Genetic and economic evaluation of Japanese Black (Wagyu) cattle breeding schemes[1]

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ABSTRACT: Deterministic simulation was used to evaluate 10 breeding schemes for genetic gain and profitability and in the context of maximizing returns from investment in Japanese Black cattle breeding. A breeding objective that integrated the cow-calf and feedlot segments was considered. Ten breeding schemes that differed in the records available for use as selection criteria were defined. The schemes ranged from one that used carcass traits currently available to Japanese Black cattle breeders (Scheme 1) to one that also included linear measurements and male and female reproduction traits (Scheme 10). The latter scheme represented the highest level of performance recording. In all breeding schemes, sires were chosen from the proportion selected during the first selection stage (performance testing), modeling a two-stage selection process. The effect on genetic gain and profitability of varying test capacity and number of progeny per sire and of ultrasound scanning of live animals was examined for all breeding schemes. Breeding schemes that selected young bulls during performance testing based on additional individual traits and information on carcass traits from their relatives generated additional genetic gain and profitability. Increasing test capacity resulted in an increase in genetic gain in all schemes. Profitability was optimal in Scheme 2 (a scheme similar to Scheme 1, but selection of young bulls also was based on information on carcass traits from their relatives) to 10 when 900 to 1,000 places were available for performance testing. Similarly, as the number of progeny used in the selection of sires increased, genetic gain first increased sharply and then gradually in all schemes. Profit was optimal across all breeding schemes when sires were selected based on information from 150 to 200 progeny. Additional genetic gain and profitability were generated in each breeding scheme with ultrasound scanning of live animals for carcass traits. Ultrasound scanning of live animals was more important than the addition of any other traits in the selection criteria. These results may be used to provide guidance to Japanese Black cattle breeders.

Key Words: Beef Cattle, Breeding Program Design, Breeding Schemes, Carcass Traits, Japanese Black Cattle

 J. Anim. Sci. 2005. 83:2021–2032

Introduction

The domestic Japanese beef industry is based on four native breeds: Japanese Black, Japanese Brown, Japanese Poll, and Japanese Shorthorn. These breeds produce approximately 44% of the domestic beef (Oyama et al., 2002). The Japanese Black cattle play a significant part in the Japanese beef industry because it is numerically the largest breed group and comprises approximately 93% of the national purebred beef cow herd (Sasaki, 2001). In addition, Japanese Black cattle produce highly marbled beef compared with the other Japanese beef breeds (Namikawa, 1992). Marbling is the most important trait in Japan because carcass value is primarily determined by the degree of marbling (Hirooka and Groen, 1999).

Hirooka et al. (1998a,b) developed breeding objectives for beef cattle in Japan, which included carcass and growth traits. Hirooka and Groen (1999) determined the effects of production circumstances on expected response for growth and carcass traits to selection of bulls. They reported significant annual genetic gains for beef marbling. In the long run, the inclusion of additional traits in the selection criteria seems inevitable. Inclusion of some of these traits may cause undesirable correlated changes in other sets of traits. Therefore, alternative designs of these cases need to be evaluated for their

[1]We thank Kyoto University, Kyoto, Japan for provision of facilities and the Japan Society for the Promotion of Science (JSPS) for funding this study. This paper was written when A. K. Kahi was on leave from the Animal Breeding and Genetics Group, Dept. of Anim. Sci., Egerton Univ., Njoro, Kenya.

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Received April 13, 2005.

Accepted June 9, 2005.

ability to achieve genetic progress and for their return on investment in genetic selection.

This article evaluates Japanese Black cattle breeding schemes that are possible with different levels of performance recording. Breeding schemes ranged from one that only used carcass traits currently available to Japanese Black cattle breeders to one that included linear measurements and male and female reproduction traits in a two-stage selection process. Breeding schemes were assessed based on genetic gain and profit per cow in the population and on maximization of returns from investment in Japanese Black cattle breeding.

Materials and Methods

The Japanese Black cattle breeding structure was modeled using the computer program ZPLAN (Karras et al., 1997). The program uses biological, statistical, and economic parameters to calculate the annual genetic gain for the breeding objective, genetic gain for single traits, and returns on investment adjusted for costs (profit) using gene-flow and selection index methodology. In addition, the program calculates selection indices for breeding animals and applies order statistics to obtain adjusted selection intensities for populations with finite sizes. These calculations assume that parameters and selection strategies remain unchanged during the investment period and consider only one round of selection. Decreased genetic variance due to selection and inbreeding is ignored.

Breeding Objective and Estimation of Economic Values

In Japan, beef production systems are, in practice, separated into two different segments: cow-calf and feedlot. Organizationally, these systems are integrated because the feedlot segment depends on the cow-calf segment for animals to be fattened for slaughter. Hirooka et al. (1998a) used a bioeconomic model to simulate cow-calf and feedlot segments and the integrated (cow-calf + feedlot) system for Japanese Black cattle in Japan and to develop breeding objectives for each system. MacNeil and Newman (1994) pointed out that the inherent inefficiency of beef production may result from the separation of objectives by production segment, which may differ from overall industry objectives. In these situations, breeding objectives for the integrated systems should meet the goals of both segments. Here, the breeding objective for the integrated system developed by Hirooka et al. (1998a,b) was used. Emphasis was placed on production of marbled beef for the domestic Japanese market. Slaughter was set to occur at a weight of 585 kg for females and 650 kg for males.

The breeding objective comprises breeding values and economic values for traits that directly influence either income or costs of the production enterprise. Traits considered in the breeding objective included: birth weight (**BWT,** kg), weaning weight (**WWT,** kg), mature weight (**MWT,** kg), daily gain during the feedlot period (**DG,** g/d), carcass marbling score (**MS**) based on standards of the JMGA (1988), LM area (**LMA,** mm^2), rib thickness at the 6th- and 7th-rib section (**RT,** mm), and s.c. fat thickness at the 6th- and 7th-rib section (**SFT,** mm; Hirooka et al., 1998a,b; Hirooka and Sasaki, 1998). Economic values for traits in the breeding objectives, representing values of unit changes in traits while other traits are unchanged, were derived from the estimates reported by Hirooka et al. (1998b) and Hirooka and Sasaki (1998). Hirooka et al. (1998b) estimated economic values of BWT, WWT, MWT, DG, and MS based on economic efficiency, defined as the ratio of returns to costs. To calculate economic responses and return on investment in a breeding population, economic values estimated from profit are required. The economic values for these traits were estimated from those derived from economic efficiency (Hirooka et al., 1998b) as described previously by Smith et al. (1986) as follows:

$$EV_P^y = \left(\frac{C}{E} \times \frac{\partial E}{\partial y}\right) / PRC \qquad [1]$$

where E_P^y = economic values from profit·cow^{-1}·yr^{-1} for trait y, C = the total production costs of a cow and her progeny (¥2,440,000), E = economic efficiency (1.00), $\frac{\partial E}{\partial y}$ is the marginal economic value of trait y for life cycle economic efficiency of a cow, and PRC = total period of the reproductive cycle in yr (6.67 yr).

Hirooka and Sasaki (1998) derived economic values for MS, LMA, RT, and SFT as the partial regression coefficients estimated using multiple linear regression of carcass sale price on carcass traits. The economic values for LMA, RT, and SFT were standardized to a cow per year basis using the following equation:

$$EV_P^y = (EV_P^{MS} \times EV_{RES}^y)/EV_{RES}^{MS} \qquad [2]$$

where EV_P^{MS} = economic value from profit·cow^{-1}·yr^{-1} for MS (estimated using Eq. [1]), EV_{RES}^y = economic value for trait y estimated as the partial regression coefficient (Hirooka and Sasaki, 1998), and EV_{RES}^{MS} = economic value for MS estimated as the partial regression coefficient (Hirooka and Sasaki, 1998). Table 1 shows the economic value for the breeding objective traits derived as the life cycle economic efficiency of a cow, the partial regression coefficients estimated from the multiple linear regression of carcass sale price on carcass traits and profit·cow^{-1}·yr^{-1}. Economic values on a cow per year basis were assessed without discounting because weighting by discounted expressions is done internally in ZPLAN (Karras et al., 1997).

Population Structure and Selection Groups

The breeding structure consisted of one tier, in agreement with the current Japanese situation, where

Table 1. Economic values for traits in the breeding objective[a]

Trait[b]	$\frac{\partial E}{\partial y}$[c]	EV^{y}_{RES}, ¥[d]	EV^{y}_{P}, ¥
BWT, kg	–3.46		–1,267.80
WWT, kg	0.21		76.95
MWT, kg	0.30		109.92
DG, g/d	0.23		85.20
MS, score	53.50	45,159.00	19,603.00
LMA, mm^2		471.40	204.63
RT, mm		5,759.70	2,500.26
SFT, mm		2,131.30	925.19

[a]Economic values derived from the life cycle economic efficiency of a cow $\left(\frac{\partial E}{\partial y}\right)$, the partial regression coefficients estimated using multiple linear regression of carcass sale price on carcass traits (EV^{y}_{RES}), and profit per cow per yr (EV^{y}_{P}).

[b]BWT = birth weight; WWT = weaning weight; MWT = mature weight; DG = daily gain during the feedlot period; MS = marbling score; LMA = LM area; RT = rib thickness; and SFT = subcutaneous fat thickness.

[c]Hirooka et al. (1998b), multiplied by 1,000.

[d]Hirooka and Sasaki (1998).

there is no differentiation in the levels of performance and pedigree recording because breeding occurs in the whole population. Breeding was by AI using semen from progeny-tested bulls. Genetic gain was generated in the whole population, where bull selection and production of slaughter progenies are the main activities. Replacements bulls and females were selected on indices that included all available information at the time of selection. A total population size of 500,000 breeding cows was considered. This is the approximate population size for the Japanese Black cattle in Japan (Sasaki, 2001). The average calving and annual cow survival rates (including both death and culling) were assumed to be 85 and 92%, respectively. The calf survival rate from birth to weaning was assumed to be 98%, and the proportion of male and females calves that were suitable for breeding was 0.80 and 0.90, respectively. Male calves from planned mating were collected and performance tested in a central station. The total number of places available for performance testing was 500, and the survival rate during performance testing was assumed to be 90%. At the end of performance testing, a proportion of bulls was selected based on their growing ability (**yS**>**S** = Selection Group 1). Depending on the breeding scheme under investigation, this included information on chest girth (**CG**), scrotal circumference (**SC**), or additional information from the bull's relatives. Bulls to be used in the nucleus were selected from Group 1 in a two-stage selection process. Twenty percent of the young bulls selected in the first selection stage were test mated to ordinary cows and their progeny performance was tested for carcass traits (Sasaki, 2001). After a 4-yr waiting period, 45 bulls were selected from the progeny-tested young bulls based on the carcass records on 25 progeny and information from relatives. The selected bulls were used to produce both bulls and cows (bulls to breed sires, **S**>**S** = Selection Group 2; and bulls to breed dams, **S**>**D** = Selection Group 4). In addition, these bulls were used to produce slaughter progeny (**S**>**P** = Selection Group 6). There was no differentiation in the use of selected bulls as sires of young bulls, replacement cows, and slaughter progeny. Therefore, intensities of selection were equal for Groups 2, 4, and 6. The bulls were 5 yr old at the birth of their progeny, with a productive lifetime of 9 yr and a survival rate of 92%. Figure 1 shows the breeding plan simulated for the selection of superior bulls. Selection of cows also occurred to breed sires (**D**>**S** = Selection Group 3), dams (**D**>**D** = Selection Group 5), and slaughter progeny (**D**>**P** = Selection Group 7). The proportion of bull dams (Selection Group 3) for planned mating was assumed to be 5% of the total population. The intensities of selection were equal for Groups 5 and 7. The age at first calving and the productive lifetime of cows was 2 and 7 yr, respectively. The replacement rate was assumed to be 33% for females and 20% for males (Mukai, 1994). Calves not for replacement were shipped to calf markets for fattening and slaughter, and their carcass traits were evaluated at carcass markets.

The assumed variable costs incurred in the breeding population of 500,000 cows are shown in Table 2. The variable costs were directly related to performance and pedigree recording and applied to the complete population. These costs affect the profitability of the breeding scheme but not genetic response. Costs were based on Hirooka et al. (1998a,b); when the Japanese equivalent was missing, they were based on Kahi et al. (2003). In long-term investments such as genetic improvement, the appropriate inflation-adjusted discount rate should be low (i.e., in the 2 to 5% range; Bird and Mitchell, 1980). Therefore, returns from breeding schemes were discounted at a rate of 5% and costs at 3%. An investment period of 25 yr was assumed.

Genetic and Phenotypic Parameters

Genetic and phenotypic parameters were derived from studies with the Japanese Black cattle when available (Hirooka and Groen, 1999; Oikawa et al., 2000; Oyama et al., 2004). When not available, they were derived from studies on other beef breeds (Koots et al., 1994a,b; Maiwashe et al., 2002). In situations where estimates of phenotypic, but not genetic, correlations were found and vice versa, the phenotypic and genetic correlations were assumed to be equal (Koots et al., 1994a,b). The resulting genetic and phenotypic variance/covariance matrices were nonpositive definite. Bending was applied to find positive definite variance-covariance matrices, which were a "minimum distance" from the nonpositive definite matrices (Henshall and Meyer, 2002). The genetic and phenotypic parameters used are presented in Table 3.

Breeding Schemes, Selection Criteria, and Index Information

Breeding schemes were defined that differed in the records available for use as selection criteria. Breeding

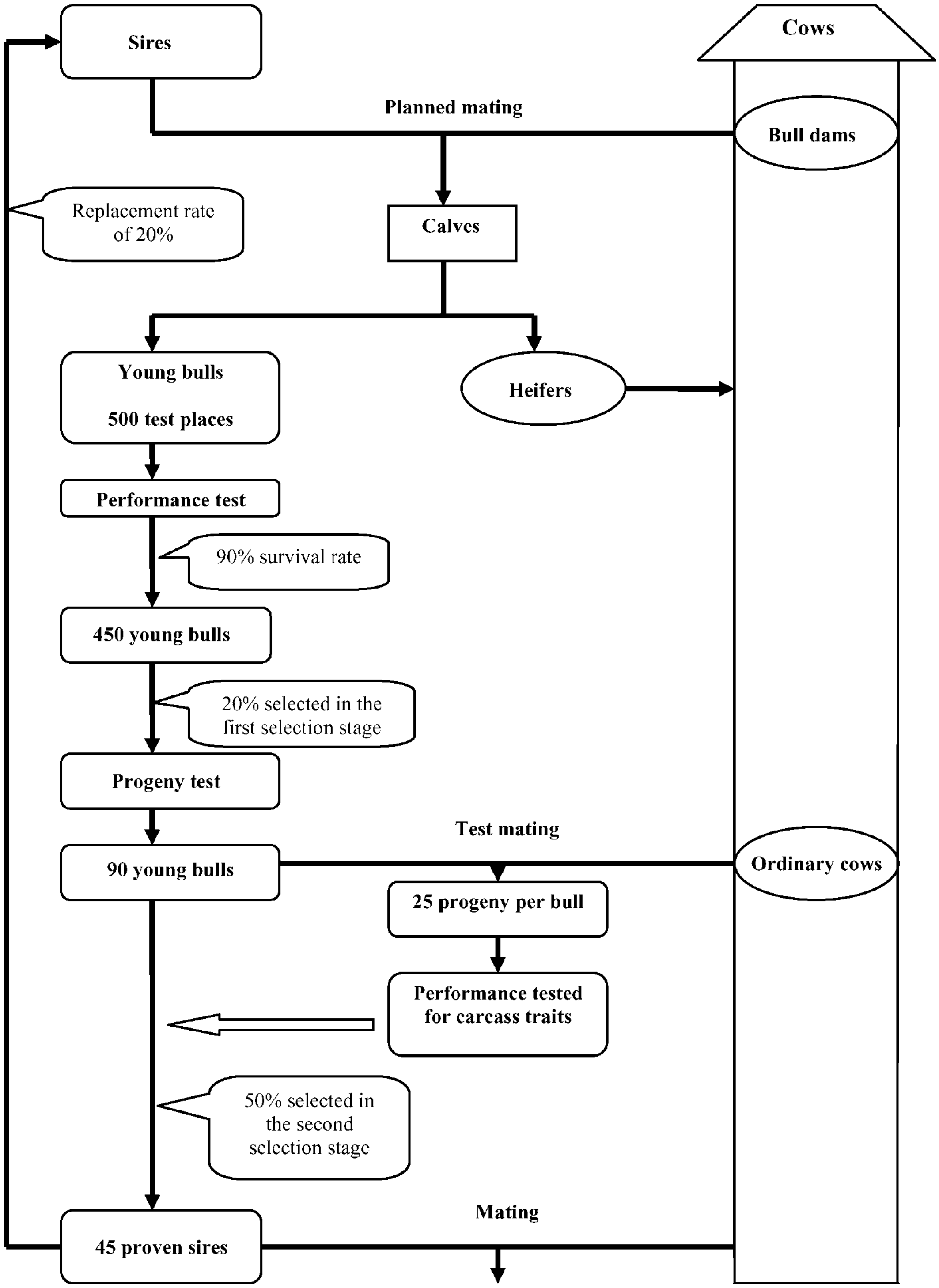

Figure 1. Flow chart showing the breeding plan simulated for the selection of superior bulls.

schemes that require increased levels of performance recording and genetic evaluation, have increased costs, which is an effect directly attributed to the scheme. The breeding schemes evaluated were ordered to represent increasing levels of performance recording. Descriptions of the schemes evaluated are as provided below.

Scheme 1: This was the base scenario, with the selection criteria being those currently used in Japan. During performance testing, young bulls (Selection Group 1) are selected based on their growth ability only, whereas other selection groups are selected based on carcass traits from relatives. The criteria therefore included measurements on daily gain during performance testing (ADG, g/d), daily gain during the feedlot period (DG, g/d), MS, LMA, RT, and SFT.

Scheme 2: Scheme 1 criteria plus information on carcass traits from the relatives of the performance tested young bulls. In Japan, one problem regarding bull selec-

Table 2. Variable costs incurred in a breeding population of 500,000 cows and the average time of cost occurrences in years

Cost element	Cost, ¥	Yr
Identification, pedigree recording, electronic data processing, etc. costs per cow	1,000	2.00
Birth weight	320	0
Weaning weight	200	0.49
Mature weight	200	3.00
Carcass traits	1,500	2.18
Chest girth	200	0.88
Scrotal size	200	0.88
Age at first calving	200	1.93
Calving interval	200	2.87
Performance testing per bull	1,000,000	0.88
Subsidy for a progeny on farm	38,000	1.00
Waiting period/(bull·yr)	850,000	5.00
Artificial insemination cost per cow	20,000	1.15

tion is the lack of any selection pressure on carcass traits until progeny testing. This scheme therefore assessed the effect of using field carcass records on genetic gain and profitability.

Scheme 3: Scheme 1 criteria plus linear measurement of CG (cm) on the performance-tested young bulls. Desired relationships between CG and carcass traits have been reported (Mukai et al., 1995).

Scheme 4: Scheme 1 criteria plus weights recorded on all animals. The weights recorded included BWT and WWT in all animals and MWT in females retained for replacement in the herd.

Scheme 5: This was a combination of Schemes 2 and 4. It allowed assessment of whether inclusion of information on carcass traits, DG, and weights from the relevant relatives was advantageous.

Scheme 6: Scheme 5 criteria plus linear measurement of CG on the performance-tested young bulls.

Scheme 7: Scheme 6 criteria plus measurement of reproduction traits on replacement females. The reproduction traits included age at first calving (**AFC,** d) and calving interval (**CI,** d).

Scheme 8: Scheme 6 criteria plus measure of SC (mm) on the performance-tested young bulls.

Scheme 9: Scheme 1 criteria plus measurement of AFC and CI on replacement females and of SC on the performance-tested young bulls.

Scheme 10: This was a combination of Schemes 7 and 8. This scheme represented the highest level of performance recording. It allowed assessment of the effects of increased investment in performance recording on genetic gain and profitability of the Japanese Black cattle breeding program.

Selection was based on the best index for the available criteria in all breeding schemes. The total number of bulls performance tested was restricted by the test capacity. This tended to make the number of candidates for selection smaller and generation intervals longer. In all breeding schemes, sires were selected from the proportion selected during the first selection stage (performance testing), modeling a two-stage selection process. For all selection groups, information sources included records on individuals, paternal half sibs, sire, dam, and half-sibs of the sire and dam. In addition, for sires, information sources included records on carcass traits of his progeny. The number of records used to select sires and dams was calculated from figures for cow-to-bull ratio (estimated internally), calving rate and cow and calf survival and culling rates at different stages.

Variations of the Test Capacity, Number of Progeny Per Sire, and of the Information Available for Selection of Bulls and Cows

Variations of the capacity for performance testing, number of progeny per sire, and of the information

Table 3. Assumed phenotypic standard deviations (σ_p), heritabilities (h^2), and genetic (below diagonal) and phenotypic (above diagonal) correlations among traits in the selection criteria and in the breeding objective

Trait[a]	σ_p	h^2	BWT	WWT	MWT	DG	MS	LMA	RT	SFT	ADG	CG	SC	AFC	CI
BWT, kg	3.46	0.43		0.43	0.30	0.20	−0.02	−0.03	−0.03	−0.04	0.16	0.15	0.03	0.56	−0.42
WWT, kg	18.40	0.30	0.52		0.37	0.21	−0.04	0.29	0.29	0.04	0.31	0.21	0.16	−0.05	−0.10
MWT, kg	54.00	0.50	0.42	0.44		0.10	0.00	0.16	0.16	0.08	0.08	0.29	0.12	−0.08	−0.08
DG, g/d	98.00	0.41	0.27	0.26	0.11		0.10	0.19	0.19	0.18	0.71	0.16	0.12	0.08	0.00
MS, score	2.01	0.56	0.21	−0.11	0.00	0.05		0.30	0.24	0.00	−0.01	0.17	0.00	−0.06	0.00
LMA, mm^2	70.85	0.46	−0.03	0.15	0.12	0.16	0.27		0.33	0.00	0.21	0.19	0.06	−0.03	0.01
RT, mm	8.00	0.38	−0.03	0.15	0.12	0.16	0.25	0.26		0.21	0.38	0.64	0.06	−0.01	−0.01
SFT, mm	7.51	0.46	−0.03	0.03	0.07	0.15	−0.03	−0.05	0.11		−0.11	−0.17	0.00	−0.01	−0.02
ADG, g/d	160.00	0.34	0.13	0.26	0.07	0.60	−0.01	0.17	0.32	−0.09		0.16	0.16	0.08	0.00
CG, cm	4.97	0.25	0.13	0.18	0.24	0.13	0.14	0.16	0.54	−0.15	0.13		0.06	−0.29	−0.14
SC, mm	21.30	0.46	0.07	0.10	0.10	0.10	0.00	0.03	0.00	0.00	0.10	0.05		0.17	0.14
AFC, d	96.60	0.20	0.47	−0.04	−0.07	0.07	−0.16	−0.09	−0.03	−0.02	0.07	−0.25	0.15		0.05
CI, d	65.79	0.05	−0.36	−0.09	−0.07	0.00	0.01	0.05	−0.05	−0.07	0.00	−0.12	−0.07	0.17	

[a]BWT = birth weight; WWT = weaning weight; MWT = mature weight; DG = daily gain during the feedlot period; MS = marbling score; LMA = LM area; RT = rib thickness; SFT = subcutaneous fat thickness; ADG = daily gain during performance testing; CG = chest girth; SC = scrotal circumference; AFC = age at first calving; and CI = calving interval.

Table 4. Genetic superiority (¥/100) of the selection groups for the different breeding schemes

Breeding scheme[b]	Selection group[a]			
	yS>S	S>S and S>D	D>S	D>D
1	96.82	719.65	545.18	229.31
2	458.35	973.09	545.18	229.31
3	152.97	772.03	545.19	229.32
4	120.92	743.56	554.21	233.11
5	464.01	977.77	554.21	233.11
6	471.17	982.13	554.21	233.11
7	475.67	984.05	568.99	239.33
8	471.18	982.13	554.21	233.11
9	96.82	719.88	545.81	229.58
10	475.67	984.05	568.99	239.33

[a]yS>S = young bulls to breed sires; S>S = bulls to breed sires; S>D = bulls to breed dams; D>S = cows to breed sires; D>D = cows to breed dams.

[b]Scheme (Sch) 1 = base scenario with young bulls being selected based on their growth ability during performance testing and carcass (marbling score, LM area, rib thickness, and s.c. fat thickness) and growth (daily gain in feedlot) information from relatives; Sch 2 = Sch 1 criteria plus carcass traits from relatives of performance tested bulls; Sch 3 = Sch 1 criteria plus chest girth; Sch 4 = Sch 1 criteria plus weights; Sch 5 = a combination of Sch 2 and 4; Sch 6 = Sch 5 criteria plus chest girth; Sch 7 = Sch 6 criteria plus reproduction traits (age at first calving and calving interval); Sch 8 = Sch 6 criteria plus scrotal circumference; Sch 9 = Sch 1 criteria plus female reproduction traits and scrotal circumference; and Sch 10 = combination of Sch 7 and 8.

available for the selection of bulls and cows were examined for all breeding schemes. The effect on annual genetic gain and profitability of varying the test capacity was investigated. Test capacity ranged from 300 to 2,000. The aim here was to determine the optimal capacity needed in the Japanese Black cattle breeding program. The number of progeny per sire fluctuated between five and 300, with the aim of determining the optimal number of progeny upon which sires could be accurately selected using an on-farm progeny test. Variable amounts of information for selection of bulls and cows were used in all breeding schemes. Carcass traits were assumed to be collected on live animals through ultrasound scanning. In this case, first-stage selection was delayed until bulls were older and also scanned for carcass traits. This was to ascertain the effect of ultrasound scanning of live animals on genetic gain and profitability in the Japanese Black cattle breeding program. Currently in Japan, it is only possible to collect carcass information after the slaughter of the animal. All simulations were repeated by including carcass traits as additional information sources in all live animals. Because ultrasound scanning of live animals is not currently practiced in Japan, the actual costs associated with ultrasound scanning were assumed to be similar to those incurred during collection of carcass information after the slaughter of the animal. In addition, the genetic and phenotypic parameter estimates for carcass traits were assumed to be equal to those of the corresponding ultrasound traits. This effectively assumed a correlation of unity between carcass and ultrasound traits. High and positive correlations between carcass and corresponding ultrasound traits have been reported, indicating that ultrasound imaging is an alternative to carcass data collection in beef breeding programs (Reverter et al., 2000; Kemp et al., 2002).

Results and Discussion

Selection Group Differences in Genetic Superiority

Differences in genetic superiority among selection groups in the breeding structure are shown in Table 4. The selection groups S>P and D>P are not shown because they did not contribute to genetic response because they involved the production of terminal individuals. Nonetheless, these selection groups had accuracy of selection similar to groups S>S and D>D, respectively, because they were selected based on the same information. The selection group yS>S had the lowest genetic superiority in breeding schemes (i.e., Schemes 1, 3, 4, and 9) that assumed the young bulls are selected based on their growth ability only during performance testing. In the other schemes that included information from relatives as well, genetic superiority was greatest in sires and least in the cows to breed dams selection group. This emphasizes the importance to genetic response of placing more emphasis on sire selection. When comparisons were made between breeding schemes, genetic superiority was greatest for breeding schemes with the highest levels of investment. As expected, among the dam groups, D>S had the highest genetic superiority because their selection intensities were higher. This group of dams participates in planned mating for production of bulls for performance and progeny testing. Contrary to conditions elsewhere, in Japan, a dam qualifies to be a bull dam only after its male progeny has been identified for performance testing. Due to the limited test places, only a small number of male progeny are tested. Therefore, increasing the number of bull dams will result in increased selection intensities because this translates into a large number of bull calves to select from in the first selection stage; however, this will result in no change in the selection intensities in the second selection stage.

Annual Monetary Genetic Gain, Returns, and Profit Per Cow

Index accuracy, annual monetary genetic gain and cost, and returns and profit per cow in the population are shown in Table 5 for the different breeding schemes. Index accuracy, annual monetary genetic gain and costs, and returns and profit per cow varied according to the breeding schemes. Breeding Scheme 1 had the least and Schemes 6, 7, 8, and 10 the greatest (0.71) index accuracies. The annual monetary genetic gain was the greatest in Scheme 7 and least in Scheme 1, whereas costs, returns, and profit per cow were the highest in Schemes 7 and 10. When Schemes 1 and 2

Table 5. Index accuracy, annual monetary genetic gain in the breeding objective, and costs, returns, and profit per cow in the population for the different breeding schemes

Breeding scheme[a]	Index accuracy	Annual genetic gain, ¥/100	Costs per cow, ¥/100	Returns per cow in the population, ¥/100	Profit per cow in the population, ¥/100
1	0.63	65.94	146.65	669.95	523.30
2	0.70	81.04	146.65	820.83	674.18
3	0.65	69.06	146.66	701.14	554.48
4	0.64	67.75	151.79	688.19	536.40
5	0.70	81.70	151.79	827.62	675.83
6	0.71	81.96	151.79	830.21	678.42
7	0.71	82.91	153.32	837.91	684.59
8	0.71	81.96	151.80	830.21	678.41
9	0.64	65.98	148.18	670.37	522.19
10	0.71	82.70	153.32	837.91	684.59

[a]Scheme (Sch) 1 = base scenario with young bulls being selected based on their growth ability during performance testing and carcass (marbling score, LM area, rib thickness, and s.c. fat thickness) and growth (daily gain in feedlot) information from relatives; Sch 2 = Sch 1 criteria plus carcass traits from relatives of performance tested bulls; Sch 3 = Sch 1 criteria plus chest girth; Sch 4 = Sch 1 criteria plus weights; Sch 5 = a combination of Sch 2 and 4; Sch 6 = Sch 5 criteria plus chest girth; Sch 7 = Sch 6 criteria plus reproduction traits (age at first calving and calving interval); Sch 8 = Sch 6 criteria plus scrotal circumference; Sch 9 = Sch 1 criteria plus female reproduction traits and scrotal circumference; and Sch 10 = combination of Sch 7 and 8.

are compared, additional genetic gain and profitability were generated when information on carcass traits from relatives of the performance-tested young bulls was included in the selection criteria. Scheme 2 assessed the effect of using field carcass records on genetic gain and profitability.

Schemes 2 and 5 had the same index accuracy. There was only a small difference in annual genetic gain and costs, and returns and profit per cow between these schemes. The difference in annual genetic gain and returns and profit per cow was smaller than that between Schemes 1 and 4. This result emphasizes the importance of including information on carcass traits from relatives of the performance-tested young bulls. In Japan, carcass quality is economically very important and is the most desired characteristic to be improved. Selecting young bulls on the basis of their growth ability during performance testing is a less desirable strategy both genetically and economically. Thus, there is a need to include information on field carcass records from relatives of bulls to avoid potential losses of genetically superior candidates early in the selection process.

Desirable correlations exist between CG during performance testing and carcass traits (Mukai et al., 1995). Inclusion of CG in Scheme 3 resulted in some increase in index accuracy, annual genetic gain, and profitability. The increase was greater than that obtained when BW (Scheme 3) and female reproduction traits (Scheme 9) were included as additional selection criteria traits. Therefore, in the absence of field carcass records, CG potentially is a good criterion for selection to improve total merit of the carcass. There were small differences in the annual genetic gain and returns and profit per cow as a result of inclusion of SC as a trait in the selection criteria (Scheme 6 vs. Scheme 8, and Scheme 7 vs. Scheme 10). In this case, index accuracy remained the same. Very low correlations between SC and breeding objective traits were assumed here. These parameters were based on literature values because of unavailability of estimates for the Japanese Black cattle breed. Scrotal circumference is important as a selection criterion for both reproductive and maternal performance in females (Maiwashe et al., 2002). There is a need to estimate reliable genetic and phenotypic correlations between SC and growth and carcass traits under Japanese conditions.

Annual Genetic Gain in Individual Traits

Annual genetic gains for individual traits included in the breeding objective for the different breeding schemes are presented in Table 6. Utilization of information on carcass traits from relatives of performance-tested young bulls increased genetic gains for these traits. Inclusion of body weights in Scheme 4 markedly increased responses in BWT, WWT, MWT, and DG. With the introduction of AFC, CI, and SC in Scheme 9, improvement of carcass traits was similar to that obtained in Scheme 1. This was as a result of the low genetic relationship that exists between reproductive and carcass traits of fattening animals (Oyama et al., 2004), and it implies that genetic improvement in carcass traits can be achieved without causing undesirable correlated changes in reproductive traits.

Generally, schemes that included information on the relatives of performance-tested young bulls (Schemes 4 to 8 and 10) had higher genetic gains for BW and carcass traits than schemes that did not include this information. For example, a comparison of Schemes 2 and 5 showed that gains in BW and carcass traits in the latter scheme were greater than in the former scheme.

Table 6. Annual genetic gain for individual traits included in the breeding objective for the different breeding schemes

	Traits[a]							
Breeding scheme[b]	BWT, kg	WWT, kg	MWT, kg	DG, g/d	MS, score	LMA, mm^2	RT, mm	SFT, mm
1	0.07	0.23	0.68	4.86	0.20	4.47	0.54	0.07
2	0.08	0.09	0.69	3.43	0.26	5.29	0.59	0.14
3	0.08	0.22	0.98	3.96	0.21	4.54	0.60	0.06
4	0.18	0.32	1.56	4.91	0.22	4.15	0.49	0.07
5	0.11	0.16	1.26	3.56	0.26	5.25	0.58	0.14
6	0.10	0.16	1.28	3.55	0.27	5.26	0.59	0.13
7	0.11	0.18	1.39	3.60	0.27	5.21	0.58	0.13
8	0.10	0.16	1.28	3.55	0.27	5.26	0.59	0.13
9	0.07	0.23	0.69	4.86	0.20	4.47	0.53	0.07
10	0.11	0.18	1.39	3.60	0.27	5.20	0.58	0.13

[a]BWT = birth weight; WWT = weaning weight; MWT = mature weight; DG = daily gain during the feedlot period; MS = marbling score; LMA = LM area; RT = rib thickness; SFT = s.c. fat thickness.
[b]Scheme (Sch) 1 = base scenario with young bulls being selected based on their growth ability during performance testing and carcass (marbling score, LM area, rib thickness, and subcutaneous fat thickness) and growth (daily gain in feedlot) information from relatives; Sch 2 = Sch 1 criteria plus carcass traits from relatives of performance tested bulls; Sch 3 = Sch 1 criteria plus chest girth; Sch 4 = Sch 1 criteria plus weights; Sch 5 = a combination of Sch 2 and 4; Sch 6 = Sch 5 criteria plus chest girth; Sch 7 = Sch 6 criteria plus reproduction traits (age at first calving and calving interval); Sch 8 = Sch 6 criteria plus scrotal circumference; Sch 9 = Sch 1 criteria plus female reproduction traits and scrotal circumference; and Sch 10 = combination of Sch 7 and 8.

Inclusion of more information during performance testing improved the accuracy of selecting young bulls for progeny testing, which consequently leads to an increase in genetic response.

Of interest is the genetic gain for MS. As indicated previously, MS is the most important trait in Japan from an economic point of view. The genetic gain in MS was desirable but smaller than the 0.46 value reported by Hirooka and Groen (1999). This difference could be due to differences in the genetic and economic parameters used and the number of traits included in the selection criteria and breeding objectives, the number of selection stages assumed, and the number of selection groups modeled. The present study used more recent estimates of genetic parameters and economic values that were estimated from profit. In addition, more traits were included in the breeding objective and selection criteria. Hirooka and Groen (1998) included MS as the only carcass traits in the breeding objective, whereas the selection criteria traits were BWT and WWT, DG and MS, and MWT assumed to be available in the candidate bull and his progeny, in candidate's progeny, and in candidate's dam, respectively. Hirooka and Groen (1998) only considered the second-stage selection process and three sire selection pathways. The first-stage selection process and dam selection pathways were ignored. To calculate the genetic gain in the complete population, the responses in all selection groups contributing to the cumulative genetic gain are needed (Rendel and Robertson, 1950). Usually, in breeding programs, more emphasis is placed on sire selection because of its importance to genetic response. Consequently, the response in the sire selection pathways is expected to be high.

Effect of Varying the Test Capacity and the Number of Progeny Per Sire

Figure 2 shows the effect of varying the test capacity on genetic gain. Only results in schemes 1, 2, 5, and 10 are presented. Increasing the test capacity resulted in an increase in the genetic gain in all schemes. The increase in genetic gain was greater in Scheme 1 than in the other schemes. At high test capacities, there was a decrease in the selection intensity of bulls in the first stage of selection for beef performance testing. The decreased selection intensity caused by the larger number of bulls in performance testing was largely compen-

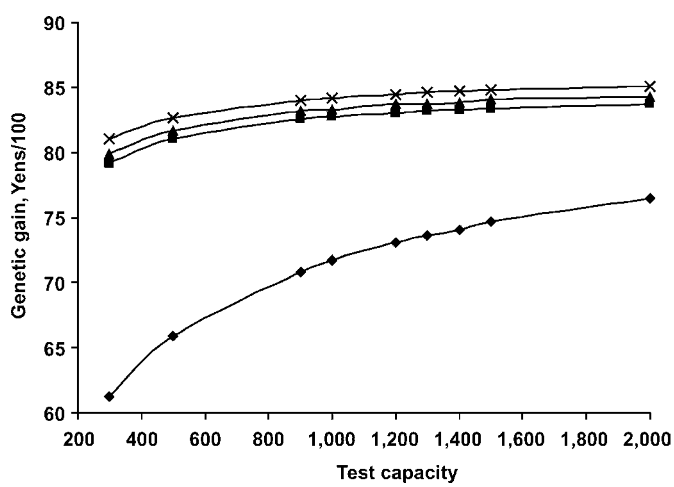

Figure 2. Effect of varying the test capacity on annual genetic gain under Breeding Schemes 1 (◆), 2 (■), 5 (▲), and 10 (×).

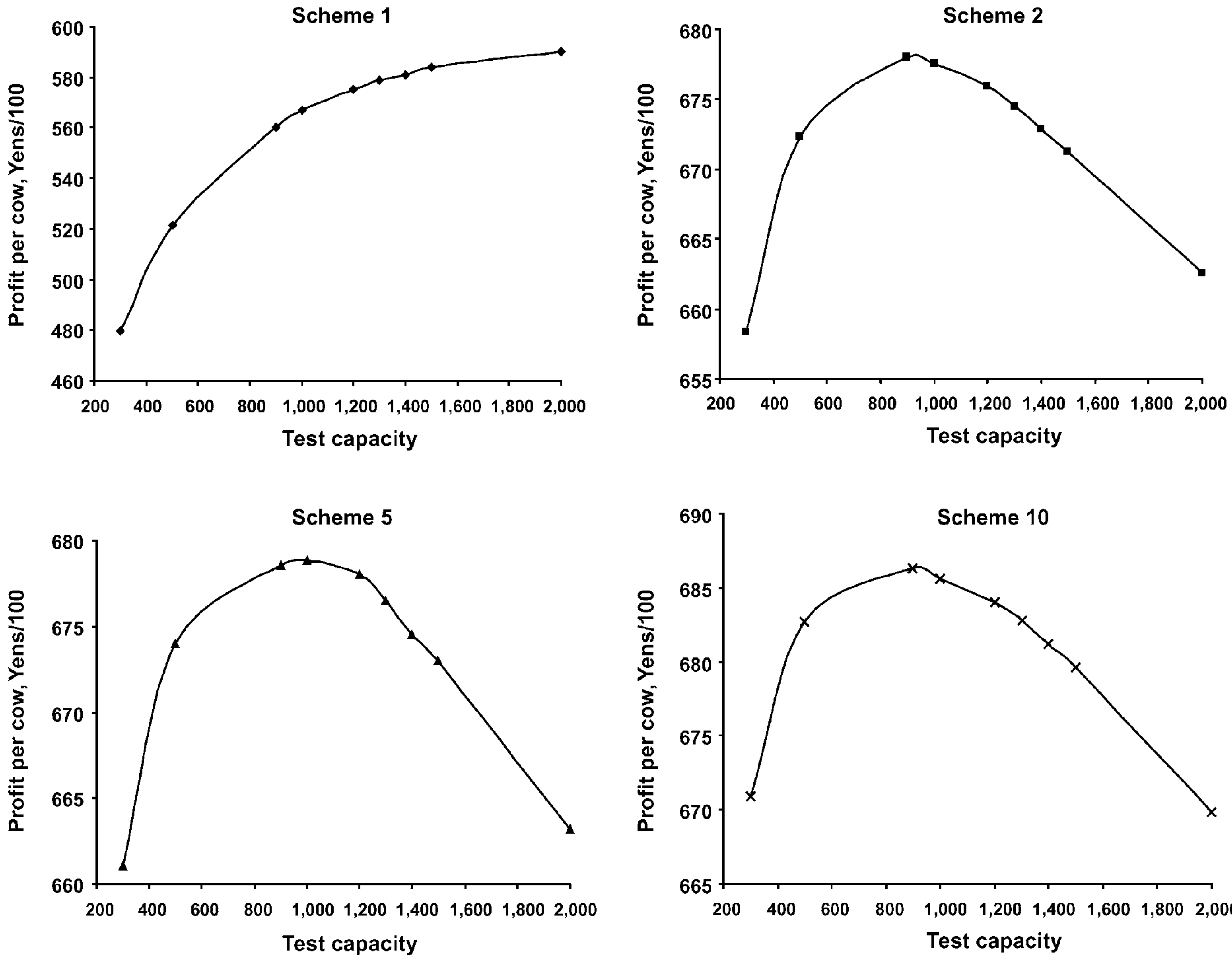

Figure 3. Effect of varying the test capacity on profit per cow under Breeding Schemes 1, 2, 5, and 10.

sated for by the high selection intensities in the second stage of selection.

Figure 3 presents results for the effect on profit per cow of varying the test capacity in Schemes 1, 2, 5, and 10. An increase in test capacity is associated with an increase in costs incurred during the waiting period and progeny testing. In Scheme 1, profit per cow in the population increased markedly with an increase in the test capacity, the effect initially increasing fast and then gradually after a test capacity of 1,500. Under this scheme, the optimal test capacity would be greater than 2,000. In Scheme 2, profit per cow increased with increased test capacity, reaching an optimum at 1,000 places and then decreasing as the test capacity increased to 2,000. The optimal test capacity for Schemes 5 and 10 was 900 places. This result suggests that the optimal test capacity changes with the breeding schemes and thus, with the level of recording. Optimal test capacity is high with low levels of recording and when young bulls are selected based on their own performance alone. Inclusion of additional information from relatives of young bulls during first-stage selection process markedly decreased the optimal test capacity. Optimal test capacity was determined more by the number of traits used in the selection of young bulls than in the number used for the other selection groups.

The effect of varying the number of progeny per sire on genetic gain and on profit per cow in Schemes 1, 2, 5, and 10 is shown in Figures 4 and 5, respectively. As the number of progeny increased (Figure 4), genetic gain first increased sharply and then gradually in all schemes. The curve of profit per cow (Figure 5) was nearly flat immediately after the optimum was achieved. Consequently, increasing the number of progeny per sire had little effect on profits per cow. The optimal number of progeny per sire was 200 for Scheme 1 and 2 and 150 for Schemes 5 and 10. Under conditions in Japan, these numbers are not difficult to attain given the field system for progeny testing carcass traits of beef cattle currently in use. Over 40% of steers slaughtered at abattoirs are graded, and these carcass grade

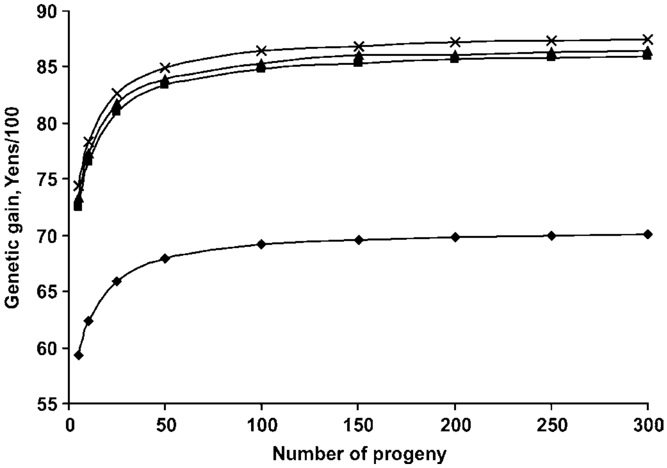

Figure 4. Effect of varying the number of progeny per sire on annual genetic gain in Breeding Schemes 1 (◆), 2 (■), 5 (▲), and 10 (×).

records can be used to evaluate beef bulls (Sasaki, 2001).

Effect of Ultrasound Scanning of Live Animals

Index accuracy, annual monetary genetic gain and costs, and returns and profit per cow in the population for the different breeding schemes are shown in Table 7. Table 8 shows the annual genetic gain for individual traits for the different breeding schemes. As expected, there was an increase in index accuracy, genetic gain and costs, and returns and profit per cow when carcass traits were assumed to be collected on live animals through ultrasound scanning (Table 7). A comparison of Tables 5 and 7 indicates that the increase ranged from 18 to 30% for index accuracy, 17 to 43% for genetic gain, 10 to 12% for costs, 17 to 42% for return, and 18 to 52% for profit per cow in the population. Similarly, there were marked increases in the annual genetic gains for carcass traits (Table 8).

Ultrasound scanning of live animals was more important than addition of any other traits in the selec-

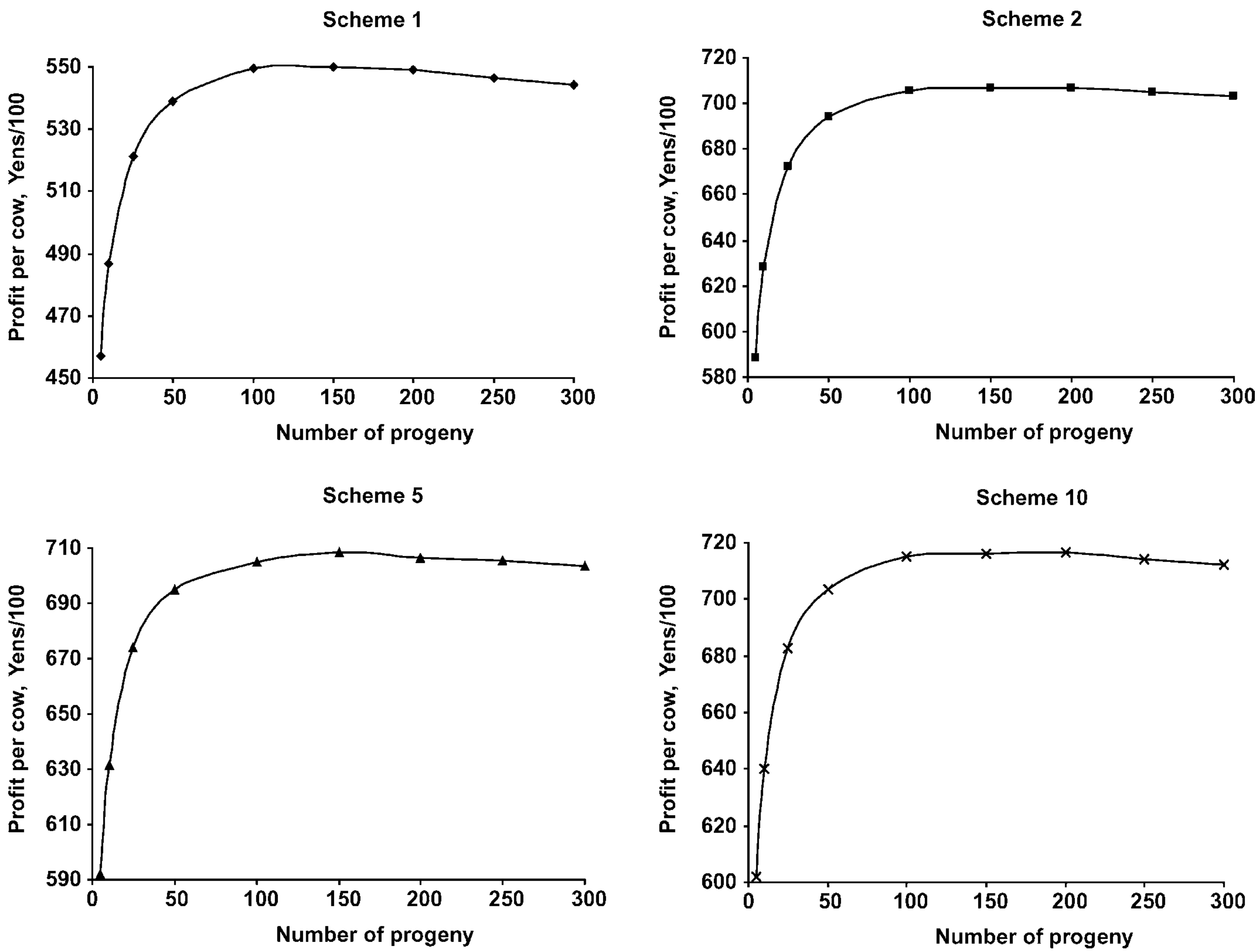

Figure 5. Effect of varying the number of progeny per sire on profit per cow under Breeding Schemes 1, 2, 5, and 10.

Table 7. Index accuracy, annual monetary genetic gain in the breeding objective, and costs, returns, and profit per cow in the population for the different breeding schemes when there is ultrasound scanning for carcass traits on live animals

Breeding scheme[a]	Index accuracy	Annual genetic gain, ¥/100	Costs per cow, ¥/100	Returns per cow in the population, ¥/100	Profit per cow in the population, ¥/100
1	0.82	93.97	162.90	954.54	791.64
2	0.83	94.60	162.90	960.81	797.91
3	0.82	94.10	162.91	955.79	792.88
4	0.83	94.91	168.04	964.11	796.07
5	0.84	95.64	168.04	971.50	803.46
6	0.84	95.69	168.04	971.98	803.94
7	0.85	96.43	169.56	979.74	810.18
8	0.84	95.69	168.04	972.00	803.96
9	0.82	94.00	164.42	954.89	790.47
10	0.85	96.43	169.56	979.77	810.21

[a]Scheme (Sch) 1 = base scenario with young bulls being selected based on their growth ability during performance testing and carcass (marbling score, LM area, rib thickness, and s.c. fat thickness) and growth (daily gain in feedlot) information from relatives; Sch 2 = Sch 1 criteria plus carcass traits from relatives of performance tested bulls; Sch 3 = Sch 1 criteria plus chest girth; Sch 4 = Sch 1 criteria plus weights; Sch 5 = a combination of Sch 2 and 4; Sch 6 = Sch 5 criteria plus chest girth; Sch 7 = Sch 6 criteria plus reproduction traits (age at first calving and calving interval); Sch 8 = Sch 6 criteria plus scrotal circumference; Sch 9 = Sch 1 criteria plus female reproduction traits and scrotal circumference; and Sch 10 = combination of Sch 7 and 8.

tion criteria. In the genetic evaluation of bulls in Japan, carcass measurements are taken from slaughtered progeny. This method is slow and expensive because results are available only when the progeny of a sire are slaughtered. Use of ultrasound scanning will allow for more accurate genetic evaluation because information on all relatives can be used, thereby increasing the accuracy of selection. In addition, it will be possible to select at an earlier age, allowing for a shorter generation interval, resulting in faster genetic gains, and thus benefiting the Japanese beef industry's most desirable trait for genetic improvement. Because carcass quality is very important economically and is the most desired characteristic to be improved in Japan, investment in ultrasound scanning techniques is worthwhile. Nonetheless, a large increase in cost to the breeding program should not be underestimated because this can be a significant barrier to the adoption of any beneficial technology in breeding (Kahi et al., 2003).

Table 8. Annual genetic gain for individual traits in the breeding objective for the different breeding schemes when there is ultrasound scanning for carcass traits on live animals

	Traits[a]							
Breeding scheme[b]	BWT, kg	WWT, kg	MWT, kg	DG, g/d	MS, score	LMA, mm^2	RT, mm	SFT, mm
1	0.09	0.04	0.71	3.26	0.32	5.94	0.65	0.14
2	0.09	0.07	0.83	3.40	0.32	6.01	0.66	0.15
3	0.09	0.04	0.68	3.23	0.32	5.94	0.65	0.14
4	0.12	0.06	1.09	3.41	0.32	5.98	0.65	0.14
5	0.11	0.07	1.11	3.52	0.32	6.07	0.66	0.15
6	0.11	0.07	1.09	3.50	0.32	6.07	0.66	0.14
7	0.12	0.09	1.19	3.57	0.32	6.09	0.66	0.14
8	0.11	0.07	1.09	3.50	0.32	6.07	0.66	0.14
9	0.08	0.05	0.71	3.26	0.32	5.94	0.65	0.14
10	0.12	0.09	1.20	3.57	0.32	6.09	0.66	0.14

[a]BWT = birth weight; WWT = weaning weight; MWT = mature weight; DG = daily gain during the feedlot period; MS = marbling score; LMA = LM area; RT = rib thickness; and SFT = subcutaneous fat thickness.

[b]Scheme (Sch) 1 = base scenario with young bulls being selected based on their growth ability during performance testing and carcass (marbling score, LM area, rib thickness, and s.c. fat thickness) and growth (daily gain in feedlot) information from relatives; Sch 2 = Sch 1 criteria plus carcass traits from relatives of performance tested bulls; Sch 3 = Sch 1 criteria plus chest girth; Sch 4 = Sch 1 criteria plus weights; Sch 5 = a combination of Sch 2 and 4; Sch 6 = Sch 5 criteria plus chest girth; Sch 7 = Sch 6 criteria plus reproduction traits (age at first calving and calving interval); Sch 8 = Sch 6 criteria plus scrotal circumference; Sch 9 = Sch 1 criteria plus female reproduction traits and scrotal circumference; and Sch 10 = combination of Sch 7 and 8.

Implications

This study shows that it would be beneficial for Japanese Black cattle breeders to include additional traits in the selection of young bulls during performance testing, as a screening test in a two-stage selection policy to identify animals to be progeny tested. To put some selection pressure on carcass traits, it would be profitable to include information on carcass traits from relatives of performance-tested young bulls. Inclusion of this information resulted in optimal profitability when 900 to 1,000 places were available for performance testing. Similarly, profit was optimal across all breeding schemes when sires were selected based on information from 150 to 200 progeny. Ultrasound scanning of live animals for carcass traits would be profitable under conditions in Japan; however, further work may be justified to establish actual costs associated with ultrasound scanning because accredited scanners must perform this task at the farm.

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