Comparison of Methods to Rank Bulls Across Countries

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ABSTRACT

Ayrshire (5149) and Jersey (10,525) bulls born in Canada and the US between 1950 and 1985 were ranked for genetic merit for milk and fat yields. Ranking methods included two joint evaluations (US and Canadian) using lactation records from both countries, a linear model combination of evaluations from each country's national evaluations, combined US national and converted Canadian evaluations, and combined Canadian national and converted US evaluations. Correlations of linear model combined evaluations for milk yield with joint evaluations were .96 for Ayrshires and .98 for Jerseys for US joint evaluations and .89 and .84 for Canadian joint evaluations. Correlations of combined national and converted evaluations with joint evaluations ranged from .88 to .94 for Ayrshires and from .83 to .98 for Jerseys. Variation and correlations between joint and linear model combined evaluations were consistent across birth year of bull. Sire-son correlations were similar for US joint and linear model combined evaluations but were lower for Canadian joint evaluations. Estimated genetic progress for bulls born from 1970 to 1985 was similar for Jerseys from US joint and linear model combined evaluations but for Ayrshires was over 25% higher from US joint evaluation than from linear model combined evaluation. For both breeds, progress estimated from Canadian joint evaluation was over 20% lower than from linear model combined evaluation. Results for milk and fat yields were similar. Joint evaluation provides the most accurate evaluations because it uses all relationships. However, because linear model combination evaluations are highly correlated with joint evaluations and usually are superior to national evaluations extended with converted foreign evaluations, they are recommended if joint evaluation is not feasible.

(**Key words**: joint evaluation, international sire comparison, linear model, conversion)

Abbreviation key: **BCA** = breed class average, **INTERBULL** = International Bull Evaluation Service, **LMC** = linear model combined.

INTRODUCTION

Comparing dairy bulls from different countries is necessary for breeders and dairy

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producers to select the best bulls from around the world. Making fair comparisons is difficult because countries may use different units for genetic evaluations or have different genetic levels for their base populations. Each national evaluation system establishes the genetic base for its own population and an evaluation unit that is a function of the unit of measure, the base for age standardization, and the base for genetic variance. In addition, traits may differ because of method of measurement or definition, or genotype × environment interaction may cause true genetic values to vary among countries.

The first approach for making fair comparisons of bulls across countries was to develop formulas that convert a bull's estimated transmitting ability in the exporting country to the base and unit equivalent in the importing country (3, 16). Such methods have been recommended by the International Bull Evaluation Service (**INTERBULL**) (4).

An alternative approach proposed by Schaeffer (11) and applied by Jacques and Klemetsdal (5), Rozzi et al. (10), and Banos et al. (2) combines bull information from different countries under a linear model that uses relationships among bulls across countries. Data from each country can be mean daughter yield deviations (12, 14) or, if these are unavailable, deregressed animal model bull evaluations (1). Genetic relationships between bull populations across country are necessary for successful implementation of this method. Such relationships can result from use of sires or their descendants in more than one country (2). This method assumes a genetic correlation of 1 between merit of bulls in each country.

The usefulness of converted or combined evaluations is reduced if there is genotype × environment interaction or heterosis. Conversion methods recommended by INTERBULL account for a genetic correlation of less than 1 between countries (6). In regression methods to compute conversion formulas, existence of a genotype × environment interaction would properly cause a reduction in the estimated regression coefficient. Linear model methodology can account for these problems if appropriate terms are fitted. However, a linear model assumes covariances of 0 among residuals within country, which results in increased prediction error variances and possible overestimation of evaluation accuracy within country (11). Because an animal model can include information from all relatives, it is preferred for each country's national evaluation.

Provided that adequate relationships exist among various cattle populations, that a genotype × country interaction does not exist, and that records for progeny of imported bulls are unbiased, the most accurate comparison would result from combining cow records from all countries and then computing an evaluation of all animals across countries (joint evaluation). The Jersey and Ayrshire populations in Canada and the US have many common ancestors (2), and Canadian and US Ayrshires and Jerseys were jointly evaluated in a study by Agriculture Canada and USDA (7, 9). However, such an approach would have extremely large computing requirements if it were extended to many countries or to breeds with large populations.

The objective of this study was to compare rankings of Canadian and US Ayrshire and Jersey bulls from combined evaluations computed using a linear model (**LMC**) with those from joint evaluations and those from national evaluations extended with converted evaluations.

MATERIALS AND METHODS

Data were Ayrshire and Jersey bull evaluations from July 1990 US (13) and August 1990 Canadian (8) animal model evaluations for milk and fat yields. Bulls were born between 1950 and 1985 and were required to have at least five effective daughters in each country; an effective daughter is the amount of information provided by a single daughter in a herd with an infinite number of management group mates. For Ayrshires, 3442 bulls had Canadian evaluations, and 1838 bulls had US evaluations; for Jerseys, there were 2401 Canadian and 8294 US bull evaluations. Of these evaluations, 131 Ayrshires and 170 Jerseys bulls had evaluations in both countries. Total number of bulls across countries was 5149 Ayrshires and 10,525 Jerseys. Data subsets based on birth year (bulls born in 1970 or later), daughters in 10 herds or more in the country of first evaluation, or country of evaluation also were investigated. All analyses were within breed.

For the LMC evaluation method, national evaluations first were deregressed and stan-

TABLE 1. Intercepts (a) and slopes (b) for computing US PTA and Canadian breed class average (BCA) from conversion equations[1] and combined evaluation under a linear model[2] (LMC) and number of bulls on which a and b were based by breed and trait.

Breed	Final evaluation	Method	Milk		Fat		Number of bulls
			a[3]	b[4]	a[3]	b[4]	
Ayrshire	PTA	Conversion	–34	33	–.2	1.44	30
		LMC	–1	34	.8	1.39	5149
	BCA	Conversion	–.70	.022	–.86	.589	12
		LMC	.04	.029	–.55	.719	5149
Jersey	PTA	Conversion	–357	33	–11.5	1.52	21
		LMC	–339	38	–10.8	1.56	10,525
	BCA	Conversion	9.59	.037	6.24	.772	30
		LMC	9.01	.026	6.93	.639	10,525

[1]Conversion to US PTA developed by USDA; conversion to Canadian BCA developed by Agriculture Canada.

[2]Banos et al. (1).

[3]Kilograms for PTA.

[4]Kilograms/BCA for PTA; BCA/kilogram for Canadian BCA.

dardized within each country of evaluation using the method of Banos et al. (1). These deregressed and standardized evaluations then were pooled and analyzed using a linear model (2). A heritability of .29 across countries, a compromise between the US heritability of .25 (14) and the Canadian heritability of .33, was assumed. Resulting evaluations were back-transformed and expressed to the base and units of both countries, which produced two sets of LMC evaluations: one in kilograms and one in Canadian breed class average (**BCA**) points. Intercepts from LMC were differences between country solutions, and slopes were ratios of factors used to standardize deregressed evaluations in each country (Table 1).

The LMC evaluations in kilograms or BCA points were compared with corresponding joint evaluations. These joint evaluations were computed using Canadian and US cow records and the US and Canadian national evaluation systems employed for the second 1990 evaluations (9), except that a heterogeneous variance adjustment (15) was included in the US system.

The LMC evaluations also were compared with national evaluations extended with converted evaluations. For each country, a set of evaluations was created that included national evaluations for bulls evaluated in the country and converted evaluations for bulls without a national evaluation. Conversion equations were developed by USDA and Agriculture Canada according to guidelines set by INTERBULL. Intercepts and regression coefficients for conversion equations are in Table 1 along with LMC intercepts and slopes. Because the genetic base in the Canadian evaluation system changes every year, intercepts pertain only to 1990 data.

Relationships among the evaluation methods are illustrated Figure 1.

RESULTS AND DISCUSSION

Slopes (Table 1) from LMC were similar to those from conversion formulas for both breeds and traits. Minor discrepancies in intercepts could be attributed to the small number of bulls used in derivation of conversion factors. Differences were greater for Ayrshires than for Jerseys. Differences for Holsteins, which have a large number of bulls on which to base conversion formulas, probably would be less. Such discrepancies may result in slight underestimation of converted evaluations compared with LMC evaluations. Correlations between LMC and converted evaluations for both Canadian and US bulls were .98 to .99 for both breeds and traits. Similar results were reported by Banos et al. (2).

Correlations between LMC and joint evaluations are in Table 2 by breed, trait, and evaluating country. For both traits and breeds, correlations were higher with US than with Canadian joint evaluations. Canadian and US joint evaluations were somewhat different, as indicated by correlations of .84 to .87 (not in table) between US and Canadian joint evaluations for all bulls. If only bulls evaluated in Canada were considered, correlations between Canadian and US joint evaluations were .91 to .94, which are similar to those reported by Robinson and Wiggans (9). Differences between the two evaluation systems (8, 12, 13, 14) include different heritabilities, different management group and genetic group definitions, different treatment of cows without first lactation records, different numbers of parities used, and different weights for lactation lengths, as well as presence of a herd-sire interaction effect and heterogeneous variance adjustment in the US but not the Canadian system (15). Inclusion of cows without first lactation records in Canadian evaluations and differences in definition of management groups resulted in discrepancies in number of records used in each evaluation. If only bulls with information from the same number of daughters were considered, correlations among LMC and joint evaluations were increased by 2 to 4%. Differences in genetic group definitions might have caused lower correlations of Canadian joint evaluations with US joint evaluations and with LMC evaluations for bulls born in the earlier years. These correlations increased further by 3 to 5% if only bulls born in 1970 or later were considered.

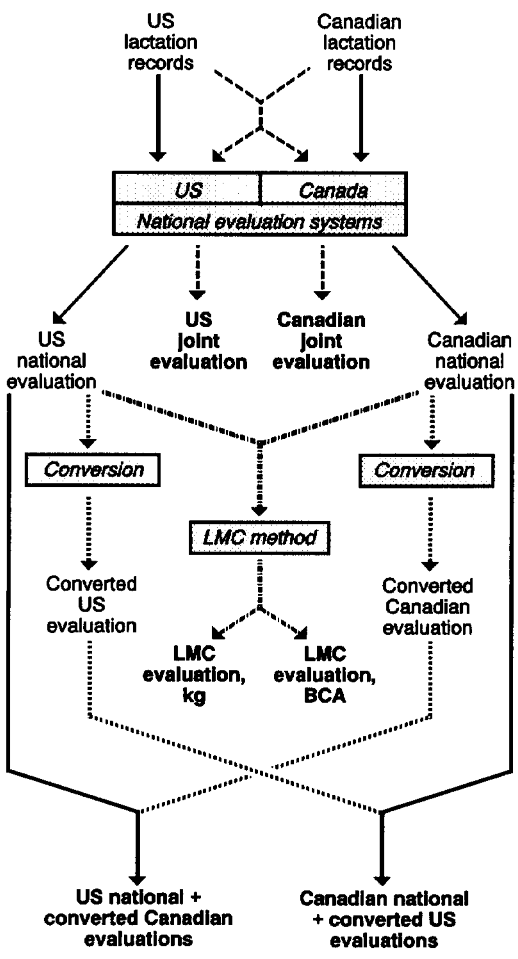

Figure 1. Relationships among data and methods for obtaining linear model combined (LMC) evaluations expressed in kilograms and breed class average (BCA) points, US and Canadian joint evaluations, US national plus converted Canadian evaluations, and Canadian national plus converted US evaluations.

Correlation of US national evaluations with US joint evaluations was higher than with Canadian joint evaluations (Table 3). Canadian national evaluations also were more highly correlated with US joint evaluations than with Canadian joint evaluations. Correlations of LMC with national evaluations were similar for both countries and were close to 1. Fewer daughter records were included in US joint evaluations than in Canadian national or LMC evaluations for 75 to 85% of Canadian bulls. Correspondingly, 67 to 75% of US bulls were evaluated with more daughter records for Canadian joint evaluations than for US national or LMC evaluations. The majority of those bulls were born before 1970. Despite differences in evaluation systems, correlations of LMC with joint evaluations were fairly high (>.80), especially for accurately proven bulls.

Correlations between the Canadian and US sets of national evaluations extended with converted evaluations were .98 to .99 for both breeds and traits for all bulls. Correlations of joint evaluations with the corresponding national plus converted evaluations were .93 to .94 for US Ayrshire and .97 to .98 for US Jersey evaluations and .88 to .89 for Canadian Ayrshire and .83 to .84 for Canadian Jersey evaluations for both traits. These correlations were similar to those of LMC with joint evaluations.

Variation of LMC, joint, and converted evaluations, as well as correlations between

TABLE 2. Correlations between linear model combined and joint evaluations by breed, data set, trait, and country of joint evaluation.

Breed	Data set	Number of bulls	Milk		Fat	
			US	Canada	US	Canada
Ayrshire	All bulls	5149	.96	.89	.95	.91
	Bulls born in 1970 or later	2040	.96	.93	.95	.94
	Bulls with daughters in ≥10 herds in country of first evaluation	1014	.98	.94	.98	.95
	Bulls first evaluated in Canada[1]	3442	.93	.91	.94	.93
	Bulls first evaluated in US[1]	1838	.99	.86	.99	.85
Jersey	All bulls	10,525	.98	.84	.98	.84
	Bulls born in 1970 or later	4709	.99	.89	.98	.88
	Bulls with daughters in ≥10 herds in country of first evaluation	2057	.99	.91	.99	.91
	Bulls first evaluated in Canada[1]	2401	.94	.88	.94	.89
	Bulls first evaluated in US[1]	8294	.99	.85	.99	.83

[1]Includes bulls evaluated in both countries.

evaluations, were consistent within birth year of bulls, which indicates that correlations in Table 2 did not result from genetic trend but signify true similarities between methods. Consistency for LMC evaluations was better for Jerseys than for Ayrshires, perhaps because of more complete male pedigree information available for Jerseys than for Ayrshires. For Ayrshires, 1192 bulls (23%) had missing sire information, and 2248 bulls (44%) had missing maternal grandsire information. For Jerseys, only 16 bulls (<1%) had missing sire information, and 1013 bulls (10%) had missing maternal grandsire information. Missing pedigree information would influence accuracy of deregression (1) as well as accuracy of bull rankings by LMC.

Sire-son correlations for LMC, joint, and national evaluations are in Table 4. These estimates can be used to assess relative accuracy of each model. For Ayrshires, many bulls had daughters in both Canada and the US, and number of daughters per bull increased substantially for joint evaluations. Because US bulls had 50% more daughters, sire-son correlation was higher for US joint evaluations than for either US or Canadian national evaluations. Although sire-son correlations for LMC evaluations were not quite as high as for US joint evaluations, the indirect LMC appeared to utilize new information efficiently and to increase accuracy of bull rankings despite missing bull pedigree information. For Jerseys, the increase in number of daughters for US bulls caused by including Canadian information was no more than 4%. Consequently, sire-son correlations were similar for LMC, US joint, and US national evaluations. However, new information for Canadian bulls from the US was reflected in increased sire-son correlations for LMC and US joint evaluations compared with Canadian national evaluations. Sire-son correlations also

TABLE 3. Correlations of national evaluations with linear model combined (LMC) and joint evaluations by breed, trait, and evaluating country.

Breed	Evaluation method	Milk		Fat	
		US	Canada	US	Canada
Ayrshire	LMC	.99	.99	.99	.99
	Joint				
	US	.99	.93	.98	.93
	Canada	.85	.91	.85	.93
Jersey	LMC	.99	.98	.99	.98
	Joint				
	US	.99	.93	.99	.93
	Canada	.84	.89	.83	.90

TABLE 4. Sire-son correlations of evaluations from linear model combined (LMC), joint, and national evaluations by breed and trait.

Breed	Evaluation method	Number of pairs	Milk	Fat
Ayrshire	LMC	788	.80	.80
	Joint			
	US	788	.82	.83
	Canada	788	.64	.65
	National			
	US	269	.78	.78
	Canada	494	.79	.79
Jersey	LMC	1624	.86	.84
	Joint			
	US	1624	.86	.85
	Canada	1624	.64	.63
	National			
	US	1119	.86	.84
	Canada	470	.75	.74

were similar for LMC and US joint evaluations if only pairs of US or Canadian proven bulls (269 US Ayrshire, 1119 US Jersey, 494 Canadian Ayrshire, and 470 Canadian Jersey pairs) were considered. Sire-son correlations for Canadian joint evaluations were lower in all cases and ranged from .63 to .65. This indicated a weakness in the Canadian evaluation system in incorporating US data, which was not resolved.

Difference in genetic merit of US and Canadian bulls was computed for bulls born in 1970 or later that had daughters in at least 10 herds in the country of first evaluation (Table 5). For Ayrshires, differences generally were small, regardless of evaluation method. A slightly larger difference for Canadian evaluations converted to US PTA indicated that these converted evaluations were underestimated compared with LMC and joint evaluations. Similarly, if PTA was converted to BCA, US bulls showed less superiority than with LMC or joint evaluation. For Jerseys, evaluations of US proven bulls were higher than those of Canadian proven bulls for both traits and all evaluation methods. Although superiority of US proven bulls was 45 kg higher for milk yield and 2 kg higher for fat yield by LMC than by US joint evaluation, standard errors indicated that these differences between methods were not significant ($P > .05$). Some early Canadian records were not included in US joint evaluation because of differences in management group definition and first lactation requirement; therefore, Canadian evaluations might have been somewhat biased. Mean differences between US national and Canadian evaluations converted to PTA were slightly, but not substantially, higher than differences for LMC and US joint evaluation. On a BCA basis, superiority of US proven bulls was 5.8 points greater for milk yield and 2.1 points greater for fat yield by LMC than by Canadian joint evaluation, which further indicates a problem with incorporating US data in the Canadian joint evaluation system. Differences between US evaluations converted to BCA and

TABLE 5. Mean differences between US and Canadian bull evaluations[1] and standard errors expressed as PTA and breed class average (BCA) for linear model combined (LMC), joint, and converted evaluations by breed and trait for bulls born in 1970 or later that had daughters in at least 10 herds in the country of first evaluation.

Breed	Evaluation method	Milk				Fat			
		PTA		BCA		PTA		BCA	
		(kg)				(kg)			
		$\overline{X}$	SE	$\overline{X}$	SE	$\overline{X}$	SE	$\overline{X}$	SE
Ayrshire	LMC	18	22	.5	.6	.2	.9	.1	.6
	Joint	−10	26	.3	.6	−1.0	1.0	.2	.6
	Conversion	54	22	.1	.6	1.4	.9	.1	.6
Jersey	LMC	326	26	8.7	.7	9.6	1.0	6.1	.7
	Joint	281	26	2.9	.7	7.5	1.1	.7	.5
	Conversion	354	25	9.2	.7	10.8	1.0	5.6	.7

[1]For LMC and joint evaluation methods, difference is mean evaluation for bulls first evaluated in the US minus mean evaluation for bulls first evaluated in Canada. For conversion of Canadian BCA to US PTA, difference is national minus converted evaluation; for conversion of US PTA to Canadian BCA, difference is converted minus national evaluation.

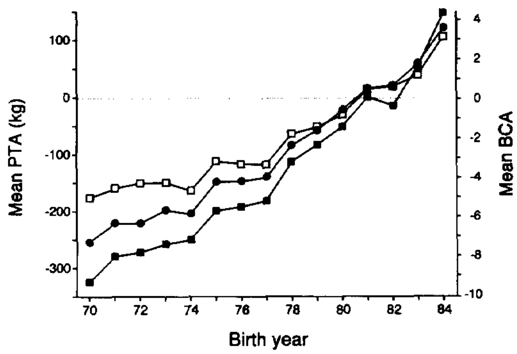

Figure 2. Mean Ayrshire bull evaluations for milk yield expressed as PTA and breed class average (BCA) by linear model combined (●), US joint (■), and Canadian joint (□) evaluation methods by bull birth year.

Canadian national evaluations were similar to those for LMC.

Genetic trend in evaluations for milk yield for US and Canadian bulls born in 1970 or later is shown for Ayrshires in Figure 2 and for Jerseys in Figure 3 for LMC and US and Canadian joint evaluation methods. Trends for fat were similar and are not shown. Although LMC evaluations were expressed as both US PTA and Canadian BCA points, different groups of cows were included in establishing the base: US cows born in 1985 for the US PTA base and Canadian cows with calvings in 1988 and 1989 for the Canadian BCA base. For joint evaluations, cows in both the US and Canada were included in the base group. Distances between the lines represent the difference in genetic merit of the base populations for national evaluations. Because the US and Canadian Ayrshire populations are quite similar genetically and because the 1990 Canadian national base was close to the US base, the trend lines nearly coincide (Figure 2). For Jerseys, the Canadian population has substantially lower genetic merit, thus the large base differences in Figure 3.

For both breeds, LMC evaluations were intermediate to US and Canadian joint evaluations. For Ayrshires (Figure 2), LMC evaluations for bulls born in 1970 or later averaged 39 kg higher for milk yield and 2.2 kg higher for fat yield compared with US joint evaluations and 1 BCA lower for both traits compared with Canadian joint evaluations. For Jerseys (Figure 3), LMC evaluations averaged 31 kg lower for milk yield and .4 kg lower for fat yield than did US joint evaluations and 6.4 BCA higher for milk yield and 4.4 BCA higher for fat yield than did Canadian joint evaluations. Because Jersey bulls were predominantly from the US, LMC evaluations were much closer to US than to Canadian joint evaluations. Differences between LMC and US joint evaluations were constant over time for Jerseys, which indicates similar genetic trends under the two methods for both traits. However, differences (LMC minus US joint evaluation) for Ayrshires decreased over time, which indicates lower trends estimated by LMC than by US joint evaluation. Trends for LMC evaluations always were higher than for Canadian joint evaluations for both breeds and traits. Trends for LMC evaluations were similar to trends for national evaluations in both countries (not shown), which was expected because national evaluations were used to derive LMC evaluations. Mean differences between LMC and national evaluations (not reported) were not significantly different from 0 ($P > .05$). For bulls evaluated in the US, differences between LMC and US joint evaluations were comparable with differences for all US and Canadian bulls for both breeds and traits. Similarly, differences between LMC and Canadian joint evaluations were similar for bulls evaluated in Canada and all bulls.

Estimated improvement in evaluations for bulls born in 1970 or later (Table 6) agrees

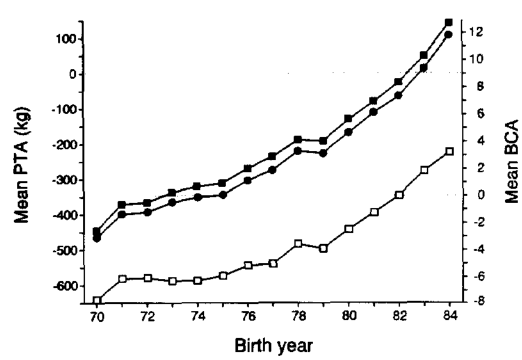

Figure 3. Mean Jersey bull evaluations for milk yield expressed as PTA and breed class average (BCA) by linear model combined (●), US joint (■), and Canadian joint (□) evaluation methods by bull birth year.

TABLE 6. Total improvement in genetic merit of bulls from birth year 1970 through 1985 expressed as PTA and breed class average (BCA) for linear model combined (LMC), joint, and national evaluations by breed and trait.

		Milk						Fat					
		PTA			BCA			PTA			BCA		
Breed	Evaluation method	All bulls	US bulls	Canadian bulls	All bulls	US bulls	Canadian bulls	All bulls	US bulls	Canadian bulls	All bulls	US bulls	Canadian bulls
		(kg)						(kg)					
Ayrshire	LMC	376	381	367	11.0	11.2	10.8	15	14	15	10.4	9.8	10.8
	Joint	472	462	475	8.3	9.7	7.6	19	17	20	8.0	8.5	8.0
	National	. . .	372	. . .	. . .	. . .	10.7	. . .	13	. . .	. . .	. . .	10.9
Jersey	LMC	574	540	552	15.2	14.3	14.7	22	21	22	14.2	13.3	14.2
	Joint	587	562	551	10.9	11.0	10.2	24	22	25	8.7	8.4	9.8
	National	. . .	536	. . .	. . .	. . .	14.8	. . .	21	. . .	. . .	. . .	13.9

with genetic trends shown in Figures 2 and 3. For Ayrshires, genetic improvement estimated across countries by US joint evaluation was 26 to 27% higher than that estimated by LMC for both traits; improvement estimated by Canadian joint evaluation was 23 to 25% lower than LMC estimates. Within-country genetic improvement estimated by national evaluations was similar to LMC improvement but lower than for US joint evaluation and higher than for Canadian joint evaluation. For Jerseys, estimates of genetic gains also were higher for US joint evaluations compared with LMC (2 to 9% across countries) and national evaluations but to a much lesser extent than for Ayrshires. Genetic progress estimated by Canadian joint evaluation for Jerseys was less than that estimated by LMC (28 to 39% across countries).

CONCLUSIONS

Indirect methods of ranking bulls across countries (conversion and LMC) were compared with joint evaluation methods that used all records and relationships from each country. Both indirect methods assumed that models used in each country's national evaluation system were similar. Differences between US and Canadian systems resulted in somewhat different evaluations from the same data. Therefore, combining national evaluations to produce exactly the same rankings as from a joint evaluation is not possible unless further effort is directed at harmonizing national evaluation systems so that they have more similar genetic parameters, included data, and defined effects.

Despite differences in evaluation systems, rankings under both indirect methods were highly correlated with rankings under joint evaluations, especially for bulls with high reliabilities. Correlations between LMC and joint evaluations were high for all birth years of 1970 or later. Some data characteristics (e.g., incomplete pedigree in LMC evaluations, inconsistencies in number of daughters in US and Canadian joint evaluations) may have prevented these correlations from being even higher. For computation of LMC, daughter yield deviations as described by VanRaden and Wiggans (12) could replace deregressed evaluations from each country. The deregression process could be a source of inaccuracies if substantial pedigree information is missing. Until daughter yield deviations become available from all participating countries, deregressed evaluations described by Banos et al. (1) can be used.

Based on comparison with joint evaluations, LMC evaluations generally were equally or more accurate than national evaluations extended with converted evaluations. For Ayrshires, some Canadian bulls appeared to be underestimated by converted evaluations. However, the number of bulls used to derive conversion factors was small. If a larger data base were used (e.g., Holstein bulls), regression coefficients would be more accurately estimated. The advantage of LMC may become more important if bulls from more than two countries are considered. The LMC can use relationships across all countries, thereby providing more information than available from pairwise comparison.

Routine implementation of joint evaluation on a large scale using all records of all animals from all countries is not currently feasible because of computing requirements but could become a reality if this barrier is overcome. Until then, LMC is a useful method for ranking dairy bulls on an international basis. Provided that each country utilizes appropriate models in its own evaluation system (i.e., animal models to account for nonrandom mating of imported sires) and that similar effects are considered in each country, LMC can combine effectively bull information from several sources and exploit genetic relationships among bulls, thereby producing accurate global sire rankings without the substantial computing requirements of joint evaluation.

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