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

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Running head: Milk yield and composition in grazing cows

Abstract. The objective of this study was to provide an update on milk production performance, heritability, genetic and phenotypic correlations among production traits which 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 (5,212 litres and 171 kg, respectively) and lowest in the JJ breed (3,713 litres and 143 kg, respectively). FF cows also produced 13.5kg 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. On the other hand, 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.

Keywords: Pasture-based cows, Holstein-Friesian, Genetics, Tasmania, Milk, Protein, Fat

Introduction

The dairy industry in Australia is very important to the agricultural sector of the economy. With an ex-factory value of $9.1 billion and farm gate value of $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, ninety percent 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 about 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), Ilawara (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 to 30-40% in New South Wales (NSW), Queensland and Western Australia (Edward 2005). 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 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 (Dairy Australia (2004). 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; 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; to identify the critical management factors underpinning milk and milk component yields and to estimate the heritability of production traits and somatic cell count.

MATERIALS AND METHODS

Site and climatic conditions

Tasmania is Australia's southern-most state with a land mass of 68,000 sq km, 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 21^0C (70^0 F) and 12^0C (54^0 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 millimeters (25 inches) in the south to 2,400 millimeters (94 inches) on the

North-West Coast. The prevailing weather pattern creates a rain shadow in the west to 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 somatic cell count (SCC) yield records of purebred Holstein-Friesian , Jersey , Guernsey, Illawarra, and Australian Reds as well as crosses of Holstein-Friesian and Jersey cows of different ages, season of calving, parity, and lactation length.

Two data sets 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, milksolids yield, lactation length, 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 lactation length. 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 lactation length <100 days were also excluded from the analyses. DATA1 finally consisted of 106, 990 records from 428 herds, over six 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 data set consisting of thirty postcodes was divided into 6 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 <1,200 L leaving a total of 65,914 records. Parity >2 were pooled and labelled as parity3. Dairy farm statistics of Tasmania is presented in Appendix 1. Least square means and summary statistics of the traits for DATA1 and DATA2 are presented in Tables 1 and 3 respectively.

Statistical analysis

DATA1. General linear models (GLM) procedure in SAS (SAS 2002) was utilised to compute least square means, standard errors (s.e.) and coefficient of variation (c.v.) of the traits. Location, herd size, breed, calving year, calving season and parity were fitted as fixed effects while age and lactation length 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:

$$Y_{ijklmnopq}=\mu+L_i+H_j+S_k+Y_l+B_m+P_n+(BS)_{km}+(BY)_{lm}+(SP)_{kn}+(BP)_{mn}+(PSY)_{nkl}+b_1(L_{ijklmno}-\bar{L}L)^2+b_2(A_{ijklmnop}-\bar{A})^2+e_{ijlkmnopq} \quad 1$$

where $Y_{ijklmopq}$ is the $_{ijklmnopq}$th observation of the dependent variables (milk, fat and protein yields and log of somatic cell count), 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 $b_1(LL_{ijklmno} - \overline{LL})^2$, and $b_2(A_{ijklmnop} - \bar{A})^2$ represent the fitting of lactation length (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. Means were compared using the least significant difference technique of SAS GLM procedure.

DATA2. In the genetic analysis of milk, fat, protein and somatic cell count, Y, P, S H and YS interaction (as previously defined), were fitted as fixed effects, while cow was used as a random effect. Age at calving (Age) and lactation length (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) with their associated standard errors (Table 4), while the log- transformed values of somatic cell count were analysed as a univariate factor.

The animal model is:

$$\cancel{y_{ij} = \mu_i + Y_{ik} + P_{il} + S_{im} + YS_{ikm} + H_{in} + \beta_1 LL_j + \beta_2 Age_j + a_{ij} + e_{ij}} \qquad 2$$

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

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 i^{th} herd (H=1,2…216), j^{th} calving season (S= (1,2…4), k^{th} calving year (Y=1,2 …6), l^{th} parity (P=1,2…3), and jk^{th} first order interaction of calving year and season (YS= 1,2…46), respectively, b_1 and b_2 are the regression coefficients of lactation length (L) and age at calving (A) respectively, a_{ijklmn} is the random additive genetic effect and $e_{iklmnopj}$ is the random residual error. A pedigree file tracing ancestry to the last 5th generation was included in the analysis of DATA2.

In matrix notation the model can be written as

$$y=\mathbf{X}b+\mathbf{Z}a+\mathbf{W}p+e,$$

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_1LL_j and b_2Age_j, a is the vector of a_{ij} additive genetic effects~~random animal 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 Aσ^2_a, Iσ^2_{pe} and Iσ^2_e = R and variance of y

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

with $V\begin{pmatrix} a \\ p \\ e \end{pmatrix} =$

$$\begin{pmatrix} G \otimes A & 0 & 0 \\ 0 & I\sigma_p^2 & 0 \\ 0 & 0 & U \end{pmatrix}$$

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

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

Where $k = I/\sigma_p^2$ was assumed constant across traits.

RESULTS

DATA1

Least squares means estimates using Model 1 are presented in Tables 1 and 2. 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 Jerseys and crossbred cows. The model fitted explained 40-43% of the variations due to environmental and management factors. Lactation length accounted for about 19.3% of the total sums of squares. The other

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210 factors influencing productivity were herd size, location, and cow age in order of decreasing
211 magnitude except for fat and protein yields where parity had greater influence than genotype
212 and location.
213
214 *Calving Year.* The effect of year of calving on milk yield, milk composition and the
215 log of somatic cell count of the cows is shown on Table 1. Total milk yield (L/lactation) was
216 significantly different ($P<0.01$) between all calving years except 2001 and 2003. Total milk
217 yield progressively increased annually by an average of 2.5-5.7% except for a 101L decline
218 from 2002 to 2003. Similar trends were observed for fat and protein yields. There was also a
219 general increase in annual total milk solids of 16-21 kg from 2001 to 2005 except for 2002
220 and 2003. Daily yields of milk, fat, protein and milksolids also progressively increased with
221 advances in calving year (except in 2003).
222
223 *Insert Table 1 here*
224 *Breed.* Milk yield was significantly different ($P<0.01$) between the three breeds
225 evaluated in this study (Table 1). Total milk, fat, protein and milksolids yields were highest in
226 FF cows, while JJ and FJ cows had similar fat and milk solids yields. JJ cows had the least
227 protein yield and somatic cell count. Differences between the FF and JJ in milk, fat and
228 protein yields were 1499 L, 13 kg and 28 kg respectively. JJ and FJ cows produced 29% and
229 18% less milk/lactation respectively, than FF cows. Protein yield followed a similar pattern.
230 (Table 1).
231
232 *Parity.* Parity significantly (P>0.01) influenced all milk production parameters (Table
233 1). Milk, fat, protein and milksolids yields were highest in cows with parity >4 and lowest in
234 first parity cows. There was an observed increase in milk, fat, protein and milksolids 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 L and 595 L respectively, compared with those between third vs fourth and fourth vs parity>4 cows (211 L and 193 L, respectively).. Total milksolids 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 milksolids are shown on (Table 1). Milk and protein yields per cow were highest in FNWest, while cows in KIsland produced the least milk, fat, protein and milksolids 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 697L. 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 milksolids yields were highest in 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 milksolids 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 milksolids than Autumn and Summer-calving cows (Table 1). On the other hand, SCC was highest in Summer-calving cows and lowest in Autumn-calving cows. Milk yield difference between Spring and Autumn-calving cows was 676 litres, while fat and protein

yields between cows calving in both seasons differed by approximately 25 kg. Daily milk, fat, protein and milksolids yields followed the same trend.

Insert Table 2 here

Combined effect and interaction between ~~B~~breed and~~by~~ calving year~~ interaction~~. Least squares means for combinations of breed and calving year are shown in Table 2. 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 the least. The general decrease in total milk yield in 2003 was lower in FF cows compared to FJ and JJ breeds. The subsequent recovery and increase in milk yield in 2004 was 353L in FJ compared with 288L and 149L 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 to 2002 in FJ and FF breeds, but declined in JJ breed. No interaction effects were detected between breed and calving years for daily milk and milksolids yields. In contrast, the difference 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 kg and 28 kg, respectively.

Milk yield (L) differences between the highest and lowest calving years for each breed were: 818, 786, and 352 for 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 to 2002, both produced equal

amounts of fat in 2003 but the FJ produced more fat than Jerseys 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 2000-2002 but the latter produced 6-15 kg more milk protein in 2003-2005. 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 2000-2001 than the other breeds while FJ produced milk with the highest SCC in 2002-2005.

Combined effect and interaction between ~~C~~calving year and~~by~~ calving season ~~interaction~~. Milk yield/lactation for all years averaged 4845, 4463, 4249 and 4094 for spring, winter, summer and autumn calving cows, respectively. Reduction in total milksolids 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 milksolids 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 calvers.

Combined effect and interaction between ~~B~~breed ~~by~~ and calving season ~~interaction~~. Least squares means for combinations of breed and calving season is shown in Table 2. 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 3) 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 day 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. Holstein Friesian 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 305d 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. On the other hand, 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 237-202 and 195–152, respectively. Somatic cell counts were similar between parity groups, production years and locations.

Insert Table 3 here

Heritability, genetic and phenotypic correlations of production traits

335 Heritability of 305d milk in FF cows was highest followed by that of 305d fat yield while h^2
336 of SCC was lowest. Phenotypic correlations among production traits ranged from 0.66 (milk
337 *vs.* fat) to 0.92 (milk vs. protein) while that between production traits and SCC ranged from -
338 0.03 (protein vs. SCC) to -0.05 for SCC *vs.* fat (Table 4). Phenotypic correlation between fat
339 and protein was higher than that between milk and fat. Similarly, genetic correlation was
340 highest between milk and protein being 0.85 and lowest between fat and SCC at 0.03.
341 Phenotypic correlations between the milk, fat and protein yields were generally higher than
342 the corresponding genetic correlations.
343
344 *Insert Table 4 here*
345
346 **DISCUSSION**
347 *Goodness of model fitting*
348 The model fitted explained between 42-45% of the variation due to the factors tested
349 for all traits considered in the study (Table 1). This would imply that there were other
350 unaccounted explanatory variables beyond the scope of the fitted model. Such variables
351 would include temporary environmental factors like feed intake, feed quality, milking
352 frequency, housing condition, diseases and other management factors. These details about
353 herd management were not available in the data used in this study. It has been reported that
354 management factors due to individual farmer experience and openness to adoption of
355 scientific and technological tools can have tremendous impact on dairy cow productivity even
356 when animals of similar breed and production merit have been used (Chapman *et al.* 2004).
357 The results of this study should therefore be interpreted in the light of the available data and
358 tested factors.
359

360 *Calving year, calving season and their interactions*

361 Total yields of milk, fat and protein in this study were higher than the values reported for low-
362 and high-bodyweight Holstein-Friesian cows in New-Zealand (Lopez *et al.* 2001), but lower
363 than the values reported by Bargo *et al.* (2002) and García *et al.* (1998; 2007) for high merit
364 cows on pasture allowance and concentrate supplementation in individual *vs*. group feeding
365 trials, respectively. Our results on total milk yield per lactation were however in agreement
366 with the findings of Grainger (1990) and García and Holmes (2001). The latter reported
367 average milk yields ranging from 4982-5409 L, s.e.=85.7 in autumn and spring-calving FF
368 cows. The higher responses in milk yield and milk component yields under experimental
369 conditions compared with aggregate data emanating from large number of cows from multiple
370 herds over diverse locations were expected. For instance, Bargo *et al.* (2002) and García *et al.*
371 (2007), offered concentrate at 1kg/4kg milk yield and 3-7kg as fed/cow/day to twenty-four
372 and fifty grazing cows respectively, whereas we evaluated data on 103,366 cows. Figures on
373 annual increases in milk yield in this study were generally lower than the national averages
374 (Dairy Australia 2006, DPIW 2005), but annual milk yields in 2000 to 2001 and 2003 to 2004
375 (Table 1) were well in agreement with published figures. The restriction of our data sets to
376 production records of only three genotypes could partly account for the discrepancy with the
377 national figures. Furthermore, differences in milk yield per cow due to higher use of
378 concentrate feeds in the states of Victoria and New South Wales (Dairy Australia 2006) may
379 also partly explain the lower milk and component yields in Tasmania. The decline in
380 production in 2002/03 calving season was attributed to feed shortages from the severe and
381 widespread drought of that season. Climatic factors such as low rainfall and adverse
382 temperatures have negative effect on milk yield in temperate cows through the
383 physiologically induced depressed feed intake (Msanga *et al.* 2000). Analysed climatic data
384 (Geography of Tasmania 2008) showed that maximum temperature was significantly lower

385 (P<0.05) in 2004 than in other years, while mean annual rainfall was 612.2±33.9 mm in 2002
386 to 2003 calving season compared with 780.4 mm in other years. Reduced rainfall could
387 depress pasture dry matter (DM) yield and metabolisable energy (ME) content, thus reducing
388 energy intake and productivity of pasture-based cows (Walker *et al.* 2004). Differences in
389 milk yield between calving years have been reported (Dairy Australia 2005, Msanga *et al.*
390 2000). Unlike in this study, White *et al*. (2002) found no significant interactions between
391 calving season and other factors.
392
393 Our results are also in agreement with seasonal variations in milk and milksolids yields
394 reported by García *et al.* (1998) for pasture-based cows. They reported that autumn-calving
395 FF cows produced significantly more milksolids than spring-calving FF cows due to the effect
396 of lush pasture with higher ME in spring (spring hump) and extended lactation due to greater
397 persistency. Typically, dairy cows attain peak yields between 3-8 weeks *postpartum* (Tekerli
398 *et al.* 2000). In pasture–based, winter-calving systems, it has been reported that the peak
399 month of milk production coincides with spring when production almost doubled that of the
400 lowest months between May and July (Edward 2005). Our findings revealed that lactation
401 length was significantly longer (p<0.05) in autumn-calving, compared with spring-calving FF
402 cows (306±0.34 *v.* 269±0.16 days). On the other hand, White *et al.* (2002) reported that
403 autumn and spring-calving cows had similar milksolids yields in northern Victoria.
404 Differences in production traits during different calving season reflect seasonal variations in
405 diverse calving systems practiced all over Australia aimed at minimising feed cost by
406 matching peak nutrient requirement for lactation with the period of highest availability of ME
407 from pastures (Walker *et al.* 2004). Although most farms practice split calving system,
408 percentage calving patterns of dairy herds in Tasmania were 51% and 38% for winter and
409 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 Jersey cows produced 23.3% less milk than Holsteins.

Total milksolids yields obtained in this study was higher than the values reported for FF cows in New Zealand (García *et al.* 1998, and Lopez *et al*. 2001). Their study evaluated two strains of FF cows bred for low and high body weights, under low stocking rates (1.95-2.25 cows/ha) supplemented with 0.4-1.20 ton DM/cow concentrate. Average stocking rate in dairy farms in Australia is about 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 and Fulkerson *et al.* 2000). The daily milksolids 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

435 decline in lactation in 2003 was 1.7% in FF while it was 2.7% in FJ and JJ. Madgwick and
436 Goddard (1989) had highlighted the possibility of slower genetic progress which might make
437 Jersey cows less competitive in the future.
438
439 *Parity*
440 Milk production is known to increase with increase in parity and cow age due to higher body
441 weight, larger capacity for dry matter intake, increase in size of the udder and recurrence of
442 pregnancy and lactations (Capuco *et al.* 2001). Lower production in primiparous cows is
443 related to competition between tissues (e.g. mammary gland *v*. peripheral tissues) for
444 metabolites for growth and lactation in the immature animal (Tekerli *et al.* 2000). Similar
445 observations to our study on the effect of parity on dairy cow performance has also been
446 reported (Val-Arreola *et al.* 2004).
447
448 *Location*
449 Milk yield per cow in 2002/03 calving season obtained in this study was higher than reported
450 averages in other states of Australia, except Western Australia and South Australia.
451 Production per cow in Tasmania was lower than that of other states except Queensland in
452 2003/04 (Dairy Australia 2005). Concerns over low production per cow *vis-a-vis* increasing
453 use of grain concentrates to benefit from increasing genetic potential of dairy cows is a main
454 issue in pasture-based dairying (Chapman *et al.* 2004). In 2001, the Australian Dairy Herd
455 Improvement Scheme (ADHIS) adopted the Australian Profit Ranking (APR) method for sire
456 breeding value evaluation as a measure of improving long term productivity and profit per
457 cow. Pasture-based dairying in Tasmania is also focussing on production per hectare as a
458 measure of farm productivity rather than productivity per cow *per se* as evidence from
459 industry reports show that the link between profit and pasture utilisation is the strongest of all

performance indicators (Dairy Australia, 2004). 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, Horan *et al.* 2005, Dairy Australia 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 to the other location. Mean altitude (meters 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 43.6m in the South and king Island. (Geography of Tasmania 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 location.

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, while 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

485 management systems than small or medium herd owners (DRDC 1996). Smaller herds, on the
486 other hand can benefit from the flexibility in land and labour management to increase per unit
487 resource (Doyle and Kelly 1998).
488
489 *Heritability of milk, fat and protein yields.*
490 The relatively small size data used in this study could lead to an over-estimation of the h^2
491 estimates. It is known that the greater the sample size, the higher the precision of additive
492 genetic estimates (Jensen 2001). However, our h^2 estimates using both univariate and
493 multivariate approaches were within the range of values reported in literature which ranged
494 from 0.31, (Wilmink 1987) to 0.49 (Pander *et al.* 1992). Meyer *et al.* (1989) compared the
495 different methods of estimating h^2 and reported 305-day milk yield h^2 of 0.37. In another
496 study that compared alternative methods of equalizing heterogeneity of variance, Boldman
497 and Freeman (1990) reported lower h^2 estimates of 0.18, 0.22, and 0.24 for untransformed
498 milk yield in low, medium, and high producing herds, respectively. Heritability estimates of
499 fat and protein yields reported in this study were slightly higher than the values reported by
500 Visscher and Goddard (1995) from five states of Australia (excluding Tasmania), probably
501 partly because they used test-day sire models in their evaluation while we utilised an animal
502 model with 305-day records. However, our results were in agreement with the work of
503 Swalve (1995) who utilised test-day, herd-year-season animal model and reported 305d milk,
504 fat and protein h^2 estimates of 0.39, 0.32 and 0.30 respectively.
505
506 Comparison of h^2 estimation methods showed that test-day approaches generally yield lower
507 estimates, (Meyer *et al.* 1989, Pander *et al.* 1992) compared with 305-day method. Issues
508 from using aggregated 305-day milk yield and the benefits of test-day random regression
509 models have been extensively reviewed (Jensen 2001). The continuation of using 305-day
510 milk yield stems from industry tradition and the limitations imposed by computations

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 lactation length, 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 micro climate 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 versus grazing only to shed more light on the cost-effective benefits of pasture-based dairying.

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

See materials and methods for definition of location and SCC.

Means bearing different superscripts within the same column are statistically different (p<0.01)

Category	Milk (L)	Fat(kg)	Protein(kg)	Milksolids (kg)	Log SCC * x10^3	Milk (L/d)	Milksolids kg/d)	n
Breed								
Friesian	5212±34.2^a	210±1.3^a	171±1.1^a	380±2.4^a	133±6.4^a	18.2±0.11^a	1.33±0.008^a	82,920
Crossbred	4253±53.7^b	196±2.1^b	150±1.7^b	346±3.7^b	135±10.^{a}0	14.9±0.18^b	1.21±0.012^b	10,001
Jersey	3713±60.0^c	197±2.4^b	143±1.9^c	340±4.2^b	127±11.3^b	13.1±0.20^c	1.19±0.014^b	14,059
Parity								
1	3482±53.8^e	158±2.1^e	119±1.8^e	277±3.7^e	157±10.^{a}	12.3±0.18^e	0.98±0.129^e	26,893
2	4020±45.2^d	184±1.8^d	141±1.5^d	326±3.1^d	132±8.5^b	14.2±0.15^d	1.15±0.011^d	22,372
3	4615±48.6^c	212±1.9^c	164±1.6^c	376±3.4^c	129±9.1^c	16.2±0.17^c	1.31±0.012^c	18,154
4	4826±51.6^b	222±2.0^b	172±1.7^b	393±3.6^b	127±9.7^c	16.9±0.18^b	1.37±0.012^b	15,081
>4	5019±51.9^a	228±2.0^a	179±1.7^a	407±3.6^a	112±9.8^d	17.5±0.18^a	1.42±0.012^a	24,490
Calving Year								
2000	4058±71.9^e	184±2.8^e	140±2.4^e	325±5.0^e	121±13.5^c	14.3±0.25^d	1.41±0.017^a	6,064
2001	4299±54.5^d	196±2.1^d	150±1.8^d	346±3.8^d	115±10.2^d	15.1±0.19^c	1.21±0.013^d	9,447
2002	4406±49.3^c	200±1.9^c	153±1.6^c	353±3.4^c	125±9.2^c	15.4±0.17^c	1.23±0.012^d	13,334
2003	4305±44.9^d	198±1.8^d	153±1.5^c	352±3.1^c	137±8.4^b	15.1±0.15^c	1.23±0.011^d	18,332
2004	4577±43.4^b	209±1.7^b	164±1.4^b	373±3.0^b	135±8.1^b	16.0±0.15^b	1.31±0.010^c	25,250
2005	4710±41.2^a	216±1.6^a	169±1.4^a	385±2.9^a	156±7.7^a	16.5±0.14^a	1.34±0.009^b	34,563
Location								
FNWest	4879±25.8^a	220±1.0^a	172±0.8^a	391±1.8^a	119±4.8^c	16.9±0.09^a	1.36±0.006^a	52,771
NWest	4498±27.2^c	206±1.1^c	159±0.9^c	365±1.9^c	129±5.1^b	15.8±0.09^b	1.28±0.006^b	25,574
CntNorth	4814±31.8^b	220±1.3^a	170±1.0^b	392±2.2^a	124±60.0^b	16.7±0.11^a	1.36±0.008^c	4,931
South	4047±60.5^d	183±2.4^d	143±2.0^d	326±4.2^d	119±11.4^c	14.3±0.21^c	1.15±0.014^d	659
NEast	4786±26.8^b	213±1.1^b	168±0.9^b	382±1.9^b	119±4.8^c	16.7±0.09^a	1.33±0.006^a	26,997
KIsland	3331±178.2^e	160±7.0^e	118±5.9^e	277±12.4^e	178±33.4^a	11.9±0.61^d	0.99±0.042^e	1058
Herd Size								
Small	4485±52.4^b	196±2.0^c	155±1.7^b	350±3.6^b	142±9.8^a	15.9±0.18^b	1.23±0.013^b	1,487
Medium	4141±41.6^d	195±1.6^c	148±1.4^d	343±2.9^c	130±7.8^a	14.5±0.14^d	1.20±0.010^c	5,766
Large	4271±39.3^c	200±1.5^b	151±1.3^c	350±2.7^b	122±7.4^b	15.0±0.13^c	1.23±0.009^b	28,228
Very large	4672±39.2^a	212±1.5^a	166±1.3^a	378±2.7^a	131±7.4^a	16.4±0.13^d	1.32±0.009^a	71,509
Calving Season								
Spring	4770±34.5^a	215±1.4^a	168±1.1^a	383±2.4^a	139±6.5^b	16.6±0.12^a	1.34±0.004^c	40,185
Summer	4249±94.4^c	190±3.7^c	148±3.1^c	338±6.6^c	146±6.7^a	14.8±0.32^c	1.18±0.023^c	1,584
Autumn	4094±42.4^c	189±1.7^c	144±1.4^c	333±2.9^c	112±8.0^d	14.6±0.15^c	1.18±0.010^c	10,130
Winter	4457±33.7^b	208±1.3^b	160±1.1^b	368±2.3^b	129±6.3^c	15.6±0.12^b	1.29±0.008^b	55,091

Table 2. Least square means ~~of interactions~~ of breed, calving year and calving season for milk, fat, protein and somatic cell count of three dairy cows 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)	Milksolids (kg)	Log SCC * x10^3	Milk (L/d)	Milksolids kg/d)	n
Breed x 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
Crossbred - 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
Crossbred – 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
Crossbred - 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
Crossbred - 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
Crossbred - 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
Friesian – 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
Friesian – 2002	5197±43.2	210±1.6	168±1.4	377±2.99	124±8.11	18.1±0.15	1.31±0.010	10499
Friesian – 2003	5109±39.2	206±1.5	169±1.3	374±2.72	133±7.3	17.9±0.13	1.30±0.009	13929
Friesian - 2004	5397±37.7	218±1.4	181±1.2	398±2.62	136±7.07	18.8±0.13	1.39±0.009	19296
Friesian - 2005	5619±35.2	226±1.3	188±1.1	413±2.45	155±6.6	19.5±0.12	1.44±0.008	26968
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
Jersey – 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
Jersey – 2002	3742±71.	197±2.8	142±2.4	340±4.96	117±13.4	13.2±0.24	1.19±0.017	1662
Jersey – 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
Jersey – 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
Jersey – 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 x 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
Crossbred - 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
Crossbred – 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
Crossbred - 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
Friesian - Spring	5310±59.1	216±1.4	175±1.1	389±2.31	143±6.3	18.6±0.11	1.36±0.008	32145
Friesian – 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
Friesian - Winter	5074±33.4	208±1.3	169±1.1	377±2.31	140±6.3	17.7±0.11	1.32±0.008	40680
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
Jersey - 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
Jersey – 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
Jersey - 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

Table 3. Descriptive statistics of 305d milk, fat, protein and 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.
[#]Parity >2 were pooled and labelled as parity 3

Category	Milk (L)				Fat (kg)				Protein (kg)				Log of SCC[*]				
Parity1[#]	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	n
1	4859	1440	1209	12997	196.6	52.88	18	509	161.6	48.65	22	469	3.83	0.976	0	8.23	18767
2	5520	1647	1247	13550	223.6	60.35	25	480	186.1	55.57	38	450	3.90	1.061	0	8.53	15677
3	6171	1746	1207	15141	250.6	66.12	27	544	207.9	57.93	16	487	4.29	1.163	0	8.94	31470
Calving Season																	
Winter	5648	1613	1207	14924	231.6	62.22	18	544	190.7	54.59	16	487	4.05	1.089	0	8.94	32998
Spring	5463	1825	1210	14946	219.1	66.37	25	517	182.3	60.62	34	468	4.12	1.134	0	8.53	24600
Summer	5542	1931	1296	12944	218.1	73.53	43	460	179.7	61.9	39	414	3.89	1.535	0	7.28	1230
Autumn	6262	1762	1230	15141	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	14946	197.5	55.03	29	495	157.5	44.93	22	468	3.83	1.235	0	8.47	4385
2001	5436	1486	1474	14199	218.1	55.90	52	472	178.8	47.81	49	456	3.83	1.111	0	7.60	6639
2002	5251	1557	1247	13112	212.6	60.81	40	507	172.9	51.27	34	432	4.08	1.014	0	7.82	9024
2003	5510	1608	1230	13861	222.5	60.86	18	517	185	53.01	40	438	4.01	1.079	0	8.15	11677
2004	5816	1699	1317	14360	236.4	63.45	27	509	197.6	56.83	26	471	4.09	1.120	0	8.39	14774
2005	6024	1929	1207	15141	245.1	71.05	31	544	204.8	65.06	16	487	4.21	1.109	0.69	8.94	19415
Location[‡]																	
FNWest	5779	1684	1209	14924	234.6	63.73	18	544	194.9	57.44	40	487	4.02	1.068	0	8.53	17152
Nwest	5897	1945	1230	15141	234.9	68.15	44	509	196.9	62.42	41	469	3.97	1.231	0	8.35	14949
CntNorth	5749	1640	1229	13929	237.0	66.52	29	514	194.3	57.19	22	435	4.13	1.082	0	8.66	12376
South	5231	1298	1273	10024	209.2	55.3	46	380	174.7	43.1	44	328	4.39	0.926	2.08	8.07	1108
Neast	5365	1631	1207	14946	216.9	62.16	27	517	179.9	55.45	16	468	4.12	1.071	0.69	8.94	18596
KIsland	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

Table 4. Heritability, phenotypic and genetic correlations (±se) of milk, fat, protein and somatic cell count of Holstein-Friesian cows

Heritability shown in bold (diagonal), phenotypic correlation and genetic correlation on upper and lower triangles respectively.
SCC=Somatic cell count

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

Appendix 1: Dairy farm facts in Tasmania

Parameter/Year	99/00	00/01	01/02	02/03	03/04	04/05	05/06
Milk production, million litres	609	590	671	585	590	600	622
Registered Dairy farms, nos	734	638	612	597	543	507	498p
Dairy cow numbers, '000	139	148	134	142	138	135	135
Employment; owners and staff, nos	1,890	NA	NA	1,700	NA	NA	NA
Gross value of production, $M	133	148	220	151	160	180p	NA
Average herd size, cows	194	231	236	213	245	271	270
Milk per cow, litres	4,381	4,177	4,646	4,304	4,219	4,497	4542
Milk per farm, '000 litres	830	925	1,116	980	1,089	1,183	NA
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

Adapted from: DPWI 2005, Dairy Australia 2006 p=predicted, NA=Not available