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Research Article

COMPARATIVE EFFICIENCY OF SIRE EVALUATION PROCEDURES IN SAHIWAL CATTLE

SANDEEP DHAWAN, A.S. YADAV, S.S. DHAKA and VIKRAM JAKHAR*
Department of Animal Genetics and Breeding, College of Veterinary Sciences
Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar-125 004, India

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ABSTRACT

The present investigation was conducted on records of 815 Sahiwal cattle, progeny of 62 sires over a period of 36 years (1975-2010) maintained at Government Livestock Farm, Hisar. Four sire evaluation procedures such as Simple Daughter Average (SDA), Ordinary Least Squares (OLS), Regressed Least Squares (RLS) and Best Linear Unbiased Predictor (BLUP) based on estimated breeding value of performance traits such as first lactation milk yield (FLY), first lactation peak yield (FPY), first lactation milk yield per day of first lactation length (MLL), first lactation milk yield per day of first calving interval (MCI) and first lactation milk yield per day of age at second calving (MSC) were compared. The results indicated that sire number 63 had the highest merit computed by SDA, RLS and sire number 27 had the highest merit for MCI computed by either of the four methods. In addition, sire number 63 had the highest merit for MSC computed by all the methods except OLS where it stood fourth in ranking. Product-moment correlations were comparatively lower than those of rank correlations barring a few exceptions. When comparison was made on the basis of coefficient of skewness, OLS was found superior for estimation of breeding value for FLY, MLL and MSC whereas RLS for FPY and BLUP for MCI. When comparison was made on the basis of coefficient of kurtosis, SDA was better for FLY and FPY; OLS for MCI; and BLUP for MLL and MSC whereas RLS was found inferior. When standard error of the estimate was considered, RLS was found to be more accurate in case of FLY, MLL, MCI and MLL. It is recommended to use BLUP where correct ratios of residual variance to sire variances are known because it gives more reliable estimate of breeding value.

Key words: Breeding values, correlations, phase traits, Sahiwal, Satiability traits

Sahiwal cattle, is the cynosure of Indian dairy industry hence its retention, conservation, improvement and propagation is the need of the hour. The animal possesses unique characteristics of hardiness, adaptability, disease resistance, efficiency of conversion of available coarse fodder especially under harsh tropical and arid condition of the region. The aim of animal breeder is to select the genetically superior bull to bring out genetic improvement in the productive as well as reproductive performance of the herd. Therefore, suitable selection criterion which gives best discrimination among sires should be formulated to evaluate sires on the basis of performance of their daughters. To improve the efficiency and accuracy of sire evaluation programme, many sire indices have been developed such as Simple Daughter Average (SDA), Least-squares (LS), Regressed Least-Squares (RLS), Best Linear Unbiased Prediction (BLUP) and Derivative Free Restricted Maximum Likelihood Method (DFREML). The literature is dotted with conflicting reports (Dhaka *et al*., 2004; Banik and Gandhi, 2006; Kamaldeep *et al.*, 2015) on comparative evaluation of various sire evaluation techniques in dairy cattle. Therefore, an effort has been made to estimate breeding values for various performance traits by different procedures and comparison of these procedures to find out the most suitable for evaluation of Sahiwal sires.

*Corresponding author: vjakhar61@gmail.com

MATERIALS AND METHODS

The data on 815 Sahiwal cows, progeny of 62 sires over a period of 36 years from 1975 to 2010 was collected from history cum pedigree sheets maintained at Government Livestock Farm, Hisar, India. The performance traits considered were: first lactation milk yield (FLY); first lactation peak yield (FPY); first lactation milk yield per day of first lactation length (MLL=FLY/FLL); first lactation milk yield per day of first calving interval (MCI=FLY/FCI) and first lactation milk yield per day of age at second calving (MSC=FLY/AFC+FCI). Breeding value of sires for different performance traits (FLY, FPY, MLL, MCI and MSC) were computed separately by using different sire evaluation procedures: Simple Daughter Average (SDA), Ordinary Least Squares (OLS), Regressed Least Squares (RLS) and Best Linear Unbiased Predictor (BLUP). In order to overcome non-orthogonality of the data, least squares and maximum likelihood computer programme of Harvey (1990) using the method of Henderson (1973) was used to estimate the effect of various tangible factors on different performance traits under study. The following mathematical model was deduced to explain the underlying biology of the traits included in the study:

$$Y_{ijkl}=\mu+s_i+h_j+c_k+b_1(X_{ijkl}-X)+b_2(X_{ijkl}-X)^2+e_{ijkl}$$

Where Y_{ijkl}=l^{th}observation on the progeny of the i^{th}sire in j^{th} period and k^{th} season of calving; μ=overall population mean; s_i=random effect of i^{th} sire; h_j=fixed effect of j^{th} period of calving; c_k=fixed effect of k^{th} season of calving; b_1 & b_2=partial regression coefficient of age at first calving, linear and quadratic, respectively on the traits; X_{ijkl}=age at first calving comparing to Y_{ijkl} observations; X=mean for age at first calving; e_{ijkl}=random error associated with each and every observation assumed to be normally and independently distributed with mean zero and variance σ_e^2 NID (0, σ^2_e)

Comparative Evaluation of Different Methods: Spearman rank correlation among ranks and simple product moment correlation coefficient among estimates of sire merit (Steel and Torrie, 1981) were used to judge the relative efficiency of different methods. The criteria used to judge accuracy of different sire evaluation procedures were the coefficient of skewness, the coefficient of kurtosis and standard error of an estimate. The coefficient of skewness close to zero and coefficient of kurtosis close to 3 was considered as perfect estimate indicating that the population follows a normal distribution, whereas low standard error of the estimates was an indicator of the better accuracy of method.

RESULTS AND DISCUSSION

The breeding values of sires were computed using the SDA, OLS, RLS and BLUP procedures for different production efficiency traits. The above mentioned procedures were compared to assess accuracy utilizing standard error of the estimates, the coefficient of skewness and kurtosis. The estimated breeding values by SDA, OLS, RLS and BLUP were presented in Tables 1 and 2.

The results for FLY (Table 1) revealed that sire number 63 had the highest merit computed by SDA and RLS while the same sire ranked fifth by OLS and third by BLUP method. Five sires out of top ten shared their ranks being in top ten positions irrespective of methods employed for computation of breeding value of sires. The perusal of Table 2 revealed that sire number 59 was found to be of lowest in merit by RLS (-120.29), second lowest by BLUP (-140.32) and third lowest by OLS (-222.2) and was unable to found place in bottom ten sires when breeding value was calculated by SDA method. Four sires out of bottom ten share their ranks being in bottom ten when breeding value was calculated by either of four methods included in the study.

The results for FPY (Table 1) indicated that sire number 27 had the highest merit computed by SDA, OLS and RLS methods whereas, the same sire ranked second by BLUP procedure. Only two sires out of top ten shared their ranks by being in top ten when breeding value was calculated by either of four methods. Sire number 61 was found to be of the lowest merit when B.V. was estimated by RLS (-0.89) and BLUP (-0.64) method but third lowest by OLS (-1.5), however, the same sire was unable to find place in bottom ten sires when breeding value was calculated using SDA method. Two sires (sire nos. 20 and 29) out of lowest ten shared their ranks by being in bottom ten irrespective of methods of computation of breeding value of sires. The contents of Table 1 for MLL revealed that sire number 64 had the highest merit computed by SDA, RLS and BLUP methods and the same sire ranked second when B.V. was calculated by OLS method. Five sires out of top ten shared their ranks by being in top ten positions irrespective of methods used for calculation of breeding value. Sire number 55 was found lowest in merit by SDA (4.24), OLS (-0.95) and BLUP (-0.38) methods and ranked the second lowest by RLS (-0.35) method. Only two sires out of lowest ten shared their ranks by being in bottom ten when breeding value was estimated by any of the four methods included in the study.

The perusal of Table 1 revealed that sire number 27 had the highest merit for MCI computed by any of the four methods. Five sires out of top ten shared their ranks by being in top ten when breeding value was calculated by either of four methods. However, sire number 68 was the lowest in merit by OLS, third lowest by BLUP and fourth lowest by RLS but was unable to find place in bottom ten sires by SDA method. In addition, two sires out of bottom ten shared their ranks by being in bottom ten when breeding value was calculated by any of the four methods.

The critical review of Table 1 indicated that sire number 63 has the highest merit for MSC computed by all the methods except for OLS (0.21) where it stood fourth in ranking. Five sires out of top ten shared their ranks by being in top ten when breeding value was calculated by either of the four methods. The results of Table 2 further revealed that sire no 81 was the lowest in merit by RLS (-0.08), second lowest by OLS (-0.19) and BLUP (-0.11) but was unable to find slot in bottom ten sires by SDA method. Also only two sires out of lowest ten shared their ranks by being in bottom ten irrespective of methods of calculation of breeding value.

Rank and Product-Moment Correlations: The rank and product-moment correlations among merit of sires for production efficiency traits by various sire evaluation

Table 1
Ranking of top ten sires for various performance traits using different procedures

Rank	Methods	Performance Traits				
		FLY	FPY	MLL	MCI	MSC
1	SDA	1937.82 (63)	10.33 (27)	6.72 (64)	4.09 (27)	1.55 (63)
	OLS	325.01 (27)	2.33 (27)	0.84 (37)	0.7 (27)	0.24 (27)
	RLS	119.63 (63)	1.03 (27)	0.56 (64)	0.23 (27)	0.1 (63)
	BLUP	169.01 (32)	1.04 (63)	0.61 (64)	0.32 (27)	0.19 (63)
2	SDA	1957 (58)	10.27 (63)	6.58 (66)	3.94 (64)	1.49 (80)
	OLS	310.45 (32)	1.41 (71)	0.83 (64)	0.47 (71)	0.22 (80)
	RLS	114.62 (27)	0.86 (90)	0.4 (37)	0.19 (64)	0.09 (85)
	BLUP	159.52 (27)	0.79 (27)	0.36 (66)	0.23 (64)	0.13 (80)
3	SDA	1955 (27)	9.92 (66)	6.44 (27)	3.87 (63)	1.47 (27)
	OLS	263.22 (71)	1.37 (90)	0.73 (27)	0.43 (88)	0.22 (32)
	RLS	110.75 (71)	0.79 (63)	0.3 (27)	0.18 (71)	0.08 (27)
	BLUP	145.39 (63)	0.77 (32)	0.34 (37)	0.23 (71)	0.1 (85)
4	SDA	1889.38 (71)	9.48 (90)	6.33 (28)	3.83 (66)	1.46 (67)
	OLS	248.81 (80)	1.34 (63)	0.68 (86)	0.39 (73)	0.21 (63)
	RLS	106.33 (85)	0.72 (71)	0.29 (85)	0.17 (85)	0.07 (80)
	BLUP	139.97 (71)	0.61 (38)	0.33 (27)	0.2 (63)	0.09 (27)
5	SDA	1887.6 (67)	9.45 (71)	6.21 (63)	3.8 (71)	1.42 (71)
	OLS	239.39 (63)	1.16 (38)	0.63 (66)	0.38 (32)	0.17 (71)
	RLS	102.92 (92)	0.7 (93)	0.28 (86)	0.16 (93)	0.07 (71)
	BLUP	124.44 (52)	0.56 (53)	0.29 (52)	0.2 (32)	0.09 (30)
6	SDA	1839.8 (32)	19.4 (32)	6.15 (74)	3.79 (67)	1.41 (85)
	OLS	196.4 (85)	1.06 (73)	0.53 (41)	0.36 (37)	0.17 (85)
	RLS	96.94 (32)	0.68 (8)	0.28 (66)	0.15 (63)	0.07 (92)
	BLUP	17.25 (85)	0.51 (66)	0.27 (28)	0.18 (52)	0.08 (71)
7	SDA	1800.24 (36)	9.2 (58)	6.1 (85)	3.76 (58)	1.39 (74)
	OLS	189.32 (88)	1.04 (7)	0.51 (88)	0.33 (85)	0.15 (88)
	RLS	87.75 (80)	0.65 (89)	0.24 (63)	0.15 (92)	0.06 (32)
	BLUP	114.9 (92)	0.5 (92)	0.26 (85)	0.17 (85)	0.06 (32)
8	SDA	1790.2 (85)	9.14 (7)	6.05 (73)	3.75 (73)	1.34 (64)
	OLS	183.14 (26)	1 (89)	0.49 (85)	0.32 (64)	0.12 (92)
	RLS	86.65 (52)	0.62 (85)	0.19 (41)	0.14 (37)	0.06 (52)
	BLUP	101.53 (58)	0.48 (57)	0.25 (63)	0.15 (73)	0.06 (26)
9	SDA	1789.14 (66)	9.14 (89)	5.86 (90)	3.67 (62)	1.34 (73)
	OLS	171.87 (58)	0.99 (83)	0.47 (32)	0.32 (63)	0.12 (26)
	RLS	71.17 (26)	0.56 (38)	0.19 (74)	0.13 (73)	0.04 (88)
	BLUP	99.41 (26)	0.47 (52)	0.24 (41)	0.15 (6)	0.06 (64)
10	SDA	1766.56 (62)	9 (73)	5.85 (71)	3.64 (74)	1.33 (65)
	OLS	162.58 (92)	0.98 (85)	0.43 (63)	0.25 (92)	0.11 (58)
	RLS	59.11 (88)	0.51 (83)	0.18 (88)	0.12 (88)	0.04 (26)
	BLUP	91.72 (80)	0.44 (58)	0.24 (32)	0.14 (37)	0.06 (65)

Figures within parenthesis are sire numbers. SDA=Simple daughter average; OLS=Ordinary least squares; RLS=Regressed least squares; BLUP=Best linear unbiased predictor; FLY=first lactation milk yield; FPY=first lactation peak yield; MLL=first lactation milk yield per day of first lactation length; MCI=first lactation milk yield per day of first calving interval (MCI); MSC=first lactation milk yield per day of age at second calving

methods are presented in Tables 3 and 4, respectively. The rank correlations calculated through different methods were very high and it ranged from 0.488 to 0.990 for SDA X BLUP and OLS X RLS for MLL (Table 3). All the product moment correlations between estimated sire merit calculated by different methods were also very high and ranged from 0.485 (SDA X BLUP) to 0.988 (OLS X RLS) for MLL (Table 4). Similar findings regarding rank and product moment correlation for estimation of sire merits by different methods were also reported by various researchers (Gaur *et al.*, 2001; Dhaka *et al.*, 2004; Banik and Gandhi, 2006; Bajetha,

Table 2
Ranking of bottom ten sires for various performance traits using different procedures

Rank	Methods	Performance Traits				
		FLY	FPY	MLL	MCI	MSC
62	SDA	1237.8 (54)	6.38 (54)	4.24 (55)	2.59 (54)	0.92 (54)
	OLS	-329.64 (28)	-1.63 (40)	-0.95 (55)	-0.51 (68)	-0.22 (28)
	RLS	-120.29 (59)	-0.89 (61)	-0.38 (61)	-0.21 (11)	-0.08 (81)
	BLUP	-150.33 (81)	-0.64 (61)	-0.38 (55)	-0.26 (81)	-0.14 (61)
61	SDA	1295 (57)	6.83 (29)	4.92 (53)	2.7 (55)	0.93 (53)
	OLS	-232.73 (68)	-1.54 (20)	-0.68 (61)	-0.44 (55)	-0.19 (81)
	RLS	-102.93 (28)	-0.78 (40)	-0.35 (55)	-0.18 (61)	-0.08 (59)
	BLUP	-140.32 (59)	-0.61 (87)	-0.35 (61)	-0.23 (59)	-0.11 (81)
60	SDA	1297.83 (18)	6.97 (18)	4.7 (54)	2.74 (18)	0.93 (18)
	OLS	-222.2 (59)	-1.5 (61)	-1.5 (40)	-0.38 (1)	-0.16 (68)
	RLS	-97.6 (81)	-0.78 (45)	-0.78 (40)	-0.18 (59)	-0.06 (28)
	BLUP	-131.3 (28)	-0.51 (1)	-0.51 (72)	-0.23 (68)	-0.11 (94)
59	SDA	1342.6 (20)	7 (26)	4.7 (26)	2.78 (26)	1.01 (1)
	OLS	-220.6 (20)	-1.24 (67)	-0.61 (1)	-0.38 (61)	-0.15 (1)
	RLS	-89 (31)	-0.72 (29)	-0.28 (62)	-0.17 (68)	-0.05 (68)
	BLUP	-106.79 (18)	-0.46 (3)	-0.3 (40)	-0.21 (94)	-0.1 (18)
58	SDA	1364.86 (4)	7 (19)	4.72 (30)	2.8 (30)	1.02 (57)
	OLS	-217.02 (81)	-1.18 (29)	-0.6 (67)	-0.36 (59)	-0.15 (20)
	RLS	-82.08 (68)	-0.66 (10)	-0.28 (31)	-0.14 (81)	-0.05 (1)
	BLUP	-96.34 (68)	-0.44 (40)	-0.3 (62)	-0.2 (61)	-0.09 (59)
57	SDA	1384.33 (1)	7.14 (20)	4.74 (29)	2.81 (53)	1.03 (50)
	OLS	-197.75 (1)	-1.16 (28)	-0.55 (62)	-0.33 (81)	-0.15 (59)
	RLS	-77.63 (10)	-0.66 (3)	-0.26 (11)	-0.14 (50)	-0.05 (61)
	BLUP	-84.48 (1)	-0.43 (4)	-0.28 (94)	-0.17 (55)	-0.08 (28)
56	SDA	1386.8 (3)	7.22 (55)	4.76 (40)	2.81 (50)	1.04 (29)
	OLS	-155.03 (61)	-1.09 (45)	-0.46 (50)	-0.32 (50)	-0.11 (41)
	RLS	-77.47 (61)	-0.65 (4)	-0.25 (1)	-0.14 (8)	-0.04 (20)
	BLUP	-76.22 (2)	-0.42 (62)	-0.23 (67)	-0.17 (2)	-0.06 (68)
55	SDA	1395.22 (81)	7.28 (30)	4.77 (50)	2.89 (57)	1.04 (4)
	OLS	-145.05 (18)	-1.05 (54)	-0.45 (72)	-0.27 (40)	-0.11 (78)
	RLS	-75.63 (18)	-0.61 (20)	-0.24 (50)	-0.13 (55)	-0.04 (78)
	BLUP	-75.69 (20)	-0.41 (20)	-0.23 (23)	-0.16 (72)	-0.05 (78)
54	SDA	1427 (53)	7.29 (4)	4.78 (23)	2.94 (19)	1.06 (61)
	OLS	-143.59 (41)	-1.05 (26)	-0.39 (31)	-0.26 (11)	-0.1 (54)
	RLS	-69.74 (1)	-0.55 (62)	-0.22 (67)	-0.13 (94)	-0.04 (18)
	BLUP	-75.47 (61)	-0.34 (45)	-0.22 (81)	-0.15 (18)	-0.05 (89)
53	SDA	1429.13 (37)	7.33 (1)	4.92 (20)	2.95 (40)	1.06 (20)
	OLS	-139.08 (54)	-1.02 (62)	-0.34 (20)	-0.2 (94)	-0.1 (61)
	RLS	-68.88 (20)	-0.55 (31)	-0.21 (94)	-0.12 (1)	-0.04 (10)
	BLUP	-72.84 (54)	-0.33 (29)	-0.19 (59)	-0.14 (50)	-0.04 (1)

Figures within parenthesis are sire numbers. SDA=Simple daughter average; OLS=Ordinary least squares; RLS=Regressed least squares; BLUP=Best linear unbiased predictor; FLY=first lactation milk yield; FPY=first lactation peak yield; MLL=first lactation milk yield per day of first lactation length; MCI=first lactation milk yield per day of first calving interval (MCI); MSC=first lactation milk yield per day of age at second calving

Table 3
Spearman Rank correlations among estimated sire merits for different performance traits calculated by various sire evaluation methods

Variable	SDA X OLS	SDA X RLS	SDA X BLUP	OLS X RLS	OLS X BLUP	RLS X BLUP
FLY	0.655	0.599	0.670	0.943	0.918	0.877
FPY	0.778	0.800	0.712	0.936	0.685	0.726
MLL	0.551	0.548	0.488	0.990	0.870	0.861
MCI	0.527	0.500	0.523	0.966	0.862	0.868
MSC	0.572	0.536	0.514	0.978	0.818	0.835

SDA=Simple daughter average; OLS=Ordinary least squares; RLS=Regressed least squares; BLUP=Best linear unbiased predictor; FLY=first lactation milk yield; FPY=first lactation peak yield; MLL=first lactation milk yield per day of first lactation length; MCI=first lactation milk yield per day of first calving interval; MSC=first lactation milk yield per day of age at second calving

Table 4
Product-moment correlation among estimated sire merits for different performance traits calculated by various sire evaluation methods

Variable	SDA X OLS	SDA X RLS	SDA X BLUP	OLS X RLS	OLS X BLUP	RLS X BLUP
FLY	0.654	0.636	0.671	0.980	0.942	0.941
FPY	0.835	0.801	0.710	0.964	0.740	0.723
MLL	0.547	0.543	0.485	0.988	0.861	0.852
MCI	0.533	0.493	0.520	0.979	0.862	0.846
MSC	0.509	0.504	0.494	0.976	0.791	0.813

SDA=Simple daughter average; OLS=Ordinary least squares; RLS=Regressed least squares; BLUP=Best linear unbiased predictor; FLY=first lactation milk yield; FPY=first lactation peak yield; MLL=first lactation milk yield per day of first lactation length; MCI=first lactation milk yield per day of first calving interval; MSC=first lactation milk yield per day of age at second calving

2006; Kumar *et al.*, 2008; Kamaldeep *et al.*, 2015). Rank and product moment correlations among sire merit calculated by various sire evaluation procedures for different performance traits revealed that product moment correlations were comparatively higher than those of rank correlations barring few exceptions.

Comparison of Different Sire Evaluation Methods: The accuracy of four methods used in the study for the estimated breeding value of sires was judged through the coefficient of skewness, coefficient of kurtosis and standard error of an estimate.

The contents of Table 5 revealed that on the basis of the standard error of the estimates, RLS method was found to be most efficient accurate in case of FLY (58.47), MLL (0.19), MCI (0.10) and MSC (0.04) whereas BLUP was adjudged as superior for FPY (0.37). When comparison was made on the basis of coefficient of skewness, OLS was found superior for estimation of breeding value for the traits like FLY (0.254), MLL (0.135) and MSC (0.376), whereas, RLS for FPY (0.065) and BLUP for MCI (0.123). When comparison was made on the basis of coefficient of kurtosis, SDA was better for FLY (-0.003) and FPY (0.066); OLS for MCI (0.216); and BLUP for MLL (0.336) and MSC (1.355) whereas RLS was found inferior when comparison was made on the basis of coefficient of kurtosis. Harvey (1990) also pointed that BLUP was more accurate (1-7%) than RLS when the usual assumptions were met and even when moderate amount of heterogeneous error variance exit. Choice among methods also to a greater extent depends upon computational difficulty and relative accuracy. RLS computations are more tedious than BLUP because of the size of the matrix that must be inverted to get to the inverse elements needed for computation of RLS estimates. Contrarily, OLS and BLUP are easy to compute since the least-squares and mixed model equations are well suited to the iterative solution and consequently inversions not required. Moreover, RLS is not a suitable method for evaluation sires as compared to mixed model equation method (Henderson, 1978). On a theoretical basis, the BLUP is the best and has minimum prediction error variance provided that true variance of random effects is known. Therefore, it is suggested use BLUP procedure in a situation where correct ratio of residual variance to sire variances known. Trade-offs between what is computationally ideal and what is practically feasible, are a fact of life in animal breeding and hence, use of OLS is suggested in situation where correct ratio of residual variance to sire variance is not known.

Table 5
The standard error, coefficient of skewness and kurtosis for different performance traits calculated by various sire evaluation methods

Variable	Coefficient of skewness				Coefficient of kurtosis				Standard error			
	SDA	OLS	RLS	BLUP	SDA	OLS	RLS	BLUP	SDA	OLS	RLS	BLUP
FLY	0.371	0.254	0.282	0.331	0.003	0.029	0.441	0.397	165.24	139.20	58.47	75.64
FPY	0.328	0.122	0.065	0.670	0.066	0.887	1.180	0.034	0.83	0.91	0.50	0.37
MLL	0.409	0.135	0.386	0.429	0.288	0.260	0.139	0.336	0.50	0.39	0.19	0.19
MCI	0.503	0.387	0.214	0.123	0.346	0.216	0.277	0.341	0.34	0.24	0.10	0.13
MSC	0.554	0.376	0.526	0.422	0.314	0.122	0.057	1.355	0.14	0.10	0.04	0.06

SDA=Simple daughter average; OLS=Ordinary least squares; RLS=Regressed least squares; BLUP=Best linear unbiased predictor; FLY=first lactation milk yield; FPY=first lactation peak yield; MLL=first lactation milk yield per day of first lactation length; MCI=first lactation milk yield per day of first calving interval; MSC=first lactation milk yield per day of age at second calving

REFERENCES

Bajetha, G. (2006). Selection of sires by using different sires evaluation methods in crossbred cattle. Ph.D. thesis, G.B. Pant University of Agriculture & Technology, Pantnagar, US. Nagar, Uttarakhand.

Banik, S. and Gandhi, R.S. (2006). Animal model versus conventional methods of sire evaluation in Sahiwal cattle. *Asian Australasian J. Anim. Sci.* **19**: 1225-1228.

Dhaka, S.S., Chaudhary, S.R., Raheja, K.L, Yadav, A.S. and Pander, B.L. (2004). Accuracy of different methods of sire evaluation for production efficiency traits in Sahiwal cattle. *Indian J. Anim. Sci*. **74**: 296-298.

Gaur, G.K., Tripathi, V.N., Mukherjee, S. and Choudhary, V.K. (2001). Efficiency of sire evaluation procedures in Frieswal cattle. *Indian J. Vet. Res*. **10**: 1-6.

Harvey, W.R. (1990). User's Guide for LSMLMW, Mixed Model Least-squares and Maximum Likelihood Computer Program. Ohio State Univ., Columbus, Mimeo.

Henderson, C.R. (1973). Sire evaluation and genetic trends. Proceedings of Animal Breeding and Genetics Symposium in honour of Dr. J.L. Lush. American Soc. Anim. Sci. Assoc. Champaign, Illinois.

Henderson, C.R. (1978). Undesirable Properties of regressed least square prediction of breeding values. *J. Dairy Sci*. **61**: 114-120.

Kamaldeep, Yadav, A.S., Dhaka, S.S., Magotra, A. and Malik, A. (2015). Efficiency of sire evaluation methods by using phase and stayability traits to improve milk yield of Murrah buffaloes. *Indian J. Anim. Res.* Print ISSN: 0367-6722/ online ISSN: 0976-0555. DOI: 10.18805/ijar.5707.

Kumar, A., Gandhi, R.S., Singh, A. and Haile, A. (2008). Comparison of animal model with other conventional methods of sire evaluation for milk production in Karan Fries cattle. *Indian J. Anim. Sci.* **78**: 1393-1396.