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Genetic and environmental factors influencing milk, protein and fat yields of pasture-based dairy cows in Tasmania

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Abstract. The objective of this study was to provide an update on milk production performance, heritability, genetic and phenotypic correlations among production traits that are valuable for management, breeding and selection decisions in pasture-based dairy systems. The study utilised a total of 106 990 lactation records of Holstein–Friesian (FF), Jersey (JJ) and their crossbreds (HF) from 428 Tasmanian dairy herds collected between 2000 and 2005. The data were analysed using the least-squares approach with a general linear model and restricted maximum likelihood approach with a linear animal model. Results indicated highly significant ($P < 0.01$) effects of breed, herd size, cow's parity, season and year of calving on milk, protein and fat yields. Average milk and protein yields per cow per lactation were highest in the FF breed (5212 L and 171 kg, respectively) and lowest in the JJ breed (3713 L and 143 kg, respectively). FF cows also produced 13.5 kg more milk fat than JJ and HF cows. Furthermore, milk, fat and protein yields were highest for cows calving during spring and lowest for autumn-calving cows. It was also evident that cows in very large herds (>1110 cows/herd) out-produced those in smaller herds. Heritability was highest for milk yield and lowest for somatic cell count ranging from 0.28 to 0.41. Genetic and phenotypic correlations between milk, fat and protein yields ranged from 0.41 to 0.85, and 0.66 to 0.92, respectively. However, genetic and phenotypic correlations between the log of somatic cell count and the production traits ranged from 0.03 to 0.09 and –0.03 to –0.05. We conclude that breed, herd size, parity, season and year of calving were among the main factors correlated with the productivity of dairy cows in Tasmania and adjustments for these factors would be mandatory for any unbiased comparison of lactation performance within and between pasture-based dairy production systems. The practical application of this information would be valuable to dairy farmers for decisions related to breeding, selection and management of their herds.

Additional keywords: Holstein–Friesian, pasture-based cows.

Introduction

The dairy industry in Australia is very important to the agricultural sector of the economy. With an ex-factory value of A$9.1 billion and farm gate value of A$3.2 billion, it is the third biggest rural industry behind beef and wheat (Dairy Australia 2006). Milk production is concentrated in the south-eastern corner of Australia, with the states of Victoria, Tasmania and South Australia accounting for 78% of the national output. Like in Victoria, dairying in Tasmania is characterised by seasonal, low-input, pasture-based milk production reliant on family labour. However, 90% of dairy farms use supplementary feeds such as hay, silage and concentrate to augment seasonal shortages in grass production (Dairy Australia 2006). Deregulation of the production sector in 2000 as well as widespread drought in 2002–03 led to substantial restructuring such as reduction in farm numbers, high cost of grain supplements and increased herd sizes (ABARE 2003). Although the Holstein–Friesian (FF) constitutes ~70% of the dairy breeds in Tasmania, there are growing numbers of other breeds including the Jersey (JJ), Friesian and Jersey crossbreds (FJ), Guernsey (GG), Illawarra (II) and Australian Reds (RR). Climatic factors also differ between dairy locations. Although milk production from Tasmania constitutes a small proportion (7%) of the national output, nearly 90% of the milk produced in Tasmania is processed for export (Dairy Australia 2006), compared with 30–40% in New South Wales, Queensland and Western Australia (Dobson 2006). Industry statistics also indicates that the Tasmanian dairy industry is growing at rates comparable to those of major dairy-producing states of Australia. Tasmania's typical climate offers an opportunity for year-round milk production, where precipitation is not limiting. Consequently, dairy production in Tasmania will continue to play a significant role in both domestic and overseas export of milk products.

Milk is synthesised by secretory cells in the mammary glands of lactating animals primarily as nutrition for the young. Factors affecting milk production in dairy animals include genetic (Tekerli *et al*. 2000), environmental and management factors (Msanga *et al*. 2000). Several studies (Madgwick and Goddard

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1989; Dobos *et al*. 2001; Wales *et al*. 2006) have identified factors affecting milk production of dairy cows in Victoria and other parts of Australia. Tasmanian dairy farmers are one of the most efficient in pasture-based dairying (Donaghy 2007). However, except for some performance indicators of the industry compiled by the Department of Primary Industry and Water (DPIW 2005; see Appendix 1) and Dairy Australia (2005), there is paucity of recent information on the key driving factors influencing dairy cattle performance in Tasmania. Therefore, the objectives of this study were: (i) to characterise and quantify the milk production of pasture-based dairy cows in Tasmania as influenced by breed, parity, location, herd size, season, parity, year and their interactions; (ii) to identify the critical management factors underpinning milk and milk component yields; and (iii) to estimate the heritability of production traits and somatic cell count (SCC).

Materials and methods

Site and climatic conditions

Tasmania is Australia's southern-most state with a land mass of 68 000 km^2, located at latitude 42° South, longitude 147° East and lies completely within the temperate zone. The summer, autumn, winter and spring seasons are in the months of December–February, March–May, June–August and September–November, respectively. Average maximum temperatures are 21°C (70°F) and 12°C (54°F) in summer and winter respectively. Summer is warm with sunny days and mild evenings, while autumn is cool with frosty nights and occasional storms. Winter is mild with occasional snows on the higher mountain peaks. The annual rainfall varies from 626 mm (25 inches) in the south to 2400 mm (94 inches) on the North-West Coast. The prevailing weather pattern creates a rain shadow in the West–East direction leaving the East coast always warmer and drier than the rest of the state.

Data source and editing

The data used in this study were obtained from TasHerd, which is the contracted herd recording agency for the Australian Dairy Herd Improvement Scheme (ADHIS) in Tasmania. The data were from 428 dairy herds and consisted of 130 366 observations on total milk, fat, protein and SCC yield records of purebred FF, JJ, GG, II and RR as well as crosses of FF and JJ cows of different ages, season of calving, parity, and lactation length (LL).

Two datasets were created. DATA1, which explored non-genetic factors affecting production traits used records from three breeds namely; FF, JJ and FJ, these being the predominant breeds in Tasmania. Small data size and incomplete records on the other breeds in regional data made genetic computation difficult, hence only records comprising of the FF breed were utilised for genetic analysis in DATA2. For each cow, records of cow number, birth date, calving date, 305-day milk yield, protein and fat yields, milk solids yield, LL, and herd number were available. This information was used to determine cow age, calving season, parity, and herd sizes. Daily milk, fat and protein yields were obtained by dividing the total milk and milk component yields by the LL. Percentage milk fat and milk protein were obtained by dividing total fat and total protein yields by total milk yield. Lactations with incomplete records i.e. missing birth date, calving date, milk or milk component yields were deleted. Records of cows with LL <100 days were also excluded from the analyses. DATA1 finally consisted of 106 990 records from 428 herds, over 6 production years. Parities greater than four were pooled as parity5. To protect farm identities, coded herd numbers and postcodes of dairy farms were used. The final dataset consisting of 30 postcodes was divided into six subsets, herein referred to as locations, based on existing local council areas. For instance, herds with postcodes 7260–7265 were grouped into the North-East location (Table 1). Herds were classified to correspond with the state's average herd size of 250 cows. Herd groups were below, similar to, twice and four times the state's average herd size. The four herd size classes were; 1–210, 211–575, 576–1100 and larger than 1100 cows per herd designated as small, medium, large and very large herds, respectively. For DATA2, additional data omitted from the analysis were all breeds except FF, cows with parity >5 and 305-day milk yield <1200 L leaving a total of 65 914 records. Parity >2 were pooled and labelled as parity3. Dairy farm statistics of Tasmania are presented in Appendix 1. Least-squares means and summary statistics of the traits for DATA1 and DATA2 are presented in Tables 1 and 2, respectively.

Statistical analyses

DATA1

General linear models (GLM) procedure in SAS (SAS 2002) was utilised to compute least-squares means, standard errors (s.e.) and coefficient of variation of the traits. Location, herd size, breed, calving year, calving season and parity were fitted as fixed effects while age and LL were included as covariates. All possible interactions between the fixed effects were included in the original model, but non-significant interactions were dropped from the final model. The model used to describe each lactation record was:

$$Y_{ijklmnopq} = \mu + L_i + H_j + S_k + Y_l + B_m + P_n + (BS)_{km} + (BY)_{lm} + (SP)_{kn} + (BP)_{mn} + (PSY)_{nkl} + b_1(LL_{ijklmno} - \overline{LL}) + b_2(A_{ijklmnop} - \bar{A}) + e_{ijlkmnopq} \quad (1)$$

where $Y_{ijklmopq}$ is the $_{ijklmnopq}$th observation of the dependent variables (milk, fat and protein yields and log of SCC), with fixed effects L_i of ith location (i = 1, 2, ... 6); H_j of jth herd size (j = 1, 2, ... 4); S_k of kth season of calving (k = 1, 2, ... 4); Y_l of lth year of calving (l = 1, 2, ... 6); B_m of mth breed (m = 1, 2, ... 3) and P_n of nth parity (n = 1, 2, ... 5). First-order interaction effects were $(BS)_{km}$ of breed and season, $(BY)_{lm}$ of breed and year, $(SP)_{kn}$ of season and parity and $(BP)_{nm}$ of breed and parity and second-order interaction effects of season, year and parity $(PSY)_{nkl}$. There was a total of 7, 11, 13, 9, and 81 combinations of *BS*, *BY*, *SP*, *BP* and *PSY* subclasses, respectively. The model terms $b_1(LL_{ijklmno} - \overline{LL})$, and $b_2(A_{ijklmnop} - \bar{A})$ represent the fitting of LL and age of the cow (A) as covariates with b_1 and b_2 as their partial regression coefficients, respectively; μ is overall mean and $e_{ijlkmnopq}$ is the random sampling error with mean zero and variance σ^2_e.

Table 1. Least-squares means ± s.e. of total milk, fat, protein yields per lactation and somatic cell count (SCC) of dairy cows by breed, parity, calving year, location, herd size and calving season

See Materials and methods for definition of location and SCC. Means with different lowercase letters within the same column are statistically different ($P < 0.01$)

Category	Milk (L)	Fat (kg)	Protein (kg)	Milk solids (kg)	Log SCC (×10[3])	Milk (L/day)	Milk solids (kg/day)	*n*
				Breed				
Friesian	5212 ± 34.2a	210 ± 1.3a	171 ± 1.1a	380 ± 2.4a	133 ± 6.4a	18.2 ± 0.11a	1.33 ± 0.008a	82 920
Crossbred	4253 ± 53.7b	196 ± 2.1b	150 ± 1.7b	346 ± 3.7b	135 ± 10.0a	14.9 ± 0.18b	1.21 ± 0.012b	10 001
Jersey	3713 ± 60.0c	197 ± 2.4b	143 ± 1.9c	340 ± 4.2b	127 ± 11.3b	13.1 ± 0.20c	1.19 ± 0.014b	14 059
				Parity				
1	3482 ± 53.8e	158 ± 2.1e	119 ± 1.8e	277 ± 3.7e	157 ± 10.0a	12.3 ± 0.18e	0.98 ± 0.129e	26 893
2	4020 ± 45.2d	184 ± 1.8d	141 ± 1.5d	326 ± 3.1d	132 ± 8.5b	14.2 ± 0.15d	1.15 ± 0.011d	22 372
3	4615 ± 48.6c	212 ± 1.9c	164 ± 1.6c	376 ± 3.4c	129 ± 9.1c	16.2 ± 0.17c	1.31 ± 0.012c	18 154
4	4826 ± 51.6b	222 ± 2.0b	172 ± 1.7b	393 ± 3.6b	127 ± 9.7c	16.9 ± 0.18b	1.37 ± 0.012b	15 081
>4	5019 ± 51.9a	228 ± 2.0a	179 ± 1.7a	407 ± 3.6a	112 ± 9.8d	17.5 ± 0.18a	1.42 ± 0.012a	24 490
				Calving year				
2000	4058 ± 71.9e	184 ± 2.8e	140 ± 2.4e	325 ± 5.0e	121 ± 13.5c	14.3 ± 0.25d	1.41 ± 0.017a	6064
2001	4299 ± 54.5d	196 ± 2.1d	150 ± 1.8d	346 ± 3.8d	115 ± 10.2d	15.1 ± 0.19c	1.21 ± 0.013d	9447
2002	4406 ± 49.3c	200 ± 1.9c	153 ± 1.6c	353 ± 3.4c	125 ± 9.2c	15.4 ± 0.17c	1.23 ± 0.012d	13 334
2003	4305 ± 44.9d	198 ± 1.8d	153 ± 1.5c	352 ± 3.1c	137 ± 8.4b	15.1 ± 0.15c	1.23 ± 0.011d	18 332
2004	4577 ± 43.4b	209 ± 1.7b	164 ± 1.4b	373 ± 3.0b	135 ± 8.1b	16.0 ± 0.15b	1.31 ± 0.010c	25 250
2005	4710 ± 41.2a	216 ± 1.6a	169 ± 1.4a	385 ± 2.9a	156 ± 7.7a	16.5 ± 0.14a	1.34 ± 0.009b	34 563
				Location				
Far north-west	4879 ± 25.8a	220 ± 1.0a	172 ± 0.8a	391 ± 1.8a	119 ± 4.8c	16.9 ± 0.09a	1.36 ± 0.006a	52771
North-west	4498 ± 27.2c	206 ± 1.1c	159 ± 0.9c	365 ± 1.9c	129 ± 5.1b	15.8 ± 0.09b	1.28 ± 0.006b	25574
Central north	4814 ± 31.8b	220 ± 1.3a	170 ± 1.0b	392 ± 2.2a	124 ± 60.0b	16.7 ± 0.11a	1.36 ± 0.008c	4931
South	4047 ± 60.5d	183 ± 2.4d	143 ± 2.0d	326 ± 4.2d	119 ± 11.4c	14.3 ± 0.21c	1.15 ± 0.014d	659
North-east	4786 ± 26.8b	213 ± 1.1b	168 ± 0.9b	382 ± 1.9b	119 ± 4.8c	16.7 ± 0.09a	1.33 ± 0.006a	26 997
King Island	3331 ± 178.2e	160 ± 7.0e	118 ± 5.9e	277 ± 12.4e	178 ± 33.4a	11.9 ± 0.61d	0.99 ± 0.042e	1058
				Herd size				
Small	4485 ± 52.4b	196 ± 2.0c	155 ± 1.7b	350 ± 3.6b	142 ± 9.8a	15.9 ± 0.18b	1.23 ± 0.013b	1487
Medium	4141 ± 41.6d	195 ± 1.6c	148 ± 1.4d	343 ± 2.9c	130 ± 7.8a	14.5 ± 0.14d	1.20 ± 0.010c	5766
Large	4271 ± 39.3c	200 ± 1.5b	151 ± 1.3c	350 ± 2.7b	122 ± 7.4b	15.0 ± 0.13c	1.23 ± 0.009b	28 228
Very large	4672 ± 39.2a	212 ± 1.5a	166 ± 1.3a	378 ± 2.7a	131 ± 7.4a	16.4 ± 0.13d	1.32 ± 0.009a	71 509
				Calving season				
Spring	4770 ± 34.5a	215 ± 1.4a	168 ± 1.1a	383 ± 2.4a	139 ± 6.5b	16.6 ± 0.12a	1.34 ± 0.004c	40 185
Summer	4249 ± 94.4c	190 ± 3.7c	148 ± 3.1c	338 ± 6.6c	146 ± 6.7a	14.8 ± 0.32c	1.18 ± 0.023c	1584
Autumn	4094 ± 42.4c	189 ± 1.7c	144 ± 1.4c	333 ± 2.9c	112 ± 8.0d	14.6 ± 0.15c	1.18 ± 0.010c	10 130
Winter	4457 ± 33.7b	208 ± 1.3b	160 ± 1.1b	368 ± 2.3b	129 ± 6.3c	15.6 ± 0.12b	1.29 ± 0.008b	55 091

Means were compared using the least significant difference technique of the SAS GLM procedure.

DATA2

In the genetic analysis of milk, fat, protein and SCC, Y, P, S, H and YS interaction (see Eqn 2), were fitted as fixed effects, while cow was used as a random effect. Age at calving (A) and LL were included as covariates in all analyses. All traits were first analysed with a univariate animal model in ASReml (Gilmour *et al*. 2006) to obtain start up values for the covariance structures in subsequent analyses. A single multivariate analysis using an animal model was performed in ASReml to estimate heritabilities as well as phenotypic (r_P) and genetic (r_G) correlations of production traits (milk, fat and protein yields), while the log-transformed values of SCC were analysed as a univariate factor.

The animal model is:

$$Y_{ijklmnop} = \mu + H_i + S_j + Y_k + P_l + (YS)_{jk} + b_1(LL_{ijklm} - \overline{LL}) + b_2(A_{ijklmn} - \bar{A}) + a_{ijklmno} + e_{ijlkmnop} \quad (2)$$

where $Y_{ijklmno}$ represents the dependent variables total milk, fat, protein and log of SCC, μ is the population mean, H_i, S_j, Y_k, P_l and YS_{jk}, are the fixed effects of the variables on ith herd (H = 1, 2, . . . 216), jth calving season (S = 1, 2, . . . 4), kth calving year (Y = 1, 2, . . . 6), lth parity (P = 1, 2, . . . 3), and jkth first-order interaction of calving year and season (YS = 1, 2, . . . 46), respectively, b_1 and b_2 are the regression coefficients of LL and age at calving (A), respectively, $a_{ijklmno}$ is the random additive genetic effect and $e_{ijklmnop}$ is the random residual error. A pedigree file tracing ancestry to the last 5th generation was included in the analysis of DATA2.

Table 2. Descriptive statistics of 305-day milk, fat, protein and somatic cell count (SCC) of Holstein–Friesian cows adjusted for terms in the animal model based on DATA2
See Materials and methods for definition of locations and SCC

Category	Milk (L)				Fat (kg)				Protein (kg)				Log of SCC				*n*
	Mean	s.d.	Min.	Max.	Mean	s.d.	Min.	Max.	Mean	s.d.	Min.	Max.	Mean	s.d.	Min.	Max.	
Parity[A]																	
1	4859	1440	1209	12 997	196.6	52.88	18	509	161.6	48.65	22	469	3.83	0.976	0	8.23	18 767
2	5520	1647	1247	13 550	223.6	60.35	25	480	186.1	55.57	38	450	3.90	1.061	0	8.53	15 677
3	6171	1746	1207	15 141	250.6	66.12	27	544	207.9	57.93	16	487	4.29	1.163	0	8.94	31 470
Calving season																	
Winter	5648	1613	1207	14 924	231.6	62.22	18	544	190.7	54.59	16	487	4.05	1.089	0	8.94	32 998
Spring	5463	1825	1210	14 946	219.1	66.37	25	517	182.3	60.62	34	468	4.12	1.134	0	8.53	24 600
Summer	5542	1931	1296	12 944	218.1	73.53	43	460	179.7	61.9	39	414	3.89	1.535	0	7.28	1230
Autumn	6262	1762	1230	15 141	251.8	68.15	38	527	210.9	60.38	40	467	3.98	1.024	0	8.06	7086
Calving year																	
2000	4844	1378	1229	14 946	197.5	55.03	29	495	157.5	44.93	22	468	3.83	1.235	0	8.47	4385
2001	5436	1486	1474	14 199	218.1	55.90	52	472	178.8	47.81	49	456	3.83	1.111	0	7.60	6639
2002	5251	1557	1247	13 112	212.6	60.81	40	507	172.9	51.27	34	432	4.08	1.014	0	7.82	9024
2003	5510	1608	1230	13 861	222.5	60.86	18	517	185	53.01	40	438	4.01	1.079	0	8.15	11 677
2004	5816	1699	1317	14 360	236.4	63.45	27	509	197.6	56.83	26	471	4.09	1.120	0	8.39	14 774
2005	6024	1929	1207	15 141	245.1	71.05	31	544	204.8	65.06	16	487	4.21	1.109	0.69	8.94	19 415
Location																	
Far north-west	5779	1684	1209	14 924	234.6	63.73	18	544	194.9	57.44	40	487	4.02	1.068	0	8.53	17 152
North-west	5897	1945	1230	15 141	234.9	68.15	44	509	196.9	62.42	41	469	3.97	1.231	0	8.35	14 949
Central-north	5749	1640	1229	13 929	237.0	66.52	29	514	194.3	57.19	22	435	4.13	1.082	0	8.66	12 376
South	5231	1298	1273	10 024	209.2	55.3	46	380	174.7	43.1	44	328	4.39	0.926	2.08	8.07	1108
North-east	5365	1631	1207	14 946	216.9	62.16	27	517	179.9	55.45	16	468	4.12	1.071	0.69	8.94	18 596
King Island	4581	1331	1210	9739	202.1	62.1	52	446	152.0	44.25	42	346	4.21	1.018	1.39	7.54	1733

[A]Parity >2 were pooled and labelled as parity3.

Table 3. Heritability, phenotypic and genetic correlations (±s.e.) of milk, fat, protein and somatic cell count (SCC) of Holstein–Friesian cows
Heritability shown in bold (diagonal), phenotypic correlation and genetic correlation on upper and lower triangles, respectively

Trait	Milk	Fat	Protein	Log SCC
Milk	**0.41 (0.047)**	0.66 (0.003)	0.92 (0.008)	–0.047 (0.004)
Fat	0.41 (0.009)	**0.37 (0.005)**	0.75 (0.002)	–0.05 (0.004)
Protein	0.85 (0.003)	0.61 (0.007)	**0.35 (0.005)**	–0.03 (0.004)
Log SCC	0.09 (0.013)	0.034 (0.013)	0.098 (0.014)	**0.28 (0.005)**

In matrix notation the model can be written as.

$$y = Xb + Za + Wp + e \tag{3}$$

where y is the vector of observations, b is the vector of fixed effects H_i, S_j, Y_k, P_l and YS_{jk}, b_1 LL_j and b_2 Age_j, a is the vector of a_{ij} additive genetic effects, p is the vector of permanent environmental effects for cows with 305-day records, e is the vector of random residual effects and X, Z, and W are the incidence matrices which relate records to fixed, animal and permanent environmental effects, respectively. It is assumed that the permanent environment and the residual effects are independently distributed with means of zero and variance σ^2_{pe} and σ^2_e, respectively. The variances of the random additive, permanent environment and random error effects are $A\ \sigma^2_a$, $I\ \sigma^2_{pe}$ and $I\ \sigma^2_e = R$ and variance of y

$$\mathrm{var}(y) = ZAZ'\sigma^2_a + WI\sigma^2_{pe}W' + R$$

$$\text{with V}\begin{pmatrix} a \\ p \\ e \end{pmatrix} = \begin{pmatrix} G\otimes A & 0 & 0 \\ 0 & I\sigma^2_p & 0 \\ 0 & 0 & U \end{pmatrix} \tag{4}$$

where G is covariance matrix of the random regression coefficients, assumed to be the same for all cows; A is additive genetic relationship matrix among the animals; $\otimes$ is Kronecker product function (Searle 1982); I is identity matrix; and U is unstructured matrix with elements that define the traits.

The mixed model equation for this model would be

$$\begin{pmatrix} X'R^{-1}X & X'R^{-1}Z & X'R^{-1}W \\ Z'R^{-1}X & Z'R^{-1}Z + G^{-1}\otimes A^{-1} & Z'R^{-1}W \\ W'R^{-1}X & W'R^{-1}Z & W'R^{-1}W + Ik \end{pmatrix}\begin{pmatrix} \hat{b} \\ \hat{a} \\ \hat{p} \end{pmatrix} = \begin{pmatrix} X'R_y^{-1} \\ Z'R_y^{-1} \\ W'R_y^{-1} \end{pmatrix} \tag{5}$$

where $k = I/\sigma^2_p$ was assumed constant across traits.

Results

DATA1

Least-squares means estimates using model 1 are presented in Tables 1 and 4. Milk, fat and protein yields were significantly different ($P < 0.01$) between cattle breeds, parity and season of calving except for fat yield, which did not differ between the JJ and crossbred cows. The model fitted explained 40–43% of the variations due to environmental and management factors. LL accounted for ~19.3% of the total sums of squares. The other factors influencing productivity were herd size, location, and cow age in order of decreasing magnitude except for fat and protein yields where parity had greater influence than genotype and location.

Calving year

The effect of year of calving on milk yield, milk composition and the log of SCC of the cows is shown on Table 1. Total milk yield (L/lactation) was significantly different ($P < 0.01$) between all calving years except 2001 and 2003. Total milk yield progressively increased annually by an average of 2.5–5.7% except for a 101-L decline from 2002 to 2003. Similar trends were observed for fat and protein yields. There was also a general increase in annual total milk solids of 16–21 kg from 2001 to 2005 except for 2002 and 2003. Daily yields of milk, fat, protein and milk solids also progressively increased with advances in calving year (except in 2003).

Breed

Milk yield was significantly different ($P < 0.01$) between the three breeds evaluated in this study (Table 1). Total milk, fat, protein and milk solids yields were highest in FF cows, while JJ and FJ cows had similar fat and milk solids yields. JJ cows had the least protein yield and SCC. Differences between the FF and JJ in milk, fat and protein yields were 1499 L, 13 and 28 kg,

Table 4. Least-squares means of breed, calving year and calving season for milk, fat, protein and somatic cell count (SCC) of three dairy cow breeds in Tasmania

See Materials and methods for definition of SCC. All tested factors were significant ($P < 0.01$)

Category	Milk (L)	Fat (kg)	Protein (kg)	Milk solids (kg)	Log SCC ($\times 10^3$)	Milk (L/day)	Milk solids (kg/day)	*n*
				Breed × year				
Crossbred								
2000	3824 ± 97.1	175 ± 3.8	134 ± 3.2	308 ± 6.73	124 ± 18.2	13.5 ± 0.33	1.09 ± 0.023	515
2001	4095 ± 76.7	187 ± 3.0	143 ± 2.5	330 ± 5.32	109 ± 14.4	14.5 ± 0.26	1.16 ± 0.018	804
2002	4278 ± 68.9	193 ± 2.7	149 ± 2.3	342 ± 4.78	135 ± 12.9	14.9 ± 0.24	1.19 ± 0.016	1173
2003	4164 ± 62.3	194 ± 2.4	149 ± 2.1	343 ± 4.79	140 ± 11.7	14.6 ± 0.21	1.20 ± 0.015	1827
2004	4547 ± 58.9	210 ± 2.3	164 ± 1.9	373 ± 4.09	134 ± 11.1	15.9 ± 0.20	1.30 ± 0.014	2518
2005	4609 ± 56.1	215 ± 2.2	165 ± 1.9	380 ± 3.89	167 ± 10.5	16.1 ± 0.19	1.32 ± 0.013	3174
Friesian								
2000	4801 ± 66.2	193 ± 2.6	153 ± 2.2	346 ± 4.59	131 ± 12.4	16.8 ± 0.23	1.21 ± 0.016	4786
2001	5147 ± 47.7	206 ± 1.8	167 ± 1.6	372 ± 3.30	120 ± 8.9	17.9 ± 0.16	1.30 ± 0.016	7442
2002	5197 ± 43.2	210 ± 1.6	168 ± 1.4	377 ± 2.99	124 ± 8.11	18.1 ± 0.15	1.31 ± 0.010	10 499
2003	5109 ± 39.2	206 ± 1.5	169 ± 1.3	374 ± 2.72	133 ± 7.3	17.9 ± 0.13	1.30 ± 0.009	13 929
2004	5397 ± 37.7	218 ± 1.4	181 ± 1.2	398 ± 2.62	136 ± 7.07	18.8 ± 0.13	1.39 ± 0.009	19 296
2005	5619 ± 35.2	226 ± 1.3	188 ± 1.1	413 ± 2.45	155 ± 6.6	19.5 ± 0.12	1.44 ± 0.008	26 968
Jersey								
2000	3550 ± 92.2	186 ± 3.6	134 ± 3.0	320 ± 6.39	109 ± 17.3	12.5 ± 0.32	1.12 ± 0.022	763
2001	3655 ± 77.7	194 ± 3.1	141 ± 2.6	335 ± 5.39	119 ± 14.5	12.9 ± 0.27	1.18 ± 0.019	1201
2002	3742 ± 71.0	197 ± 2.8	142 ± 2.4	340 ± 4.96	117 ± 13.4	13.2 ± 0.24	1.19 ± 0.017	1662
2003	3640 ± 66.4	195 ± 2.6	143 ± 2.2	337 ± 4.61	138 ± 12.5	12.9 ± 0.23	1.18 ± 0.159	2576
2004	3789 ± 64.7	201 ± 2.5	148 ± 2.1	349 ± 4.49	134 ± 12.1	13.4 ± 0.22	1.22 ± 0.015	3436
2005	3902 ± 62.8	208 ± 2.5	153 ± 2.1	361 ± 4.36	145 ± 11.8	13.8 ± 0.22	1.27 ± 0.015	4421
				Breed × season				
Crossbred								
Autumn	3900 ± 68.3	182 ± 2.6	138 ± 2.3	319 ± 4.74	103 ± 12.8	13.9 ± 0.23	1.13 ± 0.016	542
Spring	4764 ± 41.4	216 ± 1.6	168 ± 1.4	384 ± 2.87	141 ± 7.8	16.6 ± 0.14	1.35 ± 0.009	3325
Summer	3851 ± 156.6	172 ± 6.1	134 ± 5.1	307 ± 10.9	164 ± 29.4	13.4 ± 0.54	1.07 ± 0.037	85
Winter	4498 ± 38.4	213 ± 1.5	162 ± 1.3	374 ± 2.66	131 ± 7.2	15.8 ± 0.13	1.31 ± 0.009	6059
Friesian								
Autumn	5368 ± 36.8	199 ± 2.3	177 ± 1.2	395 ± 2.55	121 ± 6.9	18.7 ± 0.13	1.38 ± 0.009	8647
Spring	5310 ± 59.1	216 ± 1.4	175 ± 1.1	389 ± 2.31	143 ± 6.3	18.6 ± 0.11	1.36 ± 0.008	32 145
Summer	5094 ± 59.2	213 ± 1.3	163 ± 1.9	362 ± 4.10	129 ± 11.1	17.6 ± 0.20	1.26 ± 0.041	1448
Winter	5074 ± 33.4	208 ± 1.3	169 ± 1.1	377 ± 2.31	140 ± 6.3	17.7 ± 0.11	1.32 ± 0.008	40 680
Jersey								
Autumn	3014 ± 55.9	168 ± 2.2	117 ± 1.8	285 ± 3.88	113 ± 10.5	11.1 ± 0.19	1.02 ± 0.013	941
Spring	4235 ± 38.9	217 ± 1.5	161 ± 1.3	378 ± 2.69	133 ± 7.3	14.6 ± 0.13	1.31 ± 0.009	4715
Summer	3802 ± 196.7	200 ± 7.7	147 ± 6.5	347 ± 13.7	144 ± 36.9	13.5 ± 0.67	1.20 ± 0.047	51
Winter	3800 ± 36.5	203 ± 1.4	148 ± 1.2	352 ± 2.53	117 ± 6.9	13.4 ± 0.13	1.23 ± 0.009	8352

respectively. JJ and FJ cows produced 29 and 18% less milk/lactation, respectively, than FF cows. Protein yield followed a similar pattern (Table 1).

Parity

Parity significantly ($P > 0.01$) influenced all milk production parameters (Table 1). Milk, fat, protein and milk solids yields were highest in cows with parity >4 and lowest in first parity cows. There was an observed increase in milk, fat, protein and milk solids yields as parity increased from 1 to >4, while the lowest SCC was observed in parity >4 cows (Table 1). Milk yield differences between first- vs second-parity and second- vs third-parity cows were 538 and 595 L, respectively, compared with those between third vs fourth and fourth vs parity >4 cows (211 and 193 L, respectively). Total milk solids increased from 277 kg in primiparous cows to 407 kg in cows with parities >4.

Location

The effect of location on yields of milk, fat, protein and milk solids are shown in Table 1. Milk and protein yields per cow were highest in the far north-west (FNWest), while cows in King Island (KIsland) produced the least milk, fat, protein and milk solids yields and had the highest SCC. The difference in milk yield/cow between the dairy locations in the north-west (FNWest and NWest) and the NEast was 98 L, the difference in milk yield between all the northern locations and the south was 697 L. Dairy herds in mainland Tasmania out-produced herds in KIsland by 1274 L of milk, 48 kg of fat and 44 kg of protein per cow per year. Milk fat and milk solids yields were highest in the central north (CntNorth) and FNWest.

Herd size

Significant variation in milk production due to differences in herd size was observed. Cows in very large herds produced the most milk, fat, protein and milk solids while medium herds produced the least milk and protein yields (Table 1). Milk fat yield and average SCC did not differ between cows in medium and small herds. Cows in the small and large herds had the highest and lowest SCC, respectively.

Calving season

Spring-calving cows produced significantly more milk, fat, protein and milk solids than autumn- and summer-calving cows (Table 1). However, SCC was highest in summer-calving cows and lowest in autumn-calving cows. Milk yield difference between spring- and autumn-calving cows was 676 L, while fat and protein yields between cows calving in both seasons differed by ~25 kg. Daily milk, fat, protein and milk solids yields followed the same trend.

Combined effect and interaction between breed and calving year

Least-squares means for combinations of breed and calving year are shown in Table 4. The differences in total milk, fat and protein yields/cow between were significantly lower in JJ compared with FF and FJ breeds. Within all breeds, total milk yield increased in all calving years except 2003 when it fell. In all calving years, FF cows produced the most milk and JJ produced the least. The general decrease in total milk yield in 2003 was lower in FF cows compared with FJ and JJ breeds. The subsequent recovery and increase in milk yield in 2004 was 353 L in FJ compared with 288 and 149 L in FF and JJ breeds, respectively. Although fat and protein production patterns were similar among the breeds across calving years, gains between years were slightly lower in JJ compared with the other breeds. SCC increased during the calving year 2001–02 in FJ and FF breeds, but declined in the JJ breed. No interaction effects were detected between breed and calving years for daily milk and milk solids yields. In contrast, the differences in total milk yield between FF and FJ for all calving years averaged 958 L, while that between FF and JJ averaged 1497 L. Similarly, the differences in protein yields between FF vs FJ and FF vs JJ were 20 and 28 kg, respectively.

Milk yield (L) differences between the highest and lowest calving years for each breed were: 818, 786, and 352 for the FF, FJ and JJ breeds respectively. Milk fat yield declined by between 3 and 4 kg in FF and JJ breeds from 2002 to 2003, but increased by 1 kg in FJ during the same period. JJ cows produced more fat than FJ in 2000–02, both produced equal amounts of fat in 2003 but the FJ produced more fat than the JJ in the subsequent calving years. Of all the breeds, only the FJ produced more fat in 2003 than in 2002. Milk protein yield was similar between JJ and FJ breeds in 2000–02 but the latter produced 6–15 kg more milk protein in 2003–05. Milk protein yield was lower although not significantly ($P > 0.05$) in 2002 than 2003 in all breeds except FJ. The FF breed produced milk with higher SCC in 2000–01 than the other breeds while FJ produced milk with the highest SCC in 2002–05.

Combined effect and interaction between calving year and calving season

Milk yield/lactation for all years averaged 4845, 4463, 4249 and 4094 for spring-, winter-, summer- and autumn-calving cows, respectively. Reduction in total milk solids in autumn- and summer-calving cows, due to the drought of 2003 were 7.5 and 18.2 kg, respectively, while spring- and winter-calving cows produced 8 and 11 kg more milk solids during the same year. With the exception of spring-calving cows in 2002, 2004 and 2005, SCC was highest in summer-calving cows and lowest in autumn-calving cows.

Combined effect and interaction between breed and calving season

Least-squares means for combinations of breed and calving season is shown in Table 4. FF cows produced the most milk and milk components in all calving seasons and years. Total milk yield per lactation was lowest in autumn-calving JJ cows. In contrast, milk fat yield was highest in JJ and FJ cows that calved in spring and lowest in autumn calvings in all breeds. FF cows that calved during autumn and spring produced the most milk protein and milk solids, while autumn-calving JJ cows produced the least. SCC was highest in FJ cows that calved during summer and lowest in autumn calvings.

DATA2

Unadjusted means of total milk, fat and protein yields (Table 2) were highest in third and lowest in first-parity FF cows. Log of SCC were similar across parities. Parity three FF cows produced 651 L more milk at 305 days than their second-parity counterparts while the latter produced 661 L more milk than the first-parity cows. Mean 305-day milk fat and protein yields were highest in autumn-calving FF cows. Milk yield was lowest in spring-calving cows while fat and protein yields were lowest in summer calvers. FF cows calving in autumn produced 614 L more milk than those that calved in winter. Winter-calving cows produced 185 and 105 L more milk at 305 days than those calving in spring and summer, respectively. Autumn-calving FF cows produced 7 and 10% more total fat and protein, respectively, than their winter-calving counterparts, but the difference between summer- and spring-calving cows was marginal.

Milk, fat and protein yields per cow increased annually from 2000 to 2005 except for a slight production dip in 2002. Average annual rates of increase in yields were 3, 3 and 4% for milk, fat and protein, respectively. Milk and protein yields/cow were highest in the NWest, followed by FNWest and lowest in KIsland. However, FF cows in the CntNorth produced the highest quantity of milk fat followed by cows in the NWest and FNWest with cows in the KIsland again producing the least. The difference in milk yield/cow between the highest and the lowest producing locations was 1376 L. Fat and protein yields (kg/cow) differed less dramatically and ranged between 237 and 202 and 195 and 152, respectively. SCC was similar between parity groups, production years and locations.

Heritability, genetic and phenotypic correlations of production traits

Heritability of 305-day milk in FF cows was highest followed by that of 305-day fat yield while h^2 of SCC was lowest. Phenotypic correlations among production traits ranged from 0.66 (milk vs fat) to 0.92 (milk vs protein) while that between production traits and SCC ranged from –0.03 (protein vs SCC) to –0.05 for SCC vs fat (Table 3). Phenotypic correlation between fat and protein was higher than that between milk and fat. Similarly, genetic correlation was highest between milk and protein being 0.85 and lowest between fat and SCC at 0.03. Phenotypic correlations between the milk, fat and protein yields were generally higher than the corresponding genetic correlations.

Discussion

Goodness of model fitting

The model fitted explained between 42 and 45% of the variation due to the factors tested for all traits considered in the study (Table 1). This would imply that there were other unaccounted explanatory variables beyond the scope of the fitted model. Such variables would include temporary environmental factors like feed intake, feed quality, milking frequency, housing condition, diseases and other management factors. These details about herd management were not available in the data used in this study. It has been reported that management factors due to individual farmer experience and openness to adoption of scientific and technological tools can have tremendous impact on dairy cow productivity even when animals of similar breed and production merit have been used (D. Chapman, J. Jacobs, G. O'Brien, J. Tharmaraj and S. Kenny, unpubl. data). The results of this study should therefore be interpreted in the light of the available data and tested factors.

Calving year, calving season and their interactions

Total yields of milk, fat and protein in this study were higher than the values reported for low- and high-bodyweight FF cows in New Zealand (Lopez-Villalobos *et al.* 2001), but lower than the values reported by García *et al*. (1998, 2007) and Bargo *et al*. (2002) for high merit cows on pasture allowance and concentrate supplementation in individual vs group feeding trials, respectively. Our results on total milk yield per lactation were however in agreement with the findings of Grainger (1990) and García and Holmes (2001). The latter reported average milk yields ranging from 4982 to 5409 L, s.e. = 85.7 in autumn- and spring-calving FF cows. The higher responses in milk yield and milk component yields under experimental conditions compared with aggregate data emanating from large number of cows from multiple herds over diverse locations were expected. For instance, Bargo *et al*. (2002) and García *et al*. (2007) offered concentrate at 1 kg/4 kg milk yield and 3–7 kg as fed/cow.day to 24 and 50 grazing cows, respectively, whereas we evaluated data on 103 366 cows. Figures on annual increases in milk yield in this study were generally lower than the national averages (DPIW 2005; Dairy Australia 2006), but annual milk yields in 2000–01 and 2003–04 (Table 1) were well in agreement with published figures. The restriction of our datasets to production records of only three genotypes could partly account for the discrepancy with the national figures. Furthermore, differences in milk yield per cow due to higher use of concentrate feeds in the states of Victoria and New South Wales (Dairy Australia 2006) may also partly explain the lower milk and component yields in Tasmania. The decline in production in the 2002–03 calving season was attributed to feed shortages from the severe and widespread drought of that season. Climatic factors such as low rainfall and adverse temperatures have negative effect on milk yield in temperate cows through the physiologically induced depressed feed intake (Msanga *et al*. 2000). Analysed climatic data (http://www.answers.com/topic/geography-of-Tasmania, verified 15 January 2008) showed that maximum temperature was significantly lower ($P < 0.05$) in 2004 than in other years, while mean annual rainfall was 612.2 ± 33.9 mm in the 2002–03 calving season compared with 780.4 mm in other years. Reduced rainfall could depress pasture DM yield and metabolisable energy (ME) content, thus reducing energy intake and productivity of pasture-based cows (Walker *et al*. 2004). Differences in milk yield between calving years have been reported (Msanga *et al*. 2000; Dairy Australia 2005). Unlike in the present study, White *et al*. (2002) found no significant interactions between calving season and other factors.

Our results are also in agreement with seasonal variations in milk and milk solids yields reported by García *et al*. (1998) for pasture-based cows. They reported that autumn-calving FF cows produced significantly more milk solids than spring-calving FF cows due to the effect of lush pasture with higher ME in spring (spring hump) and extended lactation due to greater persistency. Typically, dairy cows attain peak yields between 3 and 8 weeks postpartum (Tekerli *et al*. 2000). In pasture-based, winter-calving systems, it has been reported that the peak month of milk production coincides with spring when production almost doubled that of the lowest months between May and July (Dobson 2006). Our findings revealed that LL was significantly longer ($P < 0.05$) in autumn-calving, compared with spring-calving FF cows (306 ± 0.34 vs 269 ± 0.16 days). However, White *et al*. (2002) reported that autumn- and spring-calving cows had similar milk solids yields in northern Victoria. Differences in production traits during different calving seasons reflect seasonal variations in diverse calving systems practised all over Australia aimed at minimising feed cost by matching peak nutrient requirement for lactation with the period of highest availability of ME from pastures (Walker *et al*. 2004). Although most farms practise a split-calving system, percentage calving patterns of dairy herds in Tasmania were 51 and 38% for winter and spring calvings, respectively.

Breed

Milk yield/lactation of FF cows reported in this study was comparatively lower than the performance of the North American FF strains but similar with the milk, fat and protein yields of New Zealand strains reported in the study by Horan *et al*. (2005) who also found that the mean pedigree index for milk yield was significantly higher in North American strains compared with the New Zealand strains. Our results were also similar to the findings of Dobos *et al*. (2001) in pasture-based FF heifers over three lactations and the report of White *et al*. (2002) in which JJ cows produced 23.3% less milk than Holsteins.

Total milk solids yields obtained in this study was higher than the values reported for FF cows in New Zealand (García *et al*. 1998; Lopez-Villalobos *et al.* 2001). Their study evaluated two strains of FF cows bred for low and high bodyweights, under low stocking rates (1.95–2.25 cows/ha) supplemented with 0.4–1.20 t DM/cow concentrate. Average stocking rate in dairy farms in Australia is ~2.5 cows/ha (Dairy Australia 2005). Poor efficiency of grain supplement utilisation due to higher level of substitution under low stocking rates or high pasture allowance has been reported in literature (Robaina *et al*. 1998; Stockdale 1999; Fulkerson *et al*. 2000). The daily milk solids yield reported herein are in agreement with the findings of Bryant *et al.* (2003) who utilised FF cows at a stocking rate of 4.4 cows/ha and supplemented with 1.3–1.5 t DM per annum for three seasons.

The higher performance of FJ over the JJ cows demonstrated the beneficial effect of heterosis. The rate of genetic progress in the dominant dairy breeds was evident in the annual rate of increase in milk and constituent yields. Whereas increase in milk yield/lactation averaged 5 and 5.3% in FF and FJ breeds, respectively, it was 3% in JJ. In addition, the percentage decline in lactation in 2003 was 1.7% in FF while it was 2.7% in FJ and JJ. Madgwick and Goddard (1989) had highlighted the possibility of slower genetic progress which might make JJ cows less competitive in the future.

Parity

Milk production is known to increase with increase in parity and cow age due to higher bodyweight, larger capacity for DM intake, increase in size of the udder and recurrence of pregnancy and lactations (Capuco *et al*. 2001). Lower production in primiparous cows is related to competition between tissues (e.g. mammary gland vs peripheral tissues) for metabolites for growth and lactation in the immature animal (Tekerli *et al*. 2000). Similar observations to that found in our study on the effect of parity on dairy cow performance has also been reported (Val-Arreola *et al*. 2004).

Location

Milk yield per cow in 2002–03 calving season obtained in this study was higher than reported averages in other states of Australia, except Western Australia and South Australia. Production per cow in Tasmania was lower than that of other states except Queensland in 2003–04 (Dairy Australia 2005). Concerns over low production per cow *vis-a-vis* increasing use of grain concentrates to benefit from increasing genetic potential of dairy cows is a main issue in pasture-based dairying (D. Chapman, J. Jacobs, G. O'Brien, J. Tharmaraj and S. Kenny, unpubl. data). In 2001, ADHIS adopted the Australian Profit Ranking method for sire breeding value evaluation as a measure of improving long-term productivity and profit per cow. Pasture-based dairying in Tasmania is also focussing on production per hectare as a measure of farm productivity rather than productivity per cow *per se* as evidence from industry reports show that the link between profit and pasture utilisation is the strongest of all performance indicators (Donaghy 2007). Differences in yield traits between locations, attributable to differences in the rainfall distribution pattern and geo-physical conditions, have been reported extensively in literature (Msanga *et al*. 2000; Dairy Australia 2005; Horan *et al*. 2005). A review of climate data in the study area showed that mean annual rainfall and altitude were significantly different ($P < 0.001$) between the dairying locations in Tasmania. Mean annual rainfall was lower in the South but significantly higher ($P < 0.01$) in King Island compared with the other location. Mean altitude (metres above sea level) averaged 117.7 ± 16.4 m in Central North, North West, North-East and Far North-West locations compared with an average of 43.6 m in the South and King Island (http://www.answers.com/topic/geography-of-Tasmania, verified 15 January 2008). In addition, considerable investment undertaken in the North-West and North-East areas of the state in the last decade has encouraged the emergence of corporate farmers with large herds with the attendant economies of scale (DPIW 2005). It should be noted, however, that the relatively smaller number of cows (Table 1) in the South and King Island could have some bearing on some of the responses evaluated in these locations.

Herd size

Herd sizes reported in this study were generally consistent with the national dairy herd statistics (Dairy Australia 2006). Tasmania has the highest mean herd size of 254 cows per herd, whereas Queensland has the smallest with 158 cows per herd. Higher performance in herds with large number of cows is also in agreement with results from dairying in Victoria. A benchmark study in Western Victoria that compared profitability indices of the top and bottom 10 farms indicated that large herds were more profitable and gave greater returns on capital than medium or small herds. As herd size increases, overhead and labour costs can be spread over more units (Doyle and Kelly 1998). In addition, owners of larger herds have been reported to adopt high intensity feeding systems and appeared more open to improved management systems than small or medium herd owners (DRDC 1996). Smaller herds, however, can benefit from the flexibility in land and labour management to increase per unit resource (Doyle and Kelly 1998).

Heritability of milk, fat and protein yields

The relatively small-sized data used in this study could lead to an overestimation of the h^2 estimates. It is known that the greater the sample size, the higher the precision of additive genetic estimates (Jensen 2001). However, our h^2 estimates using both univariate and multivariate approaches were within the range of values reported in literature which ranged from 0.31 (Wilmink 1987) to 0.49 (Pander *et al*. 1992). Meyer *et al*. (1989) compared the different methods of estimating h^2 and reported 305-day milk yield h^2 of 0.37. In another study that compared alternative methods of equalising heterogeneity of variance, Boldman and Freeman (1990) reported lower h^2 estimates of 0.18, 0.22, and 0.24 for untransformed milk yield in low-, medium-, and high-producing herds, respectively. Heritability estimates of fat and protein yields reported in this study were slightly higher than the values reported by Visscher and Goddard (1995) from five states of Australia (excluding Tasmania), probably partly because they used test-day sire models in their evaluation while we utilised an animal model with 305-day records. However, our results were in agreement with the work of Swalve (1995) who utilised test-day, herd-year-season animal model and reported 305-day milk, fat and protein h^2 estimates of 0.39, 0.32 and 0.30, respectively.

Comparison of h^2 estimation methods showed that test-day approaches generally yield lower estimates (Meyer *et al*. 1989; Pander *et al*. 1992) compared with the 305-day method. Issues from using aggregated 305-day milk yield and the benefits of test-day random regression models have been extensively reviewed (Jensen 2001). The continuation of using 305-day milk yield stems from industry tradition and the limitations imposed by computational requirements until recently (Jensen 2001). There is, however, a general consensus that the heritabilities for fat were, in almost all cases, lower than the heritabilities for protein, and that milk production has the highest heritability.

Conclusions

This study investigated the influence of genetic and environmental factors affecting dairy production in Tasmania. Breed, parity, age and LL, were important determinants of milk and milk solid yields under pasture-based dairy systems. Improved yields over the years were indicative of not only improvement in dairy cow genetics, but also improvement in the adoption of better management practices. Season played a significant role in the calving pattern of pasture-based dairy cows in Tasmania due to the variation in microclimate across the dairy regions. The inclusion of random cow effect in the animal model showed higher yields attributable to additive genetic variance in the FF cows, although small data size precluded the estimation of the additive genetic effects in the other breeds. This would suggest the potential for genetic manipulation to increase yields. Significant herd effect also suggested that there was scope to improve productivity through the adoption of improved management practices. Herd size as a factor of management improved production traits in very large herds thus supporting the emerging trends for larger dairy herds in Tasmania. Other management factors such as access to information and market, favourable market prices, technical and managerial support are very important if farmers are to cope with the challenge of running profitable dairy enterprises. The heritability and genetic and phenotypic correlation estimates in this study fall within the expected ranges in dairy cattle, thus confirming that years of selection of the milking herd in Tasmania will likely continue to improve genetic progress within the pasture-based dairy framework. A desirable future goal would be to conduct a comparative economic analysis of farm profitability under high grain supplementation vs grazing only to shed more light on the cost-effective benefits of pasture-based dairying.

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References

ABARE (2003) 'Australian Dairy Industry: productivity and profit.' (Dairy Australia: Melbourne) Available at http://www.abareconomics.com/publications_html/livestock/livestock_06/ausdairy_oct.pdf [Verified 9 April 2010]

Bargo F, Muller LD, Delahoy JE, Cassidy TW (2002) Milk response to concentrate supplementation of high producing dairy cows grazing at two pasture allowances. *Journal of Dairy Science* **85**, 1777–1792.

Boldman KG, Freeman AE (1990) Adjustment for heterogeneity of variances by herd production level in dairy cow and sire evaluation. *Journal of Dairy Science* **73**, 503–512.

Capuco AV, Wood DL, Baldwin R, Mcleod K, Paape MJ (2001) Mammary cell number, proliferation, and apoptosis during a bovine lactation: relation to milk production and effect of bST. *Journal of Dairy Science* **84**, 2177–2187.

Dairy Australia (2005) Production systems, productivity and profit. Australian Dairy 05.1 report, December 2005. Available at http://www.abare.gov.au/publications_html/livestock/livestock_05/ad05.pdf [Verified 9 April 2010]

Dairy Australia (2006) Production systems, productivity, profit and technology. Australian Dairy 06.1 report, October 2006. Available at http://www.abare.gov.au/publications_html/livestock/livestock_06/ausdairy_oct.pdf [Verified 9 April 2010]

Dobos RC, Nandra KS, Riley K, Fulkerson WJI, Lean J, Kellaway RC (2001) Effects of age and liveweight at first calving on first lactation milk, protein and fat yield of Friesian heifers. *Australian Journal of Experimental Agriculture* **41**, 13–19. doi:10.1071/EA00090

Dobson WD (2006) Developments in world dairy markets, 2002–2006 – implications for the US dairy industry. Babcock Institute for International Research and Development, Madison, WI. Available at http://ageconsearch.umn.edu/bitstream/37384/2/2006-3.en.pdf [Verified 9 April 2010]

Donaghy DJ (2007) The 20.12 project – utilisation of 20 tonnes of pasture dry matter/ha under irrigated and 12 tonnes under dryland conditions. Tasmanian Institute of Agricultural Research, Milestone Report 4 to Dairy Australia Project No. UT12026, Burnie, Tas.

Doyle PT, Kelly KB (1998) The Victorian Dairy Industry – improving performance. In 'Proceedings of the 9th Australian agronomy conference'. (Eds DL Michalk, JE Prately) p. 119. (The Australian Society of Agronomy: Wagga Wagga, NSW)

DPIW (2005) Dairy industry. Available at http://www.dpipwe.tas.gov.au/inter.nsf/ThemeNodes/EGIL-52Y97G?open [Verified 9 April 2010]

DRDC (1996) Benchmarking: lifting profitability beyond the average, research note 40. Dairy Research and Development Corporation, Melbourne.

Fulkerson WJ, Hough G, Goddard M, Davison T (2000) 'The productivity of Friesian cows: effect of genetic merit and level of concentrate feeding.' (Wollongbar Agricultural Institute: Wollongbar, NSW)

García SC, Holmes CW (2001) Lactation curves of autumn-and spring-calved cows in pasture-based dairy systems. *Livestock Production Science* **68**, 189–203. doi:10.1016/S0301-6226(00)00237-2

García SC, Cayzer FJ, Holmes CW, MacDonald A (1998) The effect of calving season on milk production. A system study. *Proceedings of the New Zealand Society of Animal Production* **58**, 61–63.

García SC, Pedernera M, Fulkerson WJ, Horadagoda A, Nandra K (2007) Feeding concentrates based on individual cow requirements improves the yield of milk solids in dairy cows grazing restricted pasture. *Australian Journal of Experimental Agriculture* **47**, 502–508. doi:10.1071/EA05349

Gilmour AR, Gogel BJ, Cullis BR, Welham SJ, Thompson R (2006) 'ASReml user guide. Release 1.0.' (VSN International Ltd: Hemel Hempstead, UK)

Grainger C (1990) Effect of stage of lactation and feeding level on milk yield response by stall-fed cows to change in pasture intake. *Australian Journal of Experimental Agriculture* **30**, 495–501. doi:10.1071/EA9900495

Horan B, Dillon P, Faverdin P, Delaby L, Buckley F, Rath M (2005) Strain of Holstein-Friesian by pasture-based feed system interaction for milk production; bodyweight and body condition score. *Journal of Dairy Science* **88**, 1231–1243.

Jensen J (2001) Genetic evaluation of dairy cattle using test-day models. *Journal of Dairy Science* **84**, 2803–2812.

Lopez-Villalobos N, Lemus-Ramirez V, Holmes CW, Garrick DJ (2001) Lactation curves for milk traits, live weight and body condition score for heavy and light Holstein–Friesian cows. *Proceedings of the New Zealand Society of Animal Production* **61**, 217–220.

Madgwick PA, Goddard ME (1989) Comparison of purebred and crossbred dairy cattle for Victoria, estimation of genetic effects for yield. *Australian Journal of Experimental Agriculture* **29**, 1–7. doi:10.1071/EA9890001

Meyer K, Graser HU, Hammond K (1989) Estimates of genetic parameters for first lactation test day production of Australian Black and White cows. *Livestock Production Science* **21**, 177–199. doi:10.1016/0301-6226(89)90049-3

Msanga YN, Bryant MJ, Rutam IB, Minja FN, Zylstra L (2000) Effect of environmental factors and of the proportion of Holstein blood on the milk yield and lactation length of crossbred dairy cattle on smallholder farms in north-east Tanzania. *Tropical Animal Health and Production* **32**, 23–31. doi:10.1023/A:1005288918672

Pander BL, Hill WG, Thompson R (1992) Genetic parameters of test day records of British Holstein–Friesian heifers. *Animal Production* **55**, 11–21.

Robaina AC, Grainger C, Moate P, Taylor J, Stewart J (1998) Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* **38**, 541–549. doi:10.1071/EA97087

SAS (2002) 'User's guide. Version 9.1.' (SAS Institute: Cary, NC)

Searle SR (1982) 'Matrix algebra useful for statistics.' (John Wiley and Sons: New York)

Stockdale CR (1999) The nutritive characteristics of herbage consumed by grazing dairy cows affect milk yield responses obtained from concentrate supplementation. *Australian Journal of Experimental Agriculture* **39**, 379–387. doi:10.1071/EA98080

Swalve HH (1995) The effect of test day models on the estimation of genetic parameters and breeding values for dairy yield traits. *Journal of Dairy Science* **78**, 929–938.

Tekerli M, Akinci Z, Dogan I, Akcan A (2000) Factors affecting the shape of lactation curves of Holstein cows from the Balikesir Province of Turkey. *Journal of Dairy Science* **83**, 1381–1386.

Val-Arreola D, Kebreab E, Dijkstra J, France J (2004) Study of the lactation curve in dairy cattle on farms in Central Mexico. *Journal of Dairy Science* **87**, 3789–3799.

Visscher PM, Goddard ME (1995) Genetic parameters for milk yield, survival, workability, and type traits for Australian dairy cattle. *Journal of Dairy Science* **78**, 205–220.

Wales WJ, Heard JW, Ho CKM, Leddin CM, Stockdale CR, Walker GP, Doyle PT (2006) Profitable feeding of dairy cows on irrigated dairy farms in northern Victoria. *Australian Journal of Experimental Agriculture* **46**, 743–752. doi:10.1071/EA05357

Walker GP, Dunshea FR, Doyle PT (2004) Effects of nutrition and management on the production and composition of milk fat and protein: a review. *Australian Journal of Agricultural Research* **55**, 1009–1028. doi:10.1071/AR03173

White SL, Benson GA, Washburn SP, Green JT Jr (2002) Milk production and economic measures in confinement or pasture systems using seasonally calved Holstein and Jersey cows. *Journal of Dairy Science* **85**, 95–104.

Wilmink JBM (1987) Adjustment of lactation yield for age at calving in relation to level of production. *Livestock Production Science* **16**, 321–334. doi:10.1016/0301-6226(87)90002-9

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Appendix 1. Dairy farm facts in Tasmania

Adapted from: DPWI 2005, Dairy Australia 2006. n.a., not available; P, predicted

Parameter/year	1999–2000	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06
Milk production (million L)	609	590	671	585	590	600	622
Registered dairy farms (*n*)	734	638	612	597	543	507	498P
Dairy cows (*n*)	139 000	148 000	134 000	142 000	138 000	135 000	135 000
Employment (owners and staff) (*n*)	1890	n.a.	n.a.	1700	n.a.	n.a.	n.a.
Gross value of production ($ million)	133	148	220	151	160	180P	n.a.
Average herd size (no. of cows)	194	231	236	213	245	271	270
Milk per cow (L)	4381	4177	4646	4304	4219	4497	4542
Milk per farm (L)	830 000	925 000	1 116 000	980 000	1 089 000	1 183 000	n.a.
Milk fat (%)	4.29	4.26	4.28	4.26	4.32	4.28	4.29
Milk protein (%)	3.29	3.28	3.29	3.29	3.36	3.36	3.37