number of records	Genetic effects			
		g_I	g_M	h_I	h_M
L	4,303	0	0	0	0
F_1 (L×F)	1,335	0.5	0	1	0
F_2 (F_1× F_1)	251	0.5	0.5	0.5	1
BC_1 (F_1×F)	111	0.75	0.5	0.5	1
BC_2 (BC_1×F)	64	0.875	0.75	0.25	0.5

g_I: Breed additive effects for the Friesian expressed as deviation from the Bangladeshi Local.
g_M: Maternal breed effect of Friesian dam.
h_I: Heterosis effects for Friesian and Bangladeshi Local combination.
h_M: Maternal heterosis effects.

Table 2. Least squares means for total milk production per lactation (TLP), lactation length (LL) and daily milk yield (DMY) of three local breeds and the reciprocal crosses among the breeds

Breed Groups	Number	TLP (kg)	LL (day)	DMY (kg/day)
L	3,799	540.7[a]	222[a]	2.40[a]
R	756	859.1[c]	245[ab]	3.24[c]
S	959	876.9[c]	254[bc]	3.24[c]
F_1 (L×R)	188	654.4[b]	235[ab]	2.71[b]
F_1 (R×L)	26	1,146.0[d]	278[c]	3.83[d]
F_1 (L×S)	101	791.5[c]	234[ab]	3.16[c]
F_1 (S×L)	22	725.5[bc]	235[ab]	3.18[c]
F_1 (R×S)	52	843.3[c]	242[ab]	3.38[c]
F_1 (S×R)	35	812.9[c]	248[ab]	3.01[bc]

[a-d] Means without same letters within the same column differ significantly at p<0.05.

L: Bangladeshi Local; R: Red Sindhi; S: Sahiwal.

Sahiwal breed. There was no heterosis and no significant difference between reciprocal crosses when the Bangladeshi Local and the Sahiwal and also the Red Sindhi and the Sahiwal were crossed. On the other hand, the reciprocal crosses between the Bangladeshi Local and Red Sindhi showed significant difference. When the Red Sindhi was used as cow, the cross, which showed hybrid vigor, was superior to the opposite in terms of the three performance traits.

Table 3 provides the estimates of the genetic effects for TLP, LL and DMY using various crossbred combinations between the Bangladeshi Local and the Friesian. The results showed that additive breed effects were positive and highly significant for both TLP and DMY. On the other hand, the heterosis estimates were negative and non-significant for TLP and DMY. Hirooka and Bhuiyan reported (1995) negative and non-significant heterosis effects for DMY in crossbred Bangladeshi Local and Holstein raised in CCBS. Taneja and Bhat (1974) reported a small and non-significant estimate of heterosis for milk yield for Sahiwal and Friesian crossbreds. On the other hand, Madsen and Vinther (1975) reported that when a native cattle of Thailand was crossed with Red Danish breed, the crossbred showed a positive heterosis effect. Sharma and Pirchner (1991) reported that when Friesian and Sahiwal breeds were crossed in India, a positive heterosis effect for milk yield was found. Higher level of heterosis was reported from crosses involving *Bos taurus* and *Bos indicus* breeds (Cunningham and Syrstad, 1987). These differing estimates of heterosis for milk yield reflect differences in the conditions where the animals were reared. Heterosis effect in crossbred between *Bos taurus* and *Bos indicus* is greater in a poor than in a good environment (Cunningham, 1981).

Table 3. Least squares means and regression for total milk production per lactation (TLP), lactation length (LL) and daily milk yield (DMY) of Bangladeshi Local and Friesian combination

Component	TLP (kg)	LL (day)	DMY (kg/day)
Least squares mean[a]	522.49	223	2.40
g_I	2,368.46***	43	6.99***
h_I	-23.99	48	-0.21
g_M	-1,634.93***	-24	-4.38***
h_M	236.79*	-2	0.84***

g_I: Breed additive effects for Friesian expressed as a deviation from Bangladeshi Local.

h_I: Heterosis effects for Friesian and Local combination.

h_M: Maternal heterosis effects.

g_M: Maternal breed effect for Friesian dam.

[a]: Least squares means of Bangladeshi Local.

Maternal heterosis effects were significant and maternal breed effects were negative but highly significant on TLP and DMY (table 3). Hirooka and Bhuiyan (1995) reported negative maternal heterosis effects on DMY from crosses involving Bangladeshi Local and Holstein breed. Ericson et al. (1988) reported negative maternal heterosis effects from crosses between two Swedish dairy breeds.

From results of analysis of variance using the data set III, effects of parity, year of calving and breed group were highly significant on TLP, LL and DMY (p<0.01). Season has significant effect on LL (p<0.05) but highly significant effect (p<0.01) on TLP and DMY.

Table 4 shows the least squares means for dairy performance of Bangladeshi Local, Friesian, Holstein and their breed combinations. As for TLP, pure breed Friesian produced the highest TLP (2,325.0 kg) among all breed groups. Generally, an exotic breed produces a high milk yield under seasonally hot climate when the animals are well fed and managed (Mason and Buvanendran, 1982). Bangladeshi Local breed produced lowest TLP (522.5 kg) among pure breeds.

In case of cross-breds, by crossing the Bangladeshi Local with the Friesian, the TLP of LxF was improved threefold. However, the TLP was not improved further by back crossing with the Friesian. The effect was reduced when the grading up with the Friesian was repeated more than two times (L×F×F×F). On the other hand, when the Bangladeshi Local was crossed with the other breeds such as Holstein and Jersey, the improvement of TLP was less. Crossing the F_1 cows with a Friesian bull (L×H×F, L×R×F) gave further improvement. Almost the same trends were found for LL and DMY. The mean average TLP for Friesian crossbred cows reported in the literature was 2,385 kg (Tibbo et al., 1994).

Table 4. Least squares means for total milk production per lactation (TLP), lactation length (LL) and daily milk yield (DMY) of the Bangladeshi Local, Friesian, Holstein and their crossbred combinations

Breed groups	N	TLP (kg)	LL (day)	DMY (kg/day)
F	5	2,324.98[g]	390[f]	6.12[h]
H	7	1,253.51[cde]	299[ef]	4.02[cde]
L	3,799	522.49[a]	223[cd]	2.40[a]
L×F	1,106	1,669.19[f]	290[e]	5.65[gh]
L×F×F	93	1,688.65[f]	265[d]	6.12[h]
L×F×F×F	49	1,468.71[e]	252[cd]	5.57[g]
L×F×L×F	178	1,109.88[c]	253[d]	4.41[e]
L×F×L×F×L×F	17	1,617.51[ef]	276[de]	5.56[g]
L×F×L×F×S	23	1,119.55[cd]	222[cd]	4.60[e]
L×F×S	62	832.31[b]	175[b]	4.17[de]
L×F×S×F	75	1,217.35[cd]	244[cd]	4.63[e]
L×H	778	1,006.01[c]	284[e]	3.41[b]
L×H×F	444	1,582.53[ef]	309[ef]	5.09[fg]
L×H×F×F	18	1,620.20[ef]	240[cd]	6.16[h]
L×H×F×L×F	88	1,096.76[c]	246[cd]	4.37[e]
L×H×F×S	97	822.09[b]	185[b]	3.85[cd]
L×H×F×S×F	37	1,345.19[de]	276[e]	4.81[ef]
L×H×J	19	1,513.98[ef]	291[e]	5.08[efg]
L×H×S	21	719.45[ab]	201[c]	3.50[bc]
L×J	406	1,307.39[de]	258[d]	4.93[ef]
L×J×J	38	1,162.90[cd]	232[cd]	4.63[e]
L×J×L×J	60	473.40[a]	129[a]	3.20[b]
L×R×F	19	1,636.98[ef]	306[ef]	5.01[efg]

[a-h]: Means without same letters within the same column differ significantly at $p<0.05$.

L: Bangladeshi Local; R: Red Sindhi; S: Sahiwal; F: Friesian; H: Holstein; J: Jersey.

Table 5 contains the least squares means for Red Sindhi breed combinations. As for TLP, the Red Sindhi (842.07) was the lowest among three pure breeds groups. Among the crossbreds, TLP was doubled by crossing Red Sindhi with Friesian. Furthermore, the TLP was improved by back crossing the F_1 animal to the Friesian. On the other hand, the improvement of TLP was lower than the former by crossing with other breeds such as Holstein and Jersey as in the case of Bangladeshi Local breed. When the F_1 crossbred cow between Red Sindhi and Holstein was crossed with Friesian, the TLP was improved twice as much.

Table 6 reports the least squares means for Sahiwal combinations. As for TLP, Sahiwal had the lowest (861.4 kg) TLP among three breed groups. Among crossbreds, almost the same results as with the Red Sindhi were obtained.

Table 5. Least squares means for total milk production per lactation (TLP), lactation length (LL) and daily milk yield (DMY) of the Red Sindhi combination

Breed groups	Number	TLP (kg)	LL (day)	DMY (kg/day)
F	5	2,324.98[e]	390[e]	6.12[e]
H	7	1,253.51[b]	299[d]	4.02[bc]
R	756	842.07[a]	247[bc]	3.24[ab]
R×F	148	1,688.87[c]	299[d]	5.39[e]
R×F×F	18	2,010.21[d]	319[d]	6.33[e]
R×F×L×F	11	1,245.64[b]	297[cd]	3.98[bc]
R×F×S	15	587.58[a]	189[a]	2.86[a]
R×F×S×F	28	1,177.70[b]	233[ab]	4.73[cd]
R×H	53	827.75[a]	241[abc]	3.31[ab]
R×H×F	9	1,775.19[cd]	310[d]	5.33[de]
R×H×F×S	6	1,316.58[bc]	319[d]	3.85[abc]
R×J	23	1,111.12[b]	215[ab]	5.36[de]

[a-e] Means without same letters within the same column differ significantly at $p<0.05$.

L: Bangladeshi Local; R: Red Sindhi; S: Sahiwal; F: Friesian; H: Holstein; J: Jersey.

DISCUSSION

When the Red Sindhi and the Bangladeshi Local were crossed, the reciprocal crosses were significantly different, that is, the F_1 produced using the former as female breed was superior to that produced using the latter. This effect may be due to maternal inheritance.

The maternal performance was checked further by comparing the least squares means of F_1 crossbred progeny between local cows and an exotic bull (tables 4, 5 and 6). When the Red Sindhi was mated as the female breed, the F_1 did not necessarily express a higher dairy performance than the other breeds in all three cases. That is, it was not able to be confirmed that the Red Sindhi is superior in terms of maternal inheritance traits.

The results showed that additive breed effects on both TLP and DMY were positive and highly significant between *Bos indicus* and *Bos taurus*, whereas the individual heterosis effects were not significant. Then, objectives of crossbreeding for the improvement of dairy performance in Bangladesh are limited to introduction of genes, which an exotic breed has. It becomes important how much germ plasm of a native breed adopted to the particular area will remain. This means how much germ plasm of an exotic breed will be introduced is important.

Table 6. Least squares means for total milk production per lactation (TLP), lactation length (LL) and daily milk yield (DMY) of the Sahiwal combination

Breed groups	Number	TLP (kg)	LL (day)	DMY (kg/day)
F	5	2,324.98[f]	390[d]	6.12[f]
H	7	1,253.51[c]	299[c]	4.02[bc]
S	959	861.39[a]	254[bc]	3.24[a]
S×F	236	1,828.07[e]	304[c]	5.84[ef]
S×F×F	10	2,101.31[e]	311[c]	6.35[f]
S×F×L×F	20	1,251.87[c]	264[bc]	4.90[de]
S×F×S	22	1,033.98[abc]	250[abc]	3.89[bc]
S×F×S×F	26	905.64[ab]	196[a]	4.25[cd]
S×H	86	1,095.54[bc]	291[c]	3.61[b]
S×J	23	1,355.46[cd]	240[ab]	5.11[e]
S×R×F	7	1,805.06[de]	318[c]	5.94[ef]

[a-f] Means without same letters within the same column differ significantly at p<0.05.

L: Bangladeshi Local; R: Red Sindhi; S: Sahiwal; F: Friesian; H: Holstein; J: Jersey.

Local breeds (LB) were improved twice to three times by crossing with the Friesian one or two times. The milk performance of LB×F×F×F was significantly lower than that of either LB×F or LB×F×F. It was observed that milk performance of the crossbred between LB and Friesian breed was higher than the performances of crossbreds between LB and Holstein or Jersey breed. The F_1 cows were improved almost the same as either LB×F or LB×F×F by crossing with the Friesian bull finally.

From the standpoint of the present analysis, though LB×F×F on the average had better production performance than LB×F, the difference was not statistically significant. Findings suggest that 50% level of Friesian inheritance or up to 75% improve dairy production performance of crossbred cows, but more than 75% increase in Friesian inheritance decreases production performance. Therefore, production and use of LB×F or LB×F×F seems more profitable for commercial milk production in Bangladesh.

Milk performance of Bangladeshi Local breed (LB) was poor in this analysis. They seem to be small in size, but high in ability to maintain body condition under poor quality feed stuffs. Therefore, local breeds seem more reliable for use as draft animals. On the other hand, the milk production decreases when Friesian blood becomes above 75%. Therefore crossbreds with more than 75% Friesian (LB×F×F×F etc.) seem to be profitable for beef production in Bangladesh.

REFERENCES

Alba, de. J. and B. W. Kennedy. 1994. Genetic parameters of purebred and crossbred Milking Criollos in tropical Mexico. Anim. Prod. 58:159-165.

Ahlborn, B. G. and W. D. Hohenboken. 1991. Additive and nonadditive genetic effects on milk production in dairy cattle: evidence for major individual heterosis. J. Dairy Sci. 74(2):592-602.

Cartwright, T. C., G. F. Ellis, Jr., W. E. Krose and E. K. Crouch. 1964. Hybrid vigor in Brahman-Hereford crosses. Texas Apr. Exp. Sta. Tech. Monger 1.

Cunningham, E. P. 1981. Selection and crossbreeding strategies in adverse environments. In: Animal Genetic Resources Conservation and Management. FAO Animal Production and Health Paper No 24. 279-288.

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

Dettmers, A. and B. Laseinde-Olotu. 1978. Performance of crossbred and pure breed cattle in selected Nigerian dairies. Proceedings of the First National Seminar on Dairy Development, Vom, Nigeria. (Ed. E. A. Olaloku and K. B. David-West). pp. 90-103.

Distol, O., G. Lechner and H. Krausslich. 1990. Analysis of crossbred generations by different genetic models in the German Gelbvieh population. J. Anim. Breed. Genet. 111:474-492.

Ericson, K., B. Danell and J. Rendel. 1988. Crossbreeding effects between two Swedish Dairy breeds for production traits. Livest. Prod. Sci. 20:175-192.

Freitas, A. F., C. J. Wilcox and C. N. Costa. 1998. Breed group effects on milk production of Brazilian crossbred dairy cows. J. Dairy Sci. 81:2306-2311.

Hayatnagarkar, D. D., S. S. Yeotikar, K. S. Deshpande and S. K. Auradkar. 1990. Non-genetic and genetic factors affecting some production traits in rural crossbred cows. Indian J. Dairy Sci. 43:515-520.

Hirooka, H., A. F. Groen and J. H. J. Van der Werf. 1998. Estimation of additive and non-additive genetic parameters for carcass traits on bulls in dairy, dual purpose and beef cattle breeds. Livest. Prod. Sci. 54:99-105.

Hirooka, H. and A. K. F. H. Bhuiyan. 1995. Additive and heterosis effects on milk yield and birth weight from crossbreeding experiments between Holstein and the local breed in Bangladesh. Asian-Aus. J. Anim. Sci. 8(3):295-300.

Hossain, K. B., S. Takayanagi, T. Miyake, K. Moriya, A. K. F. H. Bhuiyan and Y. Sasaki. 2002. Statistical genetic studies on cattle breeding for dairy productivity in Bangladesh: I. Genetic improvement for milk performance of local cattle populations. Asian-Aust. J. Anim. Sci. 15(5):627-632.

Koger, M., F. M. Peacock, W. G. Kirk and J. R. Crockett. 1975. Heterosis effects on weaning performance of Brahman-Shorthorn calves. J. Anim. Sci. 40:826-833.

Kohi, A. K., M. J. Mackinnon, W. Thorpe, R. L. Baker and D. Njubi. Estimation of individual and maternal additive genetic and heterotic effects for preweaning traits of Ayrshire, Brown Swiss and Sahiwal cattle in the low land tropics of Kenya. Livest. Prod. Sci. 44:139-146.

Madsen, O. and K. Vinther. 1975. Performance of purebred and crossbred dairy cattle in Thailand. Anim. Prod. 21:209-216.

Mackinnon, M. J., W. Thorpe and R. L. Baker. 1996. Sources of genetic variation for milk production in a crossbred herd in the tropics. Anim. Sci. 62:5-16.

Mason, I. L. and V. Buvanendran. 1982. Breeding plan for ruminant livestock in the tropics. FAO Animal Production and Health Paper No. 34.

Rege, J. E. O., G. S. Aboagye, S. Akah and B. K. Ahunu. 1994. Crossbreeding Jersey with Ghana Shorthorn and Sokoto Gudali cattle in a tropical environment: additive and heterotic effects for milk production, reproduction and calf growth traits. Anim. Prod. 59:21-29.

Roden, J. A. 1996. A comparison of alternative nucleus breeding systems and a sire referencing scheme for sheep improvement. Anim. Sci. 62:265-270.

SAS. 1990a. SAS® Procedure Guide (Release 6.06). SAS Inst., Inc., Cary, NC, USA.

SAS. 1990b. SAS/STAT® User's Guide (Release 6.06). Vol.2. SAS Inst., Inc., Cary, NC, USA.

Sharma, B. B. and F. Pirchner. 1991. Heterosis in Friesian× Sahiwal crosses. J. Anim. Breed. Genet. 108:241:252.

Taneja, V. K. and P. N. Bhat. 1974. Estimation of additive and non-additive effects in Sahiwal×Friesian crossbreds, first World Congress on Genetics Applied to Animal Production, 9-11. Oct. Madrid(Spain) Vol. 3. 617.

Tibbo, K., G. Wiener and D. Fielding. 1994. A review of the performances of Jersey breed of cattle and its crosses in the tropics in relation to the Friesian or Holstein and indigenous breeds. Anim. Breed. Abstr. 62:719-757.

Udo, H. M. J., J. Mejiej, F. Dawood and A. A. Diskhuizen. 1992. The benefits of cattle in mixed farm systems in Pabna, Bangladesh. Asian-Aus. J. Anim. Sci. 5(3):495-503.

Visscher, P. M. and M. E. Goddard. 1995. Genetic parameters for milk yield, survival, workability, and type traits for Australian dairy cattle. J. Dairy Sci. 78:205-220.

Yadev, A. S., S. S. Rathi and S. P. Dahiya. 1992. Genetic parameters for economic traits in Sahiwal Cattle. Journal of Dairying Foods & Home Sciences 11:81-89.