Genetic relationships between length of productive life and lifetime production efficiency in a commercial swine herd in Northern Thailand

Udomsak NOPPIBOOL[1], Mauricio A. ELZO[2], Skorn KOONAWOOTRITTRIRON[1, *] and Thanathip SUWANASOPEE[1]

1 Department of Animal Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand
2 Department of Animal Sciences, University of Florida, Gainesville, FL 32611-0910, USA

*Correspondence: Skorn Koonawootrittriron, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand. (Email: agrskk@ku.ac.th, Tel: +66-2-5791120; Fax: +66-2-5791120)

Short Title: PRODUCTIVE LIFE AND EFFICIENCY IN THAI SWINE.

ABSTRACT

Genetic parameters and trends for length of productive life (LPL), lifetime number of piglets born alive per year (LBAY), lifetime number of piglets weaned per year (LPWY), lifetime litter birth weight per year (LBWY), and lifetime litter weaning weight per year (LWWY) were estimated using phenotypic records of 3,085 sows collected from 1989 to 2013 in a commercial swine farm in Northern Thailand. The 5-trait animal model included the fixed effects of first farrowing year-season, breed group, and age at first farrowing. Random effects were animal and residual. Heritability estimates ranged from 0.04 ± 0.02 for LBWY to 0.17 ± 0.04 for LPL. Genetic correlations ranged from 0.66 ± 0.14 between LPL and LBAY to 0.95 ± 0.02 between LPWY and LWWY. Spearman rank correlations among EBV for LPL and lifetime production efficiency traits tended to be higher for boars than for sows. Sire genetic trends were negative and significant for all traits, except for LPWY. Dam genetic trends were positive and significant for all traits. Sow genetic trends were mostly positive and significant only for LPWY and LBWY. Improvement of LPL and lifetime production efficiency traits will require these traits to be included in the selection indexes used to choose replacement boars and gilts in this population.

Key Words: Swine, genetic parameters, genetic trend, length of productive life, lifetime production.

INTRODUCTION

Length of productive life (LPL) is important for the efficiency of commercial pig production systems. Commercial swine operations with higher LPL sows require lower number of replacement gilts than commercial operations with lower LPL sows. Lower replacement rates would decrease costs of production, reduce the risk of disease transfer from gilts to sows, and increase the margins of profitability (Engblom *et al*. 2009; Hoge & Bates 2011; Segura-Correa *et al*. 2011). Efficient sows with high lifetime productivity levels per year have a greater opportunity to remain longer in the herd than sows with lower yearly productivity. Thus, both LPL and lifetime production efficiency are essential for the survival of commercial swine operations (Koketsu 2007). Unfortunately, direct selection for lifetime traits cannot be done because these traits can only be measured after sows have been removed or died (Serenius & Stalder 2004, 2006; Le *et al*. 2014). Consequently, swine producers would need to use information on LPL and lifetime production efficiency traits from relatives to select replacement boars and gilts to both genetically improve their herds for these traits and increase overall income of commercial swine producers.

Heritabilities for LPL in temperate countries (0.05 ± 0.01 for Landrace and 0.10 ± 0.02 for Yorkshire in Finland, Serenius & Stalder 2004; 0.10 ± 0.01 for Landrace and Yorkshire in Poland, Sobczyńska *et al*. 2013; and 0.22 ± 0.04 for Landrace in Finland, Serenius *et al*. 2008) indicated that selection for LPL was feasible. Only a single study in Thailand estimated combined Landrace-Yorkshire heritabilities for LPL in two commercial farms (0.03 in one farm and 0.04 in a second farm; Keonouchanh 2002). Heritabilities for lifetime number of piglets weaned per year (LPWY) were available only in temperate countries (0.11 ± 0.02 in Landrace and Yorkshire, Sobczyńska *et al*. 2013; Poland; 0.23 in commercial swine, Sujipittham 2007; USA). Positive estimates of genetic correlations between LPL and LPWY of 0.8 ± 0.1 for Landrace and 0.7 ± 0.1 for Yorkshire in Poland (Sobczyńska *et al*. 2013) indicated that increasing LPL would also increase LPWY. No studies on the relationship between LPL and lifetime production efficiency traits existed in Thailand. To develop genetic improvement programs for these traits in Thailand, genetic parameters need to be obtained. Thus, the objectives of this research were: 1) to estimate genetic parameters for LPL, lifetime number of piglets born alive per year (LBAY), lifetime number of piglets weaned per year (LPWY), lifetime litter birth weight per year (LBWY), and lifetime litter weaning weight per year (LWWY), and 2) to estimate genetic trends for LPL, LBAY, LPWY, LBWY and LWWY in an open-house commercial swine population in Northern Thailand.

MATERIALS AND METHODS

Data, animals and traits

The data for this research were collected in a commercial swine farm from Northern Thailand. The original dataset of 3,541 sows (2,646 L and 895 Y) was edited for missing, erroneous and incomplete information. Only sows that had at least one lifetime production efficiency trait and known date of first farrowing and date of last weaning (i.e., sows with complete lifetime production information) were included in the final dataset. Sows with incomplete lifetime production records (i.e., sows still producing in the herd) or with missing records were eliminated from the dataset. Lastly, gilts younger than 300 d or older than 500 d of age at first farrowing were excluded from the analyses. After the editing process, the final dataset consisted of 3,085 records from 2,259 Landrace and 826 Yorkshire with complete lifetime records whose first farrowing occurred between July 1989 and August 2013. These 3,085 sows were the offspring of 615 sires and 1,336 dams. Sow records included her identification number, sire, dam, breed (Landrace and Yorkshire), birth date, parity number (1 to 10), and the farrowing date, number of piglets born alive, number of piglets weaned, litter weight at birth, and litter weight at weaning for each parity.

Traits included in the analyses were LPL, LBAY, LPWY, LBWY and LWWY. The LPL was defined as the number of days between age of sow at first farrowing and age of sow at weaning of her last litter. The LBAY was calculated as the number of piglets born alive during the lifetime of a sow divided by LPL and multiplied by 365 d. The LPWY was calculated as the number of piglets weaned during the lifetime of a sow divided by LPL and multiplied by 365 d. The LBWY was calculated as the sum of the birth weights of all piglets born during the lifetime of a sow divided by LPL and multiplied by 365 d, and LWWY was calculated as the sum of the weaning weights of all piglets weaned during the lifetime of a sow divided by LPL and multiplied by 365 d. Numbers of observations, means, and standard deviations for LPL, LBAY, LPWY, LBWY and LWWY (Table 1) were computed using the MEAN procedure of SAS (SAS 2004).

Climate, nutrition and management

The swine population was located in Chiang Mai, Northern Thailand (latitude 18° 47′ 43″ North; longitude 98° 59′ 55″ East) at an elevation 310 m above sea level. The average temperature in this area over the last thirteen years was 27°C (average minimum = 17°C; average maximum = 34.5°C), the average humidity was 73.2% (average minimum = 37%; average maximum = 99%), and the average rainfall was 1,218 mm (average minimum = 880 mm; average maximum = 1,457 mm; Thai Meteorological Department 2014). Seasons were defined as winter (November to February), summer (March to June) and rainy (July to October). All females were kept in an open-house system, whereas males were raised in an evaporative cooling system. Gilts and sows that had their first litter in the same year-season received similar feeding and management. Concentrate feeds were produced at the farm. Diet composition and amount provided to sows differed depending on their age and stage of production. Gilts and non-lactating sows received 2.5 kg/d of feed with 16% crude protein and 3,200 to 3,500 kcal/kg (two feeding times; 07.00 and 13.00 hours), whereas nursing sows received 5 to 6 kg/d of feed with 17 to 18% crude protein and 4,060 kcal/kg (four feeding times; 07.00, 10.00, 13.00 and 15.00 hours).

Gilts and sows were bred only by artificial insemination. Estrus was detected twice a day (morning and afternoon). Visual appraisal (reddening and swelling of the vulva) and boar exposure were the method of estrus detection. Boars produced within farm were chosen based on availability and on their within-farm EBV for litter size and litter weight at birth and at weaning, whereas imported boars were chosen based on their catalog EBV or suggestions from representatives of pig genetic companies. Replacement gilts were inseminated when they reached at least 140 kg of body weight, or they were 8 to 9 mo age, or they had their third observed estrus. Sows were bred twice after their second observed estrus: 12 h after detecting estrus and 12 h later. Gilts and sows were kept in individual stalls within open-house buildings with dripping, fogging, and fans placed in the farrowing unit approximately 7 d before farrowing. After weaning, sows were moved to the mating building. Piglets were weaned when they reached 5 to 7 kg of body weight or 26 to 30 d of age.

Genetic parameters

A 5-trait mixed animal model that included contemporary group (first farrowing year-season), breed group (Landrace and Yorkshire) and age at first farrowing as fixed effects and animal and residual as random effects was used to compute estimated breeding values (EBV) and estimates of variance and covariance components. Contemporary groups were defined as groups of animals belonging to first farrowing year-season subclasses because although variable numbers of parities existed per sow, all sows had first-parity records. Variance and covariance components were obtained with restricted maximum likelihood procedures (REML), which were computed using an average information algorithm (ASREML; Gilmour *et al*. 2000). The 5-trait mixed animal model in matrix notation was as follows:

$$y = Xb + Z_a Q_a g_a + Z_a g_a + e$$

where y is the vector of sow records for all traits (LPL, LBAY, LPWY, LBWY and LWWY), b is the vector of contemporary group (first farrowing year-season) effects and a covariate for age at first farrowing (mo), g_a is the vector of fixed additive genetic breed group effects (Landrace and Yorkshire), a_a is the vector of random animal additive genetic effects deviated from their breed group, X is an incidence matrix relating sow records to fixed effects in vector b, Z_a is an incidence matrix relating sow records to random animal additive genetic effects in vector a_a, Q_a is an incidence matrix relating elements of vector a_a to additive genetic breed groups in vector g_a and e is the vector of residual random effects. Animal additive genetic effects in this model refer to sow additive genetic effects that contain additive direct and maternal genetic effects. This model accounted for the additive genetic value of boars mated to sows by including them in the vector of random animal additive genetic effects. The assumptions of the 5-trait mixed animal model were:

$$\begin{bmatrix} \mathrm{y} \\ \mathrm{a_a} \\ \mathrm{e} \end{bmatrix} \sim \mathrm{MVN}\left(\begin{bmatrix} \mathrm{Xb + Z_a Q_a g_a} \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \mathrm{Z_a G_a Z'_a + R} & \mathrm{Z_a G_a} & \mathrm{R} \\ \mathrm{G_a Z'_a} & \mathrm{G_a} & 0 \\ \mathrm{R} & 0 & \mathrm{R} \end{bmatrix} \right)$$

where $\mathrm{G_a = G_0 \otimes A}$, $\mathrm{G_0}$ is a 5×5 matrix of additive genetic covariances among LPL, LBAY, LPWY, LBWY and LWWY assumed to be the same for all Landrace and Yorkshire animals, A is the numerator relationships matrix, ⊗ denotes direct product, and $\mathrm{R = R_0 \otimes I}$, where $\mathrm{R_0}$ is a 5×5 matrix of residual covariances among LPL, LBAY, LPWY, LBWY and LWWY assumed to be the same for all Landrace and Yorkshire animals, and I is an identity matrix. The pedigree file contained information of 5,525 animals, 690 sires, and 1,512 dams. The pedigree file included 427 boars used as mates during the years of the study. Estimates of variance components were used to calculate heritabilities, genetic correlations, and phenotypic correlations among the five traits. Because animal additive genetic effects in the 5-trait mixed animal model include additive direct and maternal genetic effects, heritabilities and genetic correlation estimates contain additive genetic direct and maternal variances and covariances among animals for LPL, LBAY, LPWY, LBWY and LWWY in the population.

Additive genetic predictions and genetic trends

Animal EBV were computed as the sum of their additive genetic group effect plus their random additive animal genetic effect. Only differences between additive genetic breed group effects (Landrace and Yorkshire) were estimable, thus animal EBV were deviated from Landrace. The EBV for all animals in the population were computed using the 5-trait animal model described above using estimates of variance components obtained at convergence.

Spearman rank correlations between EBV for LPL and lifetime production efficiency traits (LBAY, LPWY, LBWY and LWWY) for all animals, boars only, and sows only were estimated using the correlation procedure of SAS (SAS 2004). Spearman rank correlations between EBV for LPL and lifetime production efficiency traits were also computed separately for groups of boars and sows in the top 5%, 25%, and 50% for *any of the five traits* to assess changes in rank correlations between pairs of traits at each replacement rate.

Weighted yearly EBV means for LPL, LBAY, LPWY, LBWY and LWWY were computed for sows, sires and dams, and then they were plotted against first-farrowing year (FFY) to visualize changes in mean EBV during the years of the study. Regression coefficients of mean EBV for LPL, LBAY, LPWY, LBWY and LWWY on FFY were estimated for sows, sires, and dams using the regression procedure of the SAS program (SAS 2004).

RESULTS AND DISCUSSION

Fixed effects

The first farrowing year-season effect was important for all traits ($P < 0.001$). Estimates ranged from -358.00 ± 164.90 d (2013-rainy; $P = 0.030$) to 554.00 ± 130.80 d (1993-rainy; $P < 0.001$) for LPL, 1.23 ± 2.05 piglets (1992-summer; $P = 0.549$) to 12.15 ± 1.89 piglets (2013-winter; $P < 0.001$) for LBAY, 0.07 ± 1.81 piglets (1992-summer; $P = 0.968$) to 11.20 ± 1.69 piglets (2002-rainy; $P < 0.001$) for LPWY, -8.07 ± 3.78 kg (2002-rainy; $P = 0.033$) to 27.52 ± 3.02 kg (2013-winter; $P < 0.001$) for LBWY and -43.26 ± 16.05 kg (2002-rainy; $P = 0.007$) to 102.60 ± 12.47 kg (2009-rainy; $P < 0.001$) for LWWY. The first farrowing year-season LSM for LPL and lifetime production efficiency traits (LBAY, LPWY, LBWY and LWWY) tended to increase from 1989 to 2013. The upward trends of first farrowing year-season LSM for lifetime production efficiency traits may have been a reflection of a decrease in the quality of feed and management and (or) increasingly negative temperature and humidity effects over the years of the study. Notice that sows belonging to a given first farrowing year-season contemporary group may have farrowed in different seasons across parities. Thus, contemporary group estimates and trends included effects from all year-seasons sows were exposed to throughout their life.

Regression coefficient estimates of LPL, LBAY, LPWY, LBWY and LWWY on age at first farrowing were mostly negative or close to zero and non-significant. These regression estimates indicated LPL and lifetime production efficiency traits were not closely associated with age at first farrowing in this swine population. Sows that had their first farrowing at younger ages had similar LPL and lifetime production efficiency to sows that farrowed at older ages. These results differed from reports from other populations (Le Cozler *et al*. 1998; Saito *et al.* 2011; Sobczyńska *et al.* 2013). In Mexico, gilts that had their first farrowing before 337 d of age had higher LBAY, LPWY, LBWY and LWWY than gilts that had their first farrowing after 347 d of age (Ek-Mex *et al.* 2014). Additionally, Saito *et al.* (2011) found that gilts first mating at 188 to 229 d of age (302 to 343 d of age at first farrowing) had a higher annualized number of lifetime pigs born alive than gilts mated at 230 to 365 d of age (older than 343 d of age at first farrowing).

Yorkshire sows had longer LPL than Landrace sows (46.86 ± 24.66 d; $P = 0.046$), but similar values for both breeds were found for lifetime production efficiency traits (LBAY, LPWY, LBWY and LWWY). This indicated that similar selection criteria for replacement sows were applied regardless of breed of sow in this population. The means for LBAY (15 ± 1.68 piglets), LPWY (14 ± 1.49 piglets) and LWWY (88 ± 11.73 kg) were lower than those reported by Segura-Correa *et al.* (2014) who obtained a mean of 20 piglets for LBAY, 17 piglets for LPWY, and 101 kg for LWWY in Yorkshire sows. Ek-Mex *et al.* (2014) reported a LBAY of 23 piglets, 22 piglets for LPWY, 34 kg for LBWY and 125 kg for LWWY in four commercial farms in Mexico. The LPL for Landrace (526 d) and Yorkshire sows (573 d) in this population were lower than in other swine populations in Thailand (806 to 875 d for Landrace and 817 to 884 d for Y; Keonouchanh 2002) and Mexico (763 d for Y; Segura-Correa *et al.* 2014). Conversely, Landrace and Yorkshire LPL here were within the range of values reported in Europe and the US (489 to 652 d for Yorkshire and 493 to 617 d for Landrace; Yazdi *et al.* 2000, Sweden; Serenius *et al.* 2008, Finland; Hoge & Bates 2011, USA; Sobczyńska *et al.* 2013, Poland). The lack of differences between Landrace and Yorkshire sows for lifetime production efficiency traits found here may have occurred either because sows from these two breeds had similar genetic potential or because environmental conditions were insufficient for genetic differences between them to be expressed.

Heritability estimates

Estimates of variance components (additive genetic, environmental and phenotypic variances) for LPL, LBAY, LPWY, LBWY and LWWY in this commercial population are presented in Table 2. Additive genetic, environmental, and phenotypic variances were assumed to be homogeneous for all Landrace and Yorkshire animals in the population. As mentioned above, animal additive genetic effects in the 5-trait animal model used here contain additive direct and maternal genetic effects. Thus, estimates of additive genetic variance components, heritabilities and genetic correlations include additive genetic direct and maternal variances and covariances. Heritability estimates and their standard error for all traits are presented on the diagonal of Table 3. Values of heritability for LPL, LBAY, LPWY, LBWY and LWWY ranged from low to moderate and had low standard errors, explaining 17%, 7%, 13%, 4% and 13% of phenotypic variances, respectively. The heritability estimate for LPL in this swine population was higher than values from two swine herds in Thailand (h^2 = 0.03 and 0.04; Keonouchanh 2002), but within the range of values reported from swine populations in temperate countries (h^2 = 0.05 to 0.22; Serenius & Stalder 2004; Serenius *et al.* 2008; Nikkilä *et al.* 2013; Sobczyńska *et al.* 2013). Literature values of heritability for lifetime production efficiency traits were nearly nonexistent. Research in Poland by Sobczyńska *et al.* (2013) reported values of heritability for number of piglets weaned per year for Landrace (0.13 ± 0.02) and Yorkshire (0.11 ± 0.02) similar to the value of 0.13 ± 0.03 obtained here.

Estimates of heritability for LPL and lifetime production efficiency traits here suggested that they could be incorporated into a selection program in this population. Improving LPL along with production efficiency traits would be expected to positively impact the productivity of individual sows as well as the overall production efficiency of this swine operation. However, these traits will only be useful to select future replacement boars and gilts because they are measured at the end of their productive life. Thus, replacement gilts and boars should be chosen using LPL and lifetime production efficiency information from older relatives as well as birth and weaning litter size and litter weight information from younger sows.

Genetic and phenotypic correlations

Estimates of phenotypic and genetic correlations between LPL and lifetime production efficiency traits are presented in Table 3. Phenotypic correlations between LPL and lifetime production efficiency traits were positive and moderate (0.53 ± 0.01 to 0.95 ± 0.00). Genetic correlations between these traits were positive and high (0.66 ± 0.14 to 0.95 ± 0.02), and in agreement with estimates (0.76 to 0.84) reported by Sobczyńska *et al.* (2013). These favorable genetic correlations between lifetime production efficiency traits and LPL indicated that sows with higher additive genetic values for lifetime production efficiency traits (LBAY, LPWY, LBWY, and LWWY) tended to remain longer in the herd. Sows that have higher annual lifetime productivity are likely to be more fertile, have more piglets alive at birth and heavier litters at weaning over their lifetime, thus increasing the profitability of the business (Koketsu 2007; Sasaki & Koketsu 2008). This is because sows that remain longer in the herd and have high productivity levels will also likely be more robust than sows that have shorter herd lives (Tummaruk *et al.* 2001). Stalder *et al.* (2000) indicated that sows needed to remain in the herd for at least 3 parities to produce enough piglets to offset the costs of replacement gilts. Thus, the high and positive genetic correlations among lifetime production efficiency traits here indicated that selection for any of these traits would positively impact the others, thus increasing the overall sow LPL, decreasing replacement costs, and increasing the profitability of this swine operation. Considering the values of genetic correlations among traits and the higher heritability values for LPL, LPWY, and LWWY, the selection program could primarily target these traits. Further, provided funding were available, animals in this population could be genotyped using high-density genotyping chips (e.g., Illumina PorcineSNP60 genotyping chip). Genetic evaluations using phenotypes, pedigree, and genotypes (Aguilar *et al.* 2010) would increase the accuracy of genetic predictions for all animals in the population, particularly for boars and sows without LPL and lifetime production efficiency records.

Rank correlations

Spearman rank correlations between EBV for LPL and lifetime production efficiency traits for all animals, for boars only, and for sows only are presented in Table 4. Spearman correlation coefficients between LPL and LPWY, LBWY, and LWWY were higher (0.83 to 0.93) than correlations between LPL and LBAY (0.62 to 0.67). Thus, selection of animals for LPL will be more closely associated with changes in litter weight at birth and at weaning per year as well as with number of piglets at weaning per year than with changes in numbers of piglets at birth.

Spearman rank correlations for groups of boars in the top 5%, 25%, and 50% for any of the five traits are shown in Table 5. Rank correlations among LPL and lifetime production efficiency traits tended to be higher for boars than for sows across all replacement percentages (top 5%, 25%, and 50%). Similarly, rank correlations tended to be higher for the top 50% than the top 25% and the top 5% tended to have the lowest values. This indicated that the lower the percent replacement for a particular sex, the higher the likelihood of choosing animals with high EBV for one trait but low EBV for other traits among those in the chosen replacement rate. This will affect boars more than sows because substantially fewer boars than sow will be needed in this population. The estimated replacement rate in this population was 14% for boars and 40% for gilts during the years of the study. Research studies in various countries indicated that the top 10% of boars and 50% of gilts should be used as replacements in commercial populations in Canada (Lucia *et al.* 2000; Robinson & Buhr 2005), Switzerland, (Tarrés *et al.* 2006), Sweeden (Engblom *et al.* 2007), Thailand (Imboonta *et al.* 2007), and the US (Lucia *et al.* 2000; Rodriguez-Zas *et al.* 2003; Newcom *et al.* 2005). Appropriate replacement rates for boars and gilts in the population used in this study will depend on production and economic goals. This will require additional research that compares alternative replacement rate scenarios given target indexes that incorporate production and economic goals.

Genetic trends

Figures 1 to 5 show the trends for mean yearly EBV of sows, their sires and their dams for LPL, LBAY, LPWY, LBWY and LWWY from 1989 to 2013. Genetic trends for sires were negative and significant for LPL (-2.41 d/yr; *P* = 0.001), LBAY (-0.01 piglets/yr; *P* = 0.040), LBWY (-0.02 kg/yr; *P* = 0.035) and LWWY (-0.14 kg/yr; *P* = 0.040; Table 6). Conversely, genetic trends for dams were positive and significant for LPL (1.10 d/yr; $P = 0.010$), LBAY (0.03 piglets/yr; $P < 0.001$), LPWY (0.12 piglets/yr; $P < 0.001$), LBWY (0.04 kg/yr; $P < 0.001$), and LWWY (0.26 kg/yr; $P < 0.001$; Table 6). Sow genetic trends were mostly positive and significant only for LPWY (0.02 piglets/yr; $P = 0.015$) and LBWY (0.01 kg/yr; $P = 0.016$; Table 6). Dam EBV yearly means tended to increase for LPL and lifetime production efficiency traits from 1989 to 2013. Conversely, sire EBV yearly means tended to decrease for LPL and lifetime production efficiency traits from 1989 until 2013. Sow EBV yearly means for LPL and lifetime production efficiency traits had intermediate values between dam and sire EBV yearly means, and they also tended to increase from 1989 to 2013. The LPL yearly EBV means tended to decrease between 1989 and 2006, but to increase after 2006 until 2013. The yearly mean EBV for LBAY, LPWY, LBWY and LWWY tended to decrease from 1989 to 1997 and subsequently tended to increase until 2013.

The yearly sire EBV means were mostly higher from 1989 to 1993 and mostly lower from 1993 to 2013 than those of dams and sows for all traits. Although the magnitude of the differences between sire and dam yearly EBV means was small between 1989 and 2001, but substantially larger from 2001 to 2013. This suggested a drastic change in boar and gilts replacement selection strategies in this herd. Unlike sows, sires appeared to have been chosen based on information from traits with low association with LPL and lifetime production efficiency traits. Precise information on the sire selection strategy used in this population was unavailable. Most Thai swine producers utilize information on growth performance, semen quality and pedigree, in addition to production traits (number of piglets and weight at birth and at weaning) when selecting sires and sows. Thus, if young sires were preferentially chosen based on own post-weaning growth performance between 2001 and 2013, perhaps a larger number of sires with low EBV for LPL and lifetime production efficiency traits than sires with high EBV for these traits was chosen during these years. To improve LPL and lifetime production efficiency traits, these traits would need to be included in the selection indexes used to choose replacement boars and gilts in this population. This would help identify replacement animals that are expected to be both productive and profitable.

CONCLUSIONS

This research showed that LPL and lifetime production efficiency traits (LBAY, LPWY, LBWY, and LWWY) in a commercial swine operation in Thailand were heritable, thus suitable to be included in a genetic improvement program. LPL and lifetime production efficiency data from relatives could be used to compute preliminary EBV used for preselection of replacement boars and gilts. Rank correlations between LPL and LPWY, LBWY and LWWY were higher than between LPL and LBAY. Rank correlations among LPL and lifetime production efficiency traits tended to be higher for boars than for sows in the top 5%, 25% and 50% for any of the five traits. Sire genetic trends were negative while dam genetic trends were positive for all traits indicating that the selection procedures for sires would need to be improved in this commercial swine population.

ACKNOWLEDGMENTS

The authors are thankful for the financial support from the Royal Golden Jubilee project (RGJ) of the Thailand Research Fund (TRF), the University of Florida for supporting the training of the first author as a research scholar, and the Four T Co., Ltd for providing the phenotypic information for this research.

REFFERENCES

Aguilar I, Misztal I, Johnson DL, Legarra A, Tsuruta S, Lawlor TJ. 2010. Hot topic: A unified approach to utilize phenotypic, full pedigree, and genomic information for genetic evaluation of Holstein final score. *Journal of Animal Science* **93**, 743-752.

Ek-Mex JE, Segura-Correa JC, Alzina-López A, Batista-Garcia L. 2014. Lifetime and per year productivity of sows in four pig farms in the tropics of Mexico. *Tropical Animal Health and Production* **47**, 503-509.

Engblom L, Lundeheim N, Dalin AM, Andersson K. 2007. Sow removal in Swedish commercial herds. *Livestock Science* **106**, 76-86.

Engblom L, Lundeheim N, Schneider MDP, Dalin AM, Andersson K. 2009. Genetics of crossbred sow longevity. *Animal* **3**, 783-790.

Gilmour AR, Cullis BR, Welham SJ, Thompson R. 2000. ASREML Reference Manual. *NSW Agriculture*, USA.

Hoge MD, Bates RO. 2011. Developmental factors that influence sow longevity. *Journal of Animal Science* **89**, 1238-1245.

Imboonta N, Rydhmer L, Tumwasorn S. 2007. Genetic parameters for reproduction and production traits of Landrace sows in Thailand. *Journal of Animal Science* **85**, 53-59.

Keonouchanh S. 2002. Genetic analysis of sows longevity and lifetime productivity in two purebred swine herds. [M.Sc. Thesis], Chulalongkorn University, Bangkok, Thailand.

Koketsu Y. 2007. Longevity and efficiency associated with age structures of female pigs and herd management in commercial breeding herds. *Journal of Animal Science* **85**, 1086-1091.

Le Cozler Y, Dargon J, Lindberg JE, Aumaître A, Dourmand JY. 1998. Effect of age at first farrowing and herd management on long-term productivity of sow. *Livestock Production Science* **53**, 135-142.

Le HT, Nilsson K, Norberg E, Lundeheim N. 2014. Genetic association between leg conformation in young pigs and longevity of Yorkshire sows. In: *Proceedings of 10th World Congress on Genetics Applied to Livestock Production (WCGALP)*; 17-22 August 2014, Vancouver, Canada.

Lucia T, Dial GD, Marsh WE. 2000. Lifetime reproductive performance in female pigs having distinct reasons for removal. *Livestock Production Science* **63**, 213-222.

Newcom DW, Baas TJ, Stalder KJ, Schwab CR. 2005. Comparison of three models to estimate breeding values for percentage of loin intramuscular fat in Duroc swine. *Journal of Animal Science* **83**, 750-756.

Nikkilä MT, Stalder KJ, Mote BE, Rothschild MF, Gunsett FC, Johnson AK, Karriker LA, Boggess MV, Serenius TV. 2013. Genetic associations for gilt growth, compositional, and structural soundness traits with sow longevity and lifetime reproductive performance. *Journal of Animal Science* **91**, 1570-1579.

Robinson JAB, Buhr MM. 2005. Impact of genetic selection on management of boar replacement. *Theriogenology* **63**, 668-678.

Rodriguez-Zas SL, Southey BR, Knox RV, Connor JF, Lowe JF, Roskamp BJ. 2003. Bioeconomic evaluation of sow longevity and profitability. *Journal of Animal Science* **81**, 2915-2922.

Saito H, Sasaki Y, Koketsu Y. 2011. Associations between age of gilts at first mating and lifetime performance or culling risk in commercial herds. *Journal of Veterinary Medical Science* **73**, 555-559.

SAS. 2004. SAS OnlineDoc, Version 9.0. SAS Institute Inc., Cary, NC, USA.

Sasaki Y, Koketsu Y. 2008. Sows having high lifetime efficiency and high longevity associated with herd productivity in commercial herds. *Livestock Science* **118**, 140-146.

Segura-Correa JC, Ek-Mex EJ, Alzina-López A, Magaña-Monforte JG, Sarmiento-Frandco L, Santos-Ricalde RH. 2011. Length of productive life of sows in four pig farms in the tropics of Mexico. *Tropical Animal Health and Production* **43**, 1191-1194.

Segura-Correa JC, Herrera-Camacho J, Pérez-Sánchez RE, Gutiérrez-Vázquez E. 2014. Environmental and breed factors associated with lifetime and per year productivity of sows in a commercial farm in Michoacan, Mexico. *Scientific Papers Animal Science and Biotechnologies* **47**, 245-248.

Serenius T, Stalder KJ. 2004. Genetics of length of productive life and lifetime prolificacy in the Finnish Landrace and Large White pig populations. *Journal of Animal Science* **82**, 3111-3117.

Serenius T, Stalder KJ. 2006. Selection for sow longevity. *Journal of Animal Science* **84**, E166-E171.

Serenius T, Stalder KJ, Fernando RL. 2008. Genetic associations of sow longevity with age at first farrowing, number of piglets weaned, and wean to insemination interval in the Finnish Landrace swine population. *Journal of Animal Science* **86**, 3324-3329.

Sobczyńska M, Blicharski T, Tyra M. 2013. Relationships between longevity, lifetime productivity, carcass traits and conformation in Polish maternal pig breeds. *Journal Animal Breeding and Genetics* **130**, 361-371.

Stalder KJ, Lacy RC, Cross TL, Conaster GE, Darroch CS. 2000. Net present value analysis of sow longevity and the economic sensitivity of net present value to changes in production, market price, feed cost, and replacement gilts costs in a farrow-to-finish operation. *The Professional Animal Scientist* **16**, 33-40.

Sujipittham N. 2007. Estimation of (co)variance components and genetic parameters for litters per sow per year and pigs weaned per sow per year. [M.Sc. Thesis], Iowa State University, Ames, Iowa, USA.

Tarrés J, Bidanel JP, Hofer A, Ducrocq V. 2006. Analysis of longevity and exterior traits on Large White sows in Switzerland. *Journal of Animal Science* **84**, 2914-2924.

Thai Meteorological Department. 2014. Weather report for 2002 to 2014, Weather Station Number 327501, Chiang Mai, Thailand.

Tummaruk P, Lundeheim N, Einarsson S, Dalin AM. 2001. Reproductive performance of purebred Hampshire sows in Sweden. *Livestock Production Science* **68**, 67-77.

Yazdi MH, Rydhmer L, Ringmar-Cederberg E, Lundeheim N, Johansson K. 2000. Genetic study of longevity in Swedish Landrace sows. *Livestock Production Science* **63**, 255-264.

Table 1 Number of observations, phenotypic mean and standard deviation (SD) for length of productive life (LPL), lifetime number of piglets born alive per year (LBAY), lifetime number of piglets weaned per year (LPWY), lifetime litter birth weight per year (LBWY) and lifetime litter weaning weight per year (LWWY)

Traits	Number of records	Mean	SD
LPL	3,085	686.35	426.11
LBAY	3,077	24.39	8.18
LPWY	3,053	21.24	7.01
LBWY	3,055	38.79	14.24
LWWY	3,033	154.55	58.91

Table 2 Estimates of variance components for length of productive life and lifetime production efficiency traits

Traits†	Variance components‡		
	σ_a^2	σ_e^2	σ_p^2
LPL (d^2)	28,706.50 ± 6,379.22	137,451.00 ± 6,183.13	166,200.00 ± 4,466.00
LBAY ($piglets^2$)	4.48 ± 1.72	58.68 ± 2.13	63.16 ± 1.65
LBWY (kg^2)	7.41 ± 3.94	159.36 ± 5.43	166.80 ± 4.33
LPWY ($piglets^2$)	5.95 ± 1.48	41.57 ± 1.62	47.52 ± 1.26
LWWY (kg^2)	371.54 ± 90.40	2,566.70 ± 99.72	2,938.00 ± 78.01

†LPL = length of productive life; LBAY = lifetime number of piglets born alive per year; LBWY = lifetime litter birth weight per year; LPWY = lifetime number of piglets weaned per year and LWWY = lifetime litter weaning weight per year.

‡σ_a^2 = additive genetic variance; σ_e^2 = environmental variance and σ_p^2 = phenotypic variance.

Table 3 Heritabilities (diagonal), genetic (above diagonal) and phenotypic (below diagonal) correlations between length of productive life and lifetime production efficiency traits

Traits†	LPL	LBAY	LPWY	LBWY	LWWY
LPL	0.17 ± 0.04	0.66 ± 0.14	0.91 ± 0.06	0.95 ± 0.20	0.86 ± 0.07
LBAY	0.53 ± 0.01	0.07 ± 0.03	0.78 ± 0.08	0.85 ± 0.07	0.70 ± 0.10
LPWY	0.59 ± 0.01	0.81 ± 0.01	0.13 ± 0.03	0.75 ± 0.11	0.95 ± 0.02
LBWY	0.53 ± 0.01	0.94 ± 0.00	0.79 ± 0.01	0.04 ± 0.02	0.76 ± 0.11
LWWY	0.59 ± 0.01	0.76 ± 0.01	0.95 ± 0.00	0.79 ± 0.01	0.13 ± 0.03

†LPL = length of productive life; LBAY = lifetime number of piglets born alive per year; LBWY = lifetime litter birth weight per year; LPWY = lifetime number of piglets weaned per year and LWWY = lifetime litter weaning weight per year.

Table 4 Spearman rank correlations between EBV for LPL and lifetime production efficiency traits for all animals, boars only, and sows only

Pairs of Traits†	Spearman rank correlations		
	Animals	Boars	Sows
LPL, LBAY	0.67	0.62	0.67
LPL, LPWY	0.92	0.83	0.93
LPL, LBWY	0.87	0.87	0.86
LPL, LWWY	0.90	0.88	0.91
LBAY, LPWY	0.81	0.76	0.82
LBAY, LBWY	0.82	0.76	0.83
LBAY, LWWY	0.74	0.67	0.75
LPWY, LBWY	0.85	0.80	0.86
LPWY, LWWY	0.96	0.82	0.96
LBWY, LWWY	0.86	0.92	0.86

†LPL = length of productive life; LBAY = lifetime number of piglets born alive per year; LBWY = lifetime litter birth weight per year; LPWY = lifetime number of piglets weaned per year and LWWY = lifetime litter weaning weight per year.

Table 5 Spearman rank correlations between EBV for LPL and lifetime production efficiency traits for groups of boars and sows in the top 5%, 25% and 50% for any of the five traits

Pairs of traits†	Spearman rank correlations for boars			Spearman rank correlations for sows		
	Top 5%	Top 25%	Top 50%	Top 5%	Top 25%	Top 50%
LPL, LBAY	0.33	0.52	0.78	0.07	0.19	0.33
LPL, LPWY	0.47	0.69	0.84	0.43	0.57	0.74
LPL, LBWY	0.53	0.74	0.91	0.15	0.45	0.58
LPL, LWWY	0.72	0.78	0.91	0.09	0.45	0.66
LBAY, LPWY	-0.05	0.53	0.81	0.21	0.54	0.60
LBAY, LBWY	0.71	0.57	0.87	0.15	0.41	0.55
LBAY, LWWY	-0.03	0.35	0.81	0.17	0.34	0.47
LPWY, LBWY	0.25	0.61	0.86	0.20	0.53	0.60
LPWY, LWWY	0.14	0.68	0.86	0.33	0.74	0.83
LBWY, LWWY	0.54	0.80	0.95	0.29	0.51	0.64

†LPL = length of productive life; LBAY = lifetime number of piglets born alive per year; LBWY = lifetime litter birth weight per year; LPWY = lifetime number of piglets weaned per year and LWWY = lifetime litter weaning weight per year.

Table 6 Genetic trends for LPL and lifetime production efficiency traits for sows, sires, and dams

Animals	Traits†				
	LPL, d/yr	LBAY, piglets/yr	LPWY, piglets/yr	LBWY, kg/yr	LWWY, kg/yr
Sows	-0.66 ± 0.40 (*P* = 0.114)	0.01 ± 0.00 (*P* = 0.058)	0.02 ± 0.01 (*P* = 0.015)	0.01 ± 0.01 (*P* = 0.016)	0.06 ± 0.04 (*P* = 0.125)
Sires	-2.41 ± 0.59 (*P* = 0.0001)	-0.01 ± 0.01 (*P* = 0.040)	-0.01 ± 0.01 (*P* = 0.176)	-0.02 ± 0.01 (*P* = 0.035)	-0.14 ± 0.06 (*P* = 0.040)
Dams	1.10 ± 0.39 (*P* = 0.010)	0.03 ± 0.01 (*P* < 0.001)	0.12 ± 0.01 (*P* < 0.001)	0.04 ± 0.01 (*P* < 0.001)	0.26 ± 0.04 (*P* < 0.001)

†LPL = length of productive life; LBAY = lifetime number of piglets born alive per year; LBWY = lifetime litter birth weight per year; LPWY = lifetime number of piglets weaned per year and LWWY = lifetime litter weaning weight per year.

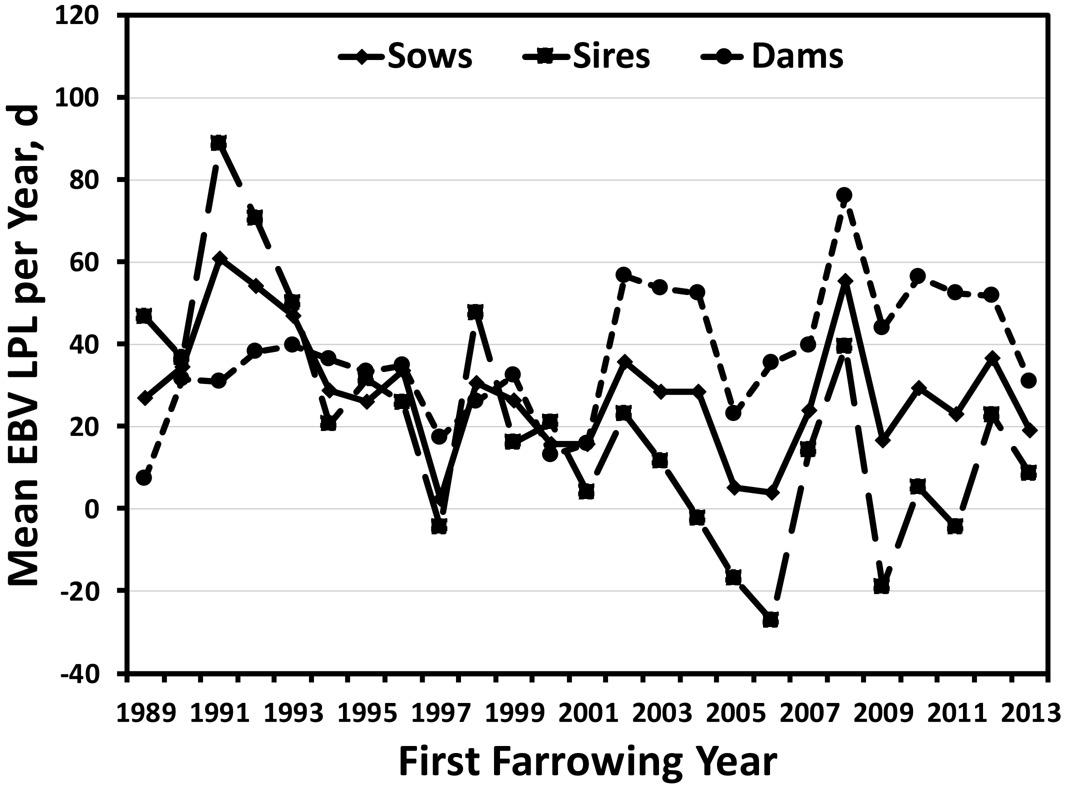

Figure 1 Yearly mean estimated breeding values (EBV) of sows, sires and dams for LPL from 1989 to 2013.

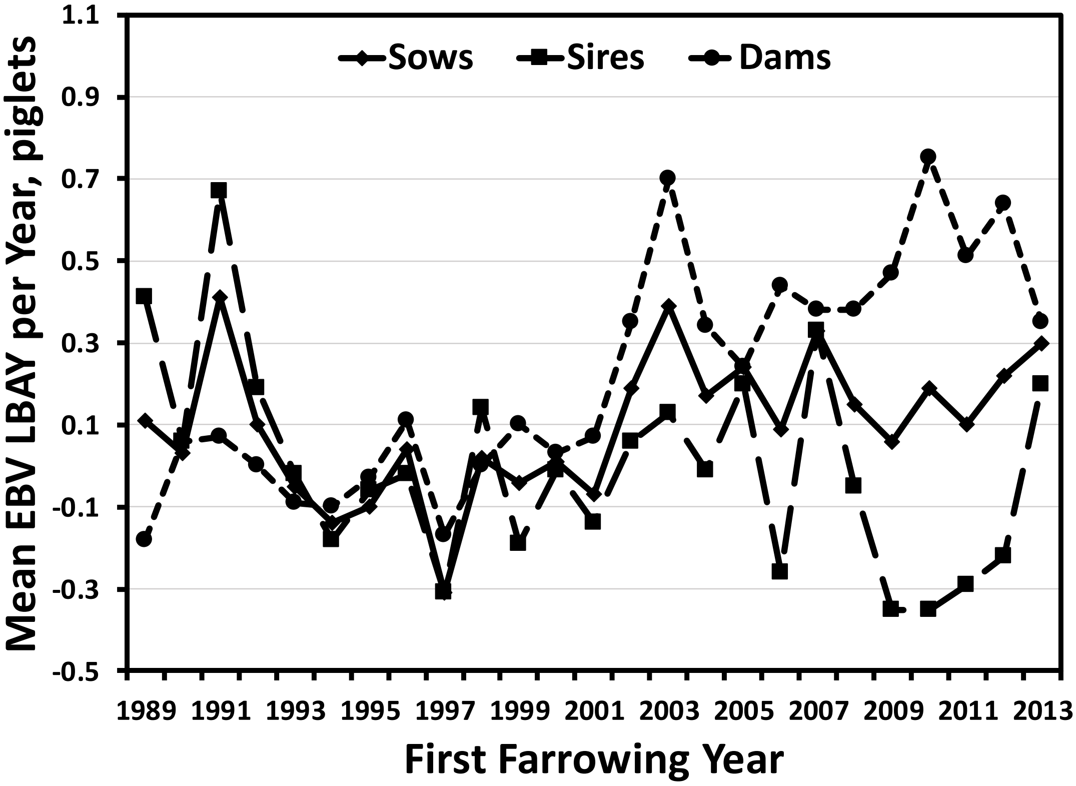

Figure 2 Yearly mean estimated breeding values (EBV) of sows, sires and dams for LBAY from 1989 to 2013.

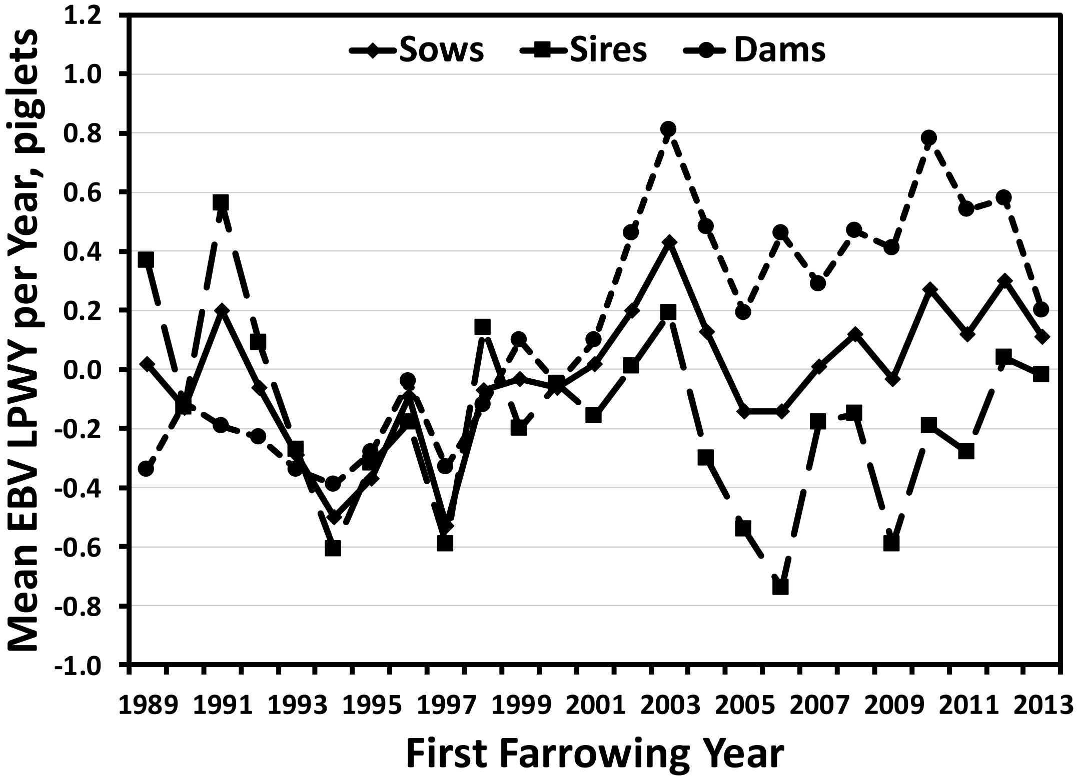

Figure 3 Yearly mean estimated breeding values (EBV) of sows, sires and dams for LPWY from 1989 to 2013.

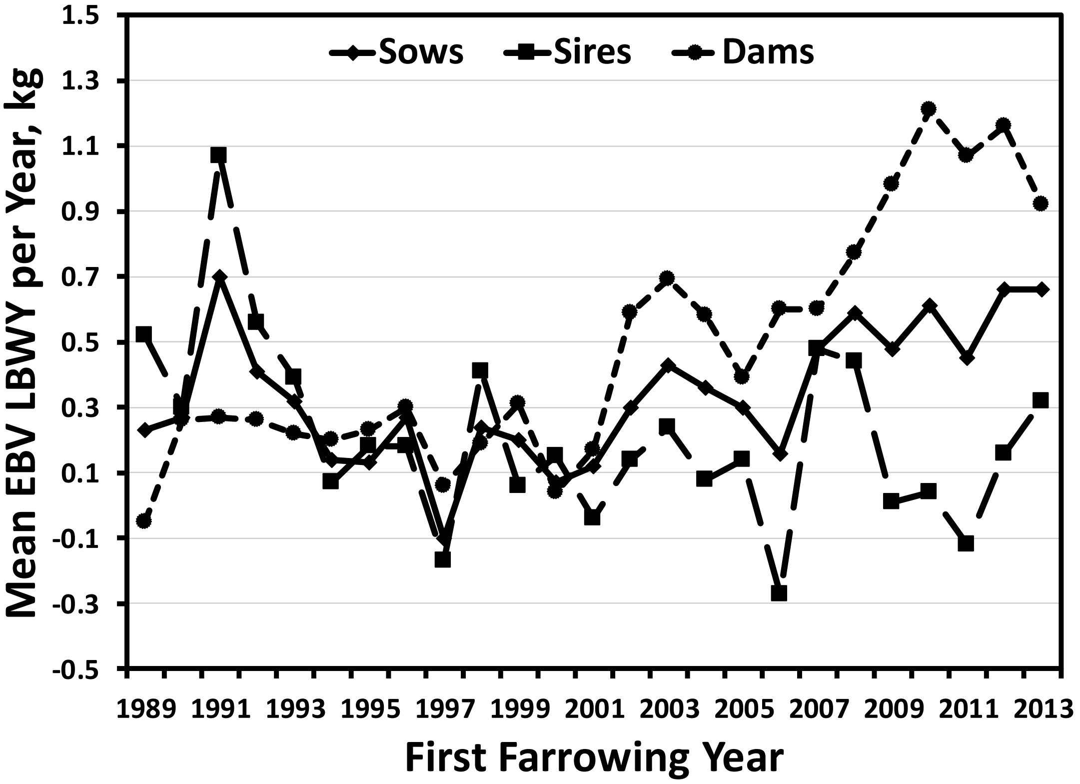

Figure 4 Yearly mean estimated breeding values (EBV) of sows, sires and dams for LBWY from 1989 to 2013.

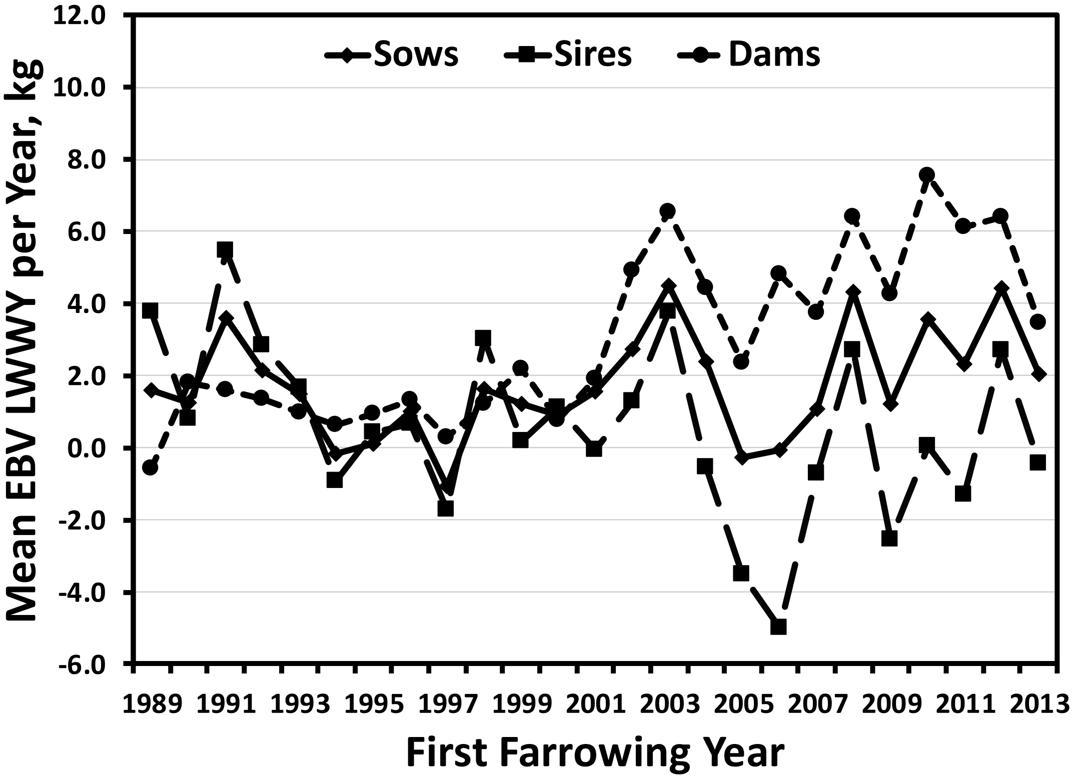

Figure 5 Yearly mean estimated breeding values (EBV) of sows, sires and dams for LWWY from 1989 to 2013.