
VOLUME 62 2002

Profitability of rotational crossbreeding programmes in commercial dairy herds

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ABSTRACT

Dairy farm profitability can be increased through the use of superior cows in the lactating herd. Genetic superiority is determined by additive genetic effects and heterosis (present in crossbred animals). Profitability is the difference between income (sale of milk, bobby and salvage animals) and costs (related to the number of cows in the herd and the land area farmed). At comparable production, bigger cows consume more feed reducing their profitability per unit feed consumed. Previous studies have identified the high productivity of first-cross cows comprising Holstein-Friesian (F) and Jersey (J) breeds. In a self-replacing herd, first-cross (F_1) animals will not be continuously available unless some straightbred animals are maintained. One approach for exploiting heterosis in a self-replacing herd, is to make use of rotational crossbreeding. This paper reports profitabilities of some rotational crossbreeding programs in comparison to farming straightbred dairy animals.

A model was used to estimate on an annual basis, the nutritional, biological and economic performance of whole herds consuming 12,000 kg dry matter per ha. Expected performances for straight- and cross-bred cows comprising F, J and Ayrshire (A) breeds, were obtained using estimates of breed and heterosis effects derived from Livestock Improvement's animal evaluation system. Costs and prices were assumed to remain constant except for the market value of milkfat which had a (marginal) return of $0.44 per kg produced in excess of base year production.

In the base year, ignoring the sourcing of replacements, F_1 FxJ herds had net income per ha of $1006. In self-replacing herds, rotational JxA had the highest income ($1008/ha) followed by straightbred J ($996/ha), rotational FxJ ($983/ha), rotational FxJxA ($958/ha), straightbred A ($915/ha), rotational FxA ($914/ha), and straightbred F ($869/ha). Genetic gain per year in each breed was taken into account using current estimates of trends. After 10 years, straightbred J herds had the highest net income ($1077/ha) followed by rotational JxA herds ($1070/ha). Results suggest that under New Zealand conditions, rotational crossbreeding programs could increase profitability of some commercial herds.

Keywords: rotational crossbreeding; heterosis; dairy cattle; profitability; simulation.

INTRODUCTION

Farm profit is the difference between income and expenditure and is strongly influenced by production per cow and stocking rate. Income arises from sale of milk, bobby calves and salvage animals. Milk pricing is determined by a formula *a* fat + *b* protein - *c* milk, with values for *a*, *b* and *c* equal to 1.98, 4.49 and 0.04, respectively for the season 1994/95 (Livestock Improvement Corporation, unpublished data).

Expenditure is related to the number of cows in the herd and the land area farmed and includes costs associated with provision of labour, fertiliser, health, breeding, repairs and maintenance. Many costs are related to provision of feed. The amount of feed required for maintenance increases with the size of the animal. Thus, larger cows require more maintenance energy than smaller cows. With fixed feed resources this extra feed requirement reduces the numbers of large cows that can be fed per hectare.

Previous studies in New Zealand (Quartermain and Carter, 1969; Ahlborn-Breier, 1989; Ahlborn-Breier and Hohenboken, 1991; Anonymous, 1994; Harris et al. 1994) have identified the high productivity of first-cross (F_1) cows comprising Holstein-Friesian (F) and Jersey (J) breeds. These F_1 FxJ cows produce more milkfat, similar protein, with less milk volume and they are smaller than straightbred Holstein-Friesians (Ahlborn-Brier, 1989). However, first-cross animals will not be available unless some straightbred animals are maintained.

One approach for exploiting heterosis in a self-replacing herd, is by way of rotational crossbreeding. For instance, in a Jersey herd, cows are artificially inseminated with semen of a straightbred F bull to produce F_1 FxJ cows. Half of F_1 cows are inseminated with Friesian semen to produce $^3/_4$ F $^1/_4$ J cows and the other half are inseminated with J semen to produce $^1/_4$ F $^3/_4$ J cows. Next, $^3/_4$ F $^1/_4$ J cows are inseminated with J semen and $^1/_4$ F $^3/_4$ J cows are inseminated with F semen. After three more generations, half of the herd will be $^2/_3$ F $^1/_3$ J and the other half will be $^1/_3$ F $^2/_3$ J. This paper reports profitabilities of some rotational crossbreeding programs in comparison to straightbreeding programs.

MATERIAL AND METHODS

A deterministic computer model was used to simulate average performance of Holstein-Friesian, Jersey, Ayrshire (A) and crossbred herds under grazing conditions. Three mating systems were modeled: straightbreeding, two- and three-breed rotational crossbreeding.

The nutritional requirements, biological and economic performances of a herd including replacements were simulated on a yearly basis. The herd was grazed on ryegrass-clover pasture the whole year with supplementation as per normal farm practice. Stocking rates were adjusted on an annual basis according to the feed requirements of cows.

Herd management

Herds were self-replacing with industry average age structure. Ages and respective proportions were: 0-1 yr, 0.22; 1-2 yr, 0.20; 2-3 yr, 0.12; 3-4 yr, 0.10; 4-5 yr, 0.09; 5-6 yr, 0.08; 6-7 yr, 0.06; 7-8 yr, 0.05; 8-9 yr, 0.04; 9-10 yr, 0.03; and 10-11 yr, 0.01. Mortality rates for rising 1-year heifers, rising 2-year heifers and cows were 7, 6 and 2%, respectively.

Cows and heifers were artificially inseminated using semen from proven straightbred sires. Calving rates in heifers and cows were assumed to be 85% with half the calves of each sex. Culling rates were variable such that the structure of the herd remained constant throughout the years. Causes of cow wastage (Holmes *et al.*, 1987) were categorised into: (1) reasons when culled animals are slaughtered and create income, and (2) reasons when the culled animals cannot be sold for income. Cows remaining in the herd after 11 years were culled.

Proportions of culled animals with respect to an average breeding cow were: male bobby calves, 0.44; surplus of female calves for rearing, 0.11; empty rising 2-year heifers, 0.05; surplus of rising 2-year heifers, 0.06; and cows for slaughter, 0.16.

Expected performance

Expected annual performance (EP) for milk, milkfat, protein and liveweight of cows was simulated by each age class. In year t the expected performance for any trait was calculated as:

$$EP_t = (q'_o\, g_t + q'_s H_t q_d)f$$

where

q_s, q_d and q_o are vectors of order 3 with elements representing the composition of an individual in terms of F, J and A fractions for sire, dam and offspring, respectively. The vector q_o is determined from $\frac{1}{2}(q_s + q_d)$;

g_t is a vector of order 3 of breed additive effects. For the year t, the vector g_t was obtained as $g_{t-1} + \Delta_g$, where Δ_g is the vector of genetic trends in the bull population for each of the three breeds (Table 1);

H_t is a matrix of order 3x3 with diagonal elements being zero and off diagonal elements being the F_1 heterosis corresponding to the breeds represented by row and column of the entry. The matrix H_t can be constructed from percentage heterosis figures as:

$$\begin{bmatrix} 0 & \%h^{FJ} x(\frac{g_t^F + g_t^J}{2}) & \%h^{FA} x(\frac{g_t^F + g_t^A}{2}) \\ \%h^{FJ} x(\frac{g_t^F + g_t^J}{2}) & 0 & \%h^{JA} x(\frac{g_t^J + g_t^A}{2}) \\ \%h^{FA} x(\frac{g_t^F + g_t^A}{2}) & \%h^{JA} x(\frac{g_t^J + g_t^A}{2}) & 0 \end{bmatrix}; \text{ and}$$

f is a multiplicative age adjustment factor. Age adjustment factors for milk and milk component yields per cow were 0.75, 0.88, 0.95, 1.0, and 0.90 for lactations 1, 2, 3, 4-7, and 8-9, respectively.

Estimates of crossbreeding parameters for milk traits and liveweight used to predict the performance of cows are shown in Table 2. These estimates were obtained from analyses using an animal model (Anonymous, 1994).

Performance of an F_1 FxJ herd ignoring source of replacements was estimated for comparison. Herds using rotational crossing were assumed at equilibrium with respect to breed composition.

TABLE 1: Genetic trends for milk traits and liveweight in New Zealand dairy breeds (Livestock Improvement Corporation, unpublished data).

Breed	Trait			
	Milk (*l*/year)	**Milkfat (kg/year)**	**Protein (kg/year)**	**Liveweight (kg/year)**
Holstein-Friesian	29.0	1.07	0.82	0.1
Jersey	26.4	1.93	0.94	0.1
Ayrshire	28.4	1.15	0.84	0.1

TABLE 2: Estimates of additive breed (g) and heterosis (h) effects for milk traits and liveweight of straightbred and crossbred Holstein-Friesian (F), Jersey (J) and Ayrshire (A) cows in New Zealand (Anonymous, 1994).

Parameter	Trait			
	Milk yield (*l*)	**Milkfat yield (kg)**	**Protein yield (kg)**	**Liveweight (kg)**
Additive breed effects				
g^F	3,503	154	121	450
g^J	2,640	149	109	350
g^A	3,368	146	121	390
Heterosis effects				
h^{FJ}	181 (5.9%)[1]	10.4 (6.9%)	7.3 (6.4%)	0
h^{FA}	106 (3.6%)	4.2 (2.8%)	3.6 (3.0%)	0
h^{JA}	172 (6.9%)	9.4 (6.4%)	7.0 (6.1%)	0

[1] Values in brackets are percentages of heterosis

TABLE 3: Assumed liveweights (kg) at different ages for different breeds.

Age (months)	Breed		
	Holstein-Friesian	**Jersey**	**Ayrshire**
Birth	35	25	30
6	120	90	110
18	310	240	290
30	450	350	390
Mature	465	365	405

Average values of liveweight for the three breeds are shown in Table 3. Liveweight gains were obtained as the difference between liveweight at different ages.

Energy and dry matter requirements

Dry matter intake (DMI) of dairy cows was calculated by dividing total requirement of metabolisable energy (ME) by an assumed energy density per kg pasture DM of 10.5 megajoules (MJ) ME. Total ME requirement was determined by summing the component values:

ME (MJ)= ME*m* + ME*g* + ME*l* + ME*p*

where

ME*m* is the ME for maintenance estimated as 0.60 x $LW^{0.75}$ x 365 (Holmes *et al*., 1987);

ME*g* is the ME for liveweight gain estimated as 26.7 x kg LW gain for growing heifers and 38.5 x kg LW gain for growing cows (Holmes et al., 1987);

ME*l* is the ME for lactation estimated as (1.2 x *l* milk) + (55.4 x kg fat) + (38.5 x kg protein) (Holmes, 1995); and

ME*p* is the ME for pregnancy estimated as 0.168 x $LW^{0.75}$ x 73 (Moe and Tyrrell, 1972), and where LW is liveweight.

Stocking Rate

Stocking rate (SR), defined as the number of mature cows grazing per ha, was calculated as the ratio of utilisable pasture per hectare to the total dry matter requirement (including replacements) per cow per year:

$$SR = \frac{\text{Utilisable pasture per ha (kgDM)}}{\text{Pasture requirement per cow (kgDM)}}$$

It was assumed that 12,000 kg DM/ha were utilised for dairy production.

Economic Analysis

The economic analysis was based on income obtained using average values of products marketed, less costs of an average New Zealand dairy farm. Profitability was expressed on a per hectare basis.

Income. Income from milk was determined as *a* fat + *b* protein - *c* milk. If the production volume of milkfat was increased in any year, that extra or marginal production was sold for low returns (Fenwick and Marshall, 1991). Marginal value per kg milkfat was $0.44 (LIC, unpublished data). The value of milkfat for the year t (vf_t) was calculated as:

$$vf_t = \frac{[(z_t - z_0)0.44] + [z_0 \cdot vf_0]}{z_t}$$

where, z_0 is initial volume of milkfat produced, z_t is volume of milkfat in year t and vf_0 is initial value of kg milkfat. In contrast, the marginal value of protein was assumed identical to the average value for protein.

Assumed values of stock sold are shown in Table 4. The value of crossbred stock was equal to the value of the nearest straightbred. For example, the value of a ³/₄ F ¹/₄ J bobby calf was taken as $60. The carcass yield was assumed on 55% for all animals. Income from other sources was taken as $96 per hectare.

Production costs. Average production costs were based on survey information (Bird, 1995) and included direct expenses and overheads. Direct expenses ($/cow) were: labour, 92; animal health, 42; breeding and herd testing, 23; farm dairy expenses, 16; and electricity, 19. Other direct expenses ($/ha) were: fertiliser, 287; weed and pest control, 21; freight, 14; and other costs, 27. Overheads ($/ha) were: repairs and maintenance, 163; vehicle expenses, 111; administration, 111; and standing charges 122.

RESULTS

Performance

Performances per cow and per hectare of different breeding programs are shown in Table 5. Rotational FxA and straightbred F herds ranked highest for milk yield per cow followed by rotational FxJxA and straightbred Ayrshires. Herds using mating systems including Jersey genes had smaller cows producing higher milkfat yields

TABLE 4: Values of dairy livestock ($).

	Breed Holstein-Friesian	Jersey	Ayrshire
Bobby calf	60	50	50
Female calf for rearing	100	80	80
Replacement heifer	781	678	678
Slaughtered animals ($/kg carcass weight)	1.23	1.23	1.23

TABLE 5: Milk components production, liveweight (LW), dry matter intake (DMI) and stocking rate (SR) of dairy herds of different breeding programs involving Holstein-Friesian (F), Jersey (J) and Ayrshire (A) breeds.

Breeding system	SR	LW	DMI	Yield Milk (l) /cow	/ha	Milkfat (kg) /cow	/ha	Protein(kg) /cow	/ha
Year 0									
Straightbreeding									
F	2.43	450.0	4930	3503	8526	154	375	121	295
J	2.88	350.0	4179	2640	7581	149	428	109	313
A	2.63	390.0	4569	3368	8845	146	384	121	318
First cross									
F_1 FxJ	2.57	401.4	4670	3253	8357	162	416	122	314
Two-breed rotation									
FxJ	2.59	399.9	4626	3193	8282	159	411	120	311
FxA	2.51	420.0	4783	3507	8797	153	383	123	310
JxA	2.70	370.0	4438	3119	8435	154	416	120	324
Three-breed rotation									
FxJxA	2.55	405.4	4707	3402	8672	155	396	123	314
Year 10									
Straightbreeding									
F	2.38	451.0	5045	3767	8961	164	390	129	306
J	2.77	351.0	4336	2877	7962	167	461	118	325
A	2.56	391.0	4689	3632	9296	157	401	129	329
First cross									
F_1 FxJ	2.49	402.4	4815	3518	8768	177	440	131	326
Two-breed rotation									
FxJ	2.52	400.9	4768	3453	8692	173	435	128	323
FxA	2.45	421.0	4903	3776	9243	163	399	131	321
JxA	2.62	371.0	4582	3380	8852	169	441	128	336
Three-breed rotation									
FxJxA	2.48	406.3	4836	3670	9107	167	415	131	326

and lower volumes of milk. Cows in the F_1 FxJ herd produced the highest milkfat yield and their liveweight was the average of straightbred Holstein-Friesian and Jersey. These rankings were almost the same after 10 years of simulation but more rapid increases in milkfat yield per cow were achieved in herds including the Jersey breed in the breeding system than in those herds including Holstein-Friesian and Ayrshire breeds.

Straightbred Jerseys ranked lowest for dry matter intake per cow and highest for stocking rate. Straightbred Holstein-Friesians ranked highest for dry matter intake and lowest for stocking rate.

Ayrshire herds ranked highest for milk production per hectare followed by rotational FxA, rotational FxJxA and straightbred Holstein-Friesian herds. Straightbred Jersey herds had the highest milkfat production per hectare followed by rotational FxJ herd. Rotational JxA herds ranked highest for protein production per hectare followed by straightbred Ayrshire and rotational FxJxA herds. These herds ranked similarly after 10 years of simulation.

Economic Analysis

Production costs and incomes per cow and per hectare of different breeding programs are shown in Table 6. Milk income per cow for crossbred herds was higher than that for straightbred herds. F_1 FxJ herds ranked highest ($740) followed by rotational FxJxA ($725) and rotational FxJ ($724). Value of milkfat was assumed to decrease because excess of production was paid in a marginal value of $0.44. The values per kg milkfat for the base year through year 10 decreased slightly and were 1.98, 1.97, 1.96, 1.95, 1.94, 1.94, 1.93, 1.93, 1.92, 1.91 and 1.90, respectively as a result of assuming a fixed area for milk production.

Production costs per cow were highest for straightbred Holstein-Friesian ($534) followed by rotational FxA ($524) and rotational FxJxA ($519).

In the base year, ignoring the source of replacements, F1 FxJ herds had a net income of $1006/ha. In self-replacing herds, rotational JxA had the highest income ($1008) followed by straightbred Jersey ($996), rotational FxJ ($983), rotational FxJxA ($958), straightbred A ($915), rotational FxA ($914), and straightbred F ($869). After 10 years, straightbred Jersey herd had the highest net income ($1077) followed by rotational JxA herds ($1070).

Further economic analysis was not undertaken for first-cross F_1 FxJ herds as these are not self-replacing.

TABLE 6: Gross and net income and production costs per cow and per hectare for different breeding programs involving Holstein-Friesian (F), Jersey (J) and Ayrshire (A) breeds.

Breeding system	Milk income $/cow	Milk income $/ha	Gross income $/cow	Gross income $/ha	Production Costs $/cow	Production Costs $/ha	Net income $/cow	Net income $/ha
				Year 0				
Straightbreeding								
F	708	1724	891	2169	534	1300	357	869
J	679	1949	830	2383	483	1387	347	996
A	698	1833	858	2254	510	1338	349	915
First cross								
F_1 FxJ	740	1900	908	2333	517	1327	392	1006
Two-breed rotation								
FxJ	724	1879	892	2315	514	1332	379	983
FxA	717	1798	889	2230	524	1315	365	915
JxA	717	1939	874	2362	501	1354	373	1008
Three-breed rotation								
FxJxA	725	1848	895	2281	519	1323	376	958
				Year 10				
Straightbreeding								
F	738	1756	923	2195	542	1289	381	906
J	731	2022	883	2444	494	1367	389	1077
A	731	1871	892	2284	517	1325	375	959
Two-breed rotation								
FxJ	767	1931	936	2357	523	1317	413	1040
FxA	749	1833	922	2257	532	1303	390	955
JxA	761	1994	919	2407	511	1337	409	1070
Three-breed rotation								
FxJxA	762	1890	933	2315	528	1309	405	1005

DISCUSSION

Caution must be taken when interpreting how crossbred cows perform when they are mixed in varying proportions with straightbred cows in the same herd (Glassey and McPherson, 1993).

Liveweight is of importance in the production system because it affects stocking rate and profitability of the dairy farm through its relation to feed requirements for maintenance. Requirements of dry matter for maintenance represented 48 - 53% of total annual requirements (data not shown). Liveweights of Jerseys were lower than that for Holstein-Friesians while that for crossbreed cows was of intermediate value (Table 5).

Production costs per cow of herds carrying bigger (Holstein-Friesian) animals were higher than those for carrying smaller (Jersey) animals. However, herds with higher stocking rates (Jersey) had higher production costs per hectare than those with lower stocking rate (Holstein-Friesian) because some production costs were proportional to stocking rate.

For the base year, crossbred herds had higher income per cow from milk sales than straightbred herds. F_1 FxJ cows showed an increase in the milk income per cow by $32 compared to Holstein-Friesian, $42 compared to Jersey and $61 compared to Ayrshire (Table 6). This was because F_1 FxJ cows produced higher milkfat and protein yields than the corresponding straightbreds and the volume produced was lower than that of Holstein-Friesians.

The real interest for the New Zealand dairy farmer, however, is overall output per unit of land. Given a fixed amount of feed per hectare, more milk was produced by Ayrshire and rotational FxA herds, more milkfat by Jersey and F_1 FxJ herds and more protein by rotational JxA herds (Table 5). In terms of economic efficiency per unit of land, the highest milk income corresponded to the Jersey herd followed by rotational JxA, F_1 FxJ and rotational FxJ herds (Table 6). Milk incomes ($) per tonne DM for these four breeding systems were 162, 162, 158 and 157, respectively.

Annual genetic gain for milkfat production for the Jersey breed has been reported higher than that for Holstein-Friesian and Ayrshire breeds (Ahlborn-Breier *et al.* 1987). This higher genetic gain per year and a small reduction in the value of milkfat lead Jersey herds to be ranked highest for net income per hectare after 10 years of simulation.

There is considerable discussion of the reproductive performance and survival rate of crossbred cattle. Ahlborn-Breier (1989) reported that F_1 FxJ cows had higher calving rate than straightbred J or F cows. Survival from birth to first calving for crossbred cattle has been reported higher than for straightbreds (McAllister, 1986; Touchberry, 1992). In this study, however, no differences in reproductive performance and survival rate were considered. Inclusion of heterosis for fertility and survival would result in more animals for sale and more opportunity to cull based on performance, and as a consequence, profitability of crossbred herds compared to straightbred herds would be still higher.

Results in this simulation indicate that crossbred cows are more productive and could be more profitable than straightbred cows. Dairy herds with F_1 FxJ cows should be considered as a major option for breed resource utilisation. However, the real challenge is to establish breeding programs that retain merits of the first crosses. Rotational crossbreeding is a practical option for New Zealand commercial dairy farmers. This requires controlled mating which is possible given the present status of artificial insemination and recording in the dairy industry.

CONCLUSIONS

From this study based on New Zealand conditions, rotational crossbreeding programs can be shown to increase profitability in commercial herds.

ACKNOWLEDGMENTS

The senior author wishes to acknowledge financial support of Consejo Nacional de Ciencia y Tecnologia (CONACYT), México and Universidad Autonoma Chapingo, México.

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