GENETIC EVALUATION OF CROSSBREEDING PERFORMANCE IN SHEEP

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by

Alistair M. Shafto

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GENETIC EVALUATION OF CROSSBREEDING PERFORMANCE IN SHEEP

BY

ALISTAIR M. SHAFTO

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

ABSTRACT

Shafto, Alistair Maxwell. PhD., The University of Manitoba, October 1993. Genetic Evaluation of Crossbreeding in Sheep. Major Professor: Gary H. Crow.

A sheep flock, maintained under a semi-confinement management system, was used for the evaluation of the recently-released Outaouais Arcott as a dam breed, and the Canadian Arcott as a terminal sire breed. Ewe productivity traits included number and total weight of lambs at birth and 42 days of age. These were measured at first parity and over all parities. The Outaouais (OU) was assessed both as a pure breed in comparison with the Suffolk (SU), and for use in a crossbreeding system by comparing the Suffolk X Outaouais cross (SUxOU) and its reciprocal (OUxSU) with the component breeds. Least squares analysis revealed that Suffolks were consistently out-performed by both the Outaouais and the crossbred ewes in the traits based on litter size. Values for the SU, OU, SUxOU and OUxSU ewes for first parity litter size at birth were 1.24±0.10, 1.61±0.11, 1.70±0.15 and 1.69±0.24 lambs respectively.

Differences in litter weight at birth and 42 days of age and litter size at 42 days of age among ewe-breed groups at first parity were not significant ($p>0.05$). Breed additive genetic effects and maternal genetic effects were not significantly different from zero in first parity performance, but heterosis values of 19.3, 16.7 and 18.7% for litter size at birth, litter weight at birth and litter weight at 42 days of age approached significance ($p<0.1$). Litter size at birth over all parities for the four breed groups (SU, OU, SUxOU and OUxSU) was 1.38±0.07, 1.93±0.06, 1.74±0.12 and 1.87±0.21 lambs, and litter size at 42 days of age, 1.30±0.08, 1.71±0.07, 1.58±0.12 and 1.70±0.20 lambs respectively. Mean litter weights at birth for all groups were approximately 6 kg and did not differ significantly among breeds. Mean litter weights at 42 days of age were 21.12±2.95 kg, 21.40±3.22 kg, 23.19±5.28 kg and 27.16±5.36 kg respectively, and again the differences were not significant. Breed additive genetic effects were significant and positive for the Outaouais at 0.68±0.21, 0.53±0.19 lambs for litter size at birth and at 42 days of age, respectively, and 1.05±0.60 and 4.24±2.07 kg for litter weight at birth and 42 days of age, respectively. Maternal genetic effects were significant only for litter weight at birth and 42 days of age and were positive for the Suffolk at 1.14±0.57 kg and 3.97±1.97 kg, respectively. Heterosis values for mean litter size at birth and 42 days of age and mean litter weight at birth and 42 days of age were 9.1%, 9.0%, 12.8% and 18.4% respectively, though only the last of these proved to be significant. Traits included in the evaluation of Canadian Arcott rams were offspring weight at birth, 42 days of age and 120 days of age. Lamb growth was evaluated on purebred SU and OU lambs, both two-way crosses of these ewe breeds and the three-way crosses of both Canadian (CA) and Hampshire (HA) rams bred to the F_1 Suffolk X Outaouais (and their reciprocal) ewes. Data were analyzed using a least squares model and the results were compared with those from a multi-trait animal model analysis on the same data. SU lambs were heavier at birth at 3.79±0.26 kg, though not significantly so over CA-sired or HA-sired lambs which averaged approximately 3.19 kg. Outaouais lambs were the lightest (2.82±0.32 kg) with the F_1 crosses being between the two. By 42 days of age, the relative positions among groups had not changed greatly with weights ranging from 10.59±1.07 to 12.57±1.20 kg. By 120 days of age, there was no significant difference ($p>0.05$) among the SU, OUxSU and the CA- and HA-sired groups. The OU and SUxOU groups were significantly lighter at 29.74±1.92 and 28.48±1.93 kg respectively. The CA- and HA-sired lambs weighed 28.90±4.32 and 27.99±4.32 kg respectively and were not significantly different. Values derived for the breed genetic effects showed Suffolk to excel over the Outaouais in terms of significant direct and maternal genetic effects for birth weight at 0.49±0.10 and 0.48±0.07 kg respectively. By 42 days, no difference was seen among breed groups for direct genetic effect though the maternal effect was still strongly shown by Suffolks (1.98±0.25 kg). By 120 days, the direct genetic effect favoured the Outaouais (3.00±1.03 kg), but maternal effects were still strongly shown by Suffolks. Heterosis effects were generally small (< 3.1%) and were not significant for any of the weights. The comparison between terminal sire breeds showed no significant advantage for either the Canadian or the Hampshire for any of the weights measured. Heterosis was not a significant factor in the weight trait analysis. Generally speaking, the relationships among groups were not changed by the animal model, and results were consistent with those from the least squares analysis. However, the animal model did demonstrate some superiority in extracting breed effects from these data in cases where breeds were not well-represented in some of the classes of the fixed effect under consideration.

FOREWORD

This PhD thesis is submitted in manuscript format and consists of two manuscripts dealing with reproductive traits and weight traits of sheep respectively. Neither manuscript has been published. However, it is planned that both will be submitted under the authorship of A.M. Shafto, G.H. Crow, J.N.B. Shrestha, R.J. Parker, and W.M. Palmer.

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INTRODUCTION

The livestock industries in many parts of the world where the production of red meat is of major importance have traditionally depended on crossbreeding to maximize productivity. In swine, for example, it has been reported that a specific three-breed cross, developed from females of a single cross which excels in maternal traits, in turn mated to sires of a third breed which excels in bodyweight gain and carcass traits, will approach maximum efficiency of production (Smith 1964; Shrestha 1973). In sheep operations in North America, a high proportion of total income is derived from the sale of market lambs, and some form of crossbreeding is utilized in most of these farm operations. Studies by several authors, including Shrestha and Vesely (1986) for example, have outlined the genetic resources in various sheep breeds, and have permitted the selection of the appropriate breeds to utilise in a crossbreeding system or in new breed development to assist in the achievement of maximum efficiency in lamb production.

Crossbred females are preferred since crossbreeding gives producers the opportunity to exploit the different types of high productivity traits from two or more breeds.

A crossbred ewe which combines the high prolificacy of the Finnish Landrace or Romanov with the out-of-season breeding tendency of the Horned Dorset, for example, could potentially have a production advantage over a purebred ewe of either breed, particularly since heterosis plays a significant role in determining reproductive performance in crossbreds.

Crossbred market lambs are preferred firstly because they tend to exhibit a marked improvement in growth and survival simply as a result of heterosis. Further, crossbreeding presents the opportunity to introduce genes in a terminal cross from an additional breed known for high rate of gain and superior carcass quality. Production economics would indicate that the large mature body size associated with the terminal sire breeds is not a characteristic ordinarily desired on the female side of the flock. This would tend to indicate that a terminal cross system should be preferred since it removes the risk of compromising flock profitability by having to maintain a ewe flock made up of individuals of unnecessarily large body size.

Three new breeds released in 1989 from the Animal Research Centre in Ottawa (now the Centre for Food and

Animal Research) were developed with these principles in mind. The management system used at the Animal Research Centre at the time of the formation of these breeds was a highly intensive, total confinement system in which animals were housed indoors in a controlled environment and lambs were weaned almost immediately after birth and raised artificially on milk replacer diets. Light control and exogenous hormones were used to synchronize estrous cycles of all ewes bred in an eight-month breeding cycle.

Before these breeds were to be accepted by the industry, it was necessary that they demonstrate high productivity under more conventional management systems. Trials were therefore designed to place these sheep in different locations, one of which was at the University Farm of the University of Manitoba. This thesis presents an analysis of the reproductive and growth performance levels in a traditional production environment in both the Outaouais and Canadian Arcotts and their crosses, and compares these breeds directly with corresponding traditional breeds, namely the Suffolk and the Hampshire, currently used by the sheep industry.

LITERATURE REVIEW

Meat continues to be a major component of the diet in North America. In 1982, Canadians consumed 70.7 kg of red meats per capita (carcass weight disappearance basis) in addition to the 22.5 kg of poultry meats. (Agriculture Canada, 1986). Lamb and mutton accounted for only about one kg of this amount, a manifestation of the small size of the industry here. The sheep industry on the continent as a whole has declined drastically since the last World War as a result of many factors, most of which relate to economic considerations which have made sheep production a financially unattractive proposition (Spedding et al. 1972).

Blaxter (1973) stated that one of the main factors limiting the energetic efficiency of sheep meat production is low ewe fecundity. Litter size and frequency of breeding, identified as two of the main determinants of ewe productivity, were shown to be interdependent on several factors and by careful application of available knowledge, total productivity could be enhanced (Large 1970). Other productivity factors including the size of the ewe (Spedding et al. 1972), longevity of ewes (Wassmuth and Beuing 1974), lamb growth rate ,and lean tissue feed conversion (Sutherland 1965; Siers 1975; Fowler et al. 1976) have also been shown to have a marked effect on the economic viability of sheep operations.

The relative importance of improvement among traits varies among farm species. In sheep, the benefit of further improvement in the rate of reproduction is much greater than for pigs or poultry since the costs affected by reproductive rate have already been reduced to low levels in species with high reproductive rates (Dickerson, 1982). Improvement in growth rate, on the other hand, may have the adverse effect of increasing the body size of breeding animals, unless growth rate improvement is limited to a rapid growth line which is used only to sire market animals. Beef cattle and sheep also have greater potential for decreasing production costs by reducing fat levels than poultry, since current fat levels in these species are far higher. The relative importance of these traits in sheep is shown in Figure 1. These fundamentals form the background against which any work in breed improvement or new breed development will be effective from the standpoint of production efficiency.

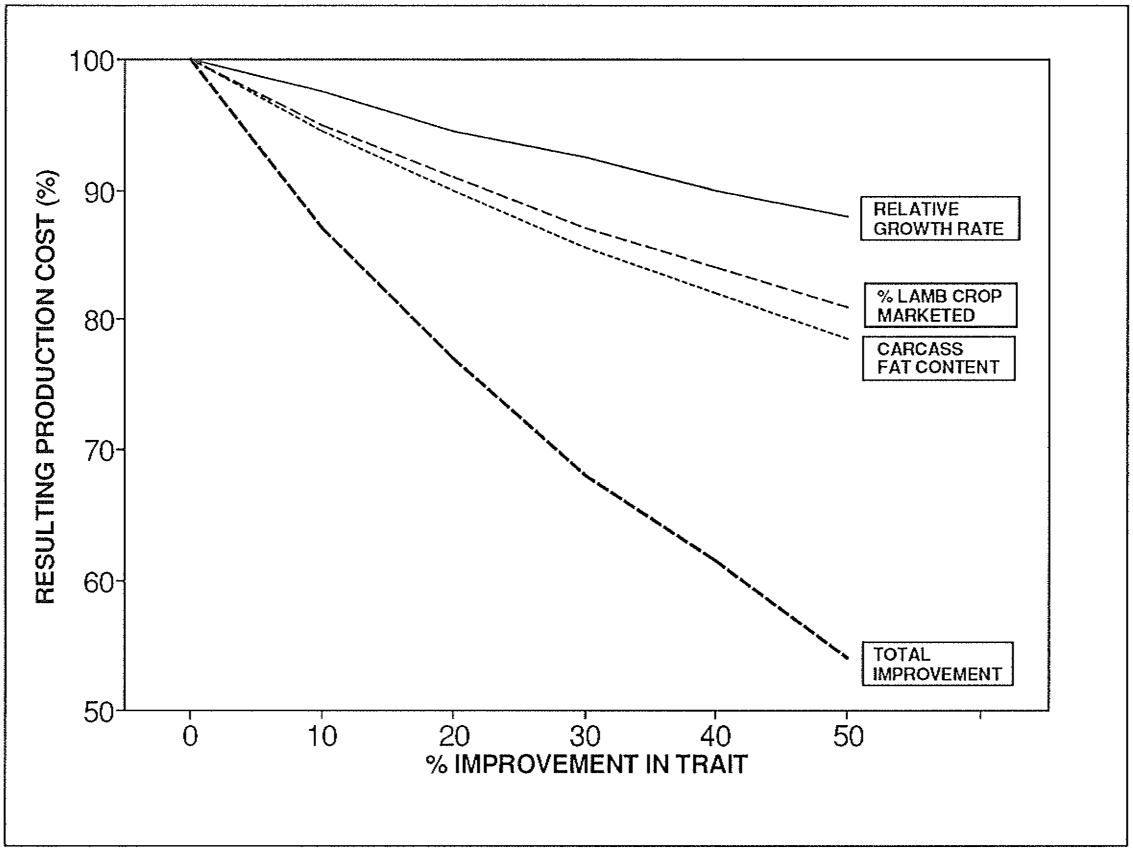

Figure 1. Potential effects on the cost of production of a kilogram of lamb protein from genetic improvement in relative growth rate, size of lamb crop raised to market and carcass fat content. (From Dickerson 1982)

Sellier (1976) showed marked differences in performance levels in many traits among several breeds of sheep. This fact alone indicates the potential that exists for improvement in productivity of the species as a whole. Breed evaluation, as has been carried out by several researchers (Sidwell et al. 1962, 1964; Singh et al. 1967; Sidwell and Miller 1971; Dickerson et al. 1972; Vesely and Peters 1972, 1979; Eikje 1974; Shrestha and Vesely 1986) is an ongoing process, particularly as the breeds evolve and as consumer requirements change. Exotic breeds of merit have been identified (Dickerson 1977) and to varying degrees have been available for importation into North America. The potential benefits from these breeds have been reviewed by Parker and Pope (1983). Most of the evaluations of productivity are done on a breed by breed basis within broad trait classifications.

Traits Associated With Productivity

Reproduction Traits

One of the major factors requiring attention in order to improve the profitability of sheep operations is the improvment of female reproductive performance (Parker and

Pope 1983). In a flock of fixed size, an increase in the number of lambs born and raised in a given time period not only increases the number of animals for sale or for flock expansion but also increases the selection differential, since the replacements form a smaller proportion of the total animals available for selection (Turner and Young, 1969).

Reproductive traits are generally characterized by low heritability (Turner 1969a). The improvement of reproductive traits in a breed through selection alone is therefore bound to take many generations. Indirect selection on weight traits for the improvement of reproductive performance has been suggested as an alternative to direct selection in some circumstances, but often there is little advantage to be gained by this approach (Turner and Young 1969). On the other hand, the Finnish Landrace and Romanov, breeds that show promise due to early maturity, longer-than-average breeding season and large litter sizes (Bradford 1972) have been available for some time. For these reasons, considerable effort has been directed either towards the development of breeding strategies utilizing two or more existing breeds that enable producers to benefit from increased production (Dickerson 1969; Jakubec 1977; Oltenacu and Boylan 1981a, 1981b;

Vesely and Swierstra 1986; Fahmy and Dufour 1988; Boujenane et al. 1991a; Bourfia and Touchberry 1993a, 1993b), or to the actual development of new breeds, such as the ones listed below, that incorporate improved reproductive capabilities into animals that have other traits of value associated with survival and growth in a local environment.

Growth Traits

In recent years, the Suffolk has dominated the Canadian sheep industry as the terminal meat sire of choice. In 1983, it was reported that 46% of the purebred lambs on the Canadian Record of Performance home test program were Suffolks (Shrestha et al. 1985). The results of trials such as those by Vesely and Peters (1979) show clearly that the breed performs well, from the standpoint of growth rate, as a purebred or in a cross-breeding program with other breeds common in this country. Dickerson et al. (1972) evaluated both growth and carcass characteristics, and like many workers, found that the Suffolk was superior to the Hampshire, Dorset and North American wool breeds in both carcass weight and yield.

Rate of gain and the production of lean, heavy carcasses were evaluated in several breeds by Wolf et al. (1980). When terminal sire breed crosses were compared for carcass composition at a constant percentage of subcutaneous fat and constant live weight, Texel crosses produced the leanest carcass while Dorset Down, Oxford, Suffolk, Ile de France and Oldenburg did not differ greatly. Texels had the heaviest side weights while Dorset Down and Ile de France showed the lowest. At the same time, Oxford, Suffolk, Ile de France and Dorset Down reached market weight in a shorter period of time than Texel and Oldenburg.

Cross-breeding Strategies

It has been shown that improvement can be made in many production-related traits in indigenous sheep populations by the introduction of exotic breeds. A review by Dyrmundsson (1973) indicated that puberty and early reproductive performance are traits in which improvement is possible. Marked improvement has been obtained with the introduction of genetic material from breeds demonstrating reproductive precocity such as the Finnish Landrace (Finnsheep), Romanov or D'man breeds (Turner 1969a, 1977; Tomes et al. 1979). In the United States, Dickerson (1977) reported that the Finnsheep offered more immediate potential than any other technology for increasing lamb production through improving reproductive efficiency. Furthermore, the carcass merit of lambs produced by Finnsheep crossbred ewes has been shown to be commercially satisfactory (Boylan et al. 1976; Olthoff and Boylan 1991b).

Careful consideration must be given to the choice of crossbreeding system when attempts are made to maximize efficiency of sheep production through the exploitation of breed differences (Nitter 1978). In swine, it has been demonstrated that the system which approaches maximum efficiency of production is a three breed cross, with females of a single cross which excels in maternal performance mated to sires of a third breed which transmits best individual performance to the three-breed offspring (Magee and Hazel 1958; Smith 1964; Moav 1966). Estimates of heterosis among various breed combinations for a variety of traits, and strategies for breed utilization have been reviewed by Nitter (1978).

While there is little doubt that prolific breeds contribute significantly to the numbers of lambs born or weaned, individual lambs from larger litters tend to have lighter weights at birth and weaning, and may take longer to reach market weight (Shrestha et al. 1982; Bourfia and

Touchberry 1992a). For this reason, the evaluation of these breeds or crossbreeding systems in terms of net benefit, relative to more traditional production systems becomes difficult.

One approach has been to develop selection indices which incorporate measurements of two or more traits together with a weighting, often based on economics, to give an evaluation of individual animal merit (Oltenacu and Boylan 1981b; Gallivan et al. 1987). An alternative approach that continues to be popular is the use of a trait such as the total weight of lamb produced per ewe over a given time period as a useful indicator of overall ewe production efficiency (Nitter 1978). As a composite production trait it includes fertility, prolificacy, maternal ability, and both lamb survival and growth rate. Recent work with traditional breeds in the U.S. has suggested that selection of ewes with high litter size at birth or at weaning and/or litter weight at birth or at weaning will genetically improve total litter weight at weaning per ewe lambing of their offspring (Abdulkhaliq et al. 1989). The National Sheep Improvement Program in the United States includes this as a single trait in its evaluation of ewe productivity (Wilson and Morrical 1991). The utilization of composite traits in sheep breed evaluation is increasing, particularly in trials that involve prolific breeds, such as the D'Man (Boujenane et al. 1991b), the ABRO synthetic dam line (Martin et al. 1981), the Romanov (Fahmy and Dufour 1988) or the Finnish Landrace (Mohd-Yusuff et al. 1992). Estimates of the genetic parameters for these traits are also being developed (Martin et al. 1981; Abdulkhaliq 1989).

Synthetic Breed Development

Historically, sheep breeders have been interested in developing new breeds of sheep by combining existing breeds with other breeds showing superiority in various traits (Rae 1952; Hill 1971). A significant reduction in time and resources was seen as a possible result of complementing established breed resources that have demonstrated superiority in production traits through planned introduction of new genetic material into existing gene pools (Turner 1969b; Dickerson 1969; Maijala 1974). Historically, the success rate in developing dam line breeds has not been as good as that for the establishment of breeds of merit in growth or carcass traits. However, with increased understanding of the underlying genetic principles that relate to reproductive traits, greater successes in breed development are seen in efforts to develop new dam lines such as the ABRO Synthetic Dam Line (Martin et al. 1980), the Cambridge (Owen et al. 1986), the Polypay (Hulet et al. 1984), and the three Arcott breeds (Shrestha et al. 1992).

The Arcott Breed Development Program

A multi-disciplinary approach to the development of an intensive sheep production system for Canada was proposed by Gowe et al. (1974) which, in addition to the concept of raising sheep under total confinement and the development of new synthetic breeds, included the evaluation of these breeds and their crosses as contributors to the improvement of the levels of productivity of the Canadian sheep industry (Heaney et al. 1980).

In the 1960's, the Animal Research Centre in Ottawa developed a specialised sire strain and two dam strains from their foundation stock which was made up from both established and imported germ plasm (Shrestha et al. 1982). During the development of these strains, all sheep were housed indoors in a controlled environment utilising eight-month breeding cycles and artificial rearing of newly-born lambs. An outline of the breeding program and observations on early weaning have been presented by Peters (1974a,b).

The synthetic sire strain (Canadian Arcott) was developed as a terminal cross meat sire breed, primarily from the Suffolk (37.4%), Ile de France (27.8%) and Leicester (13.6%) breeds with contributions from the North Country Cheviot (6.6%) and Romnelet (6.4%). The Outaouais Arcott breed, one of the dam breeds, was derived from the Finnish Landrace (49.1%), Shropshire (25.8%) and Suffolk (21.2%) breeds. Both these Arcott breeds had minor contributions totalling less than ten percent from several other breeds.

Selection was applied to the Canadian Arcott breed to increase lean muscle mass and growth rate, with lesser emphasis placed on prolificacy. Selection of lambs was done according to an index based on the growth performance of full- and half-sibs to 91 days of age. During the 1970's ram lambs were selected for carcass quality based on ultrasonic measurements of loin eye and backfat adjusted for body weight and litter size. Mature rams were selected for the subsequent breeding primarily on the basis of fertility at the first breeding, based on an ultrasonic pregnancy diagnosis of their mates 60 days after removal of the rams from breeding pens.

In the Outaouais Arcott breed, replacement ewe-lambs were selected based on growth rate to 91 days of age and the litter size of their parents. As adults, no selection was carried out on ewes during the first breeding season. From the second breeding to the final breeding, selection was based on a ewe productivity index. This index for ewes within a given age category was computed as the weight of lambs produced at 90 days of age summed over previous breedings. Any ewe that failed to produce a live lamb from the second to the fifth breeding was automatically culled. Otherwise, ewes were culled by age group, i.e. 10% were culled after the first breeding, 11% after the second, 13% after the third, 14% after the fourth and 100% after the fifth. An index of lifetime performance of dams and grand-dams (maternal and paternal) was used as the main selection criterion from 1984 until 1990.

Recent years have been characterized by increasing breed resource availability and the rapid evolution of genetic methods both for evaluating animals and improving various productivity traits of importance. The Arcott breed development program capitalized on that opportunity.

MANUSCRIPT I

Genetic evaluation of the Outaouais and Suffolk breeds for ewe productivity traits

MANUSCRIPT I

Abstract

A sheep flock, maintained under a semi-confinement management system, was used for the evaluation of the recently-released Outaouais Arcott as a dam breed. Least squares analysis was performed on ewe productivity traits at first parity and over all parities. Traits included the number and total weight of lambs per parity at both birth and 42 days of age. The Outaouais (OU) was assessed both as a pure breed in comparison with the Suffolk (SU), and in a crossbreeding system by comparing the Suffolk X Outaouais cross (SUxOU) and its reciprocal (OUxSU) with the component breeds. Suffolks were consistently out-performed by both the Outaouais and the crossbred ewes in the traits based on litter size. Values for the SU, OU, SUxOU and OUxSU ewes for first-parity litter size at birth were 1.24±0.10, 1.61±0.11, 1.70±0.15 and 1.69±0.24 lambs respectively. Differences among breed groups in first-parity litter weight at birth and 42 days and first-parity litter size at 42 days were not significant ($p>0.05$). Over all parities, values for mean litter size at birth for the four breed groups were

1.38±0.07, 1.93±0.06, 1.74±0.12 and 1.87±0.21 lambs, and for litter size at 42 days, 1.30±0.08, 1.71±0.07, 1.58±0.12 and 1.70±0.20 lambs respectively. Mean litter weights at birth for all breed groups over all parities were approximately 6 kg and did not differ significantly among breeds. Mean litter weights at 42 days were 21.12±2.95, 21.40±3.22, 23.19±5.28 and 27.16±5.36 kg respectively, and while the differences were not significant due to large error terms, the trend towards an advantage for the breed groups with the larger litter sizes was observed. Direct genetic effects for the four traits at first parity tended to favour the Outaouais over the Suffolk but were small and non-significant. Over all parities, these effects were significant ($p<0.05$) and positive in favour of the Outaouais at 0.68±0.21 and 0.53±0.19 lambs for litter size at birth and 42 days, respectively and 4.24±2.07 kg for litter weight at 42 days. Maternal genetic effects generally favoured the Suffolk over the Outaouais but were significant ($p<0.05$) only over all parities for litter weight at birth and 42 days at 1.14±0.57 and 3.97±1.97 kg, respectively. Heterosis values at first parity for litter size at birth, litter weight at birth and litter weight at 42 days were 19.3%, 16.7% and 18.7% but only the last of these was significantly different from zero ($p<0.05$). Over all parities, litter size at birth and 42 days, and litter weight at birth and 42 days were 9.1%, 9.0%, 12.8% and 18.4% respectively, none of which proved to be significantly different from zero ($p<0.05$).

Introduction

One of the major factors requiring attention in order to improve the profitability of sheep operations is the improvement of female reproductive performance (Parker and Pope 1983). An improvement in the number of lambs born in a given time period not only increases the number of animals available for sale or flock expansion but also increases the selection differential, since in a flock of fixed size, the replacements form a smaller proportion of the total animals available for selection (Turner and Young 1969).

In order to address this need, researchers at Agriculture Canada's Animal Research Centre in Ottawa (now the Centre for Food and Animal Research or CFAR) developed three highly productive breeds of sheep in an intensive production system, two of which were selected for high performance in maternal traits. While proven to be highly productive in an intensive production environment utilizing 8-month breeding cycles and artificial rearing of lambs (Shrestha et al. 1992) or 12-month breeding cycles with lambs reared with their dams (Shrestha and Heaney 1992), the breeds had yet to prove themselves in these traits in a more typical commercial production environment.

Management systems on commercial sheep operations often prevent animals from expressing their potential performance in a specific trait. Lifetime productivity cannot be measured meaningfully if breeding stock is replaced at an early age in the interest of flock improvement. Lambing interval is relatively meaningless if out-of-season breeding is not practised on the operation. Practical measurements of meaningful traits must be found for useful appraisals of animals in commercial production environments.

One approach utilizes the correlations that exist among traits. Estimates of performance for traits that are difficult to measure can then be calculated from measurements of correlated traits that can be measured more easily. The knowledge of the correlations between weight traits and reproductive traits, for example, led to attempts to accurately estimate reproductive performance from weight data. Estimates of the heritability of reproductive traits have generally been low, while those for growth traits tend to be significantly higher (Turner 1969a). Indirect selection on weight traits for the improvement of reproductive performance is therefore only recommended in situations in which the genetic correlation is high and the heritability of the weight trait is higher than that of the reproductive trait (Turner and Young 1969).

As an alternative, the weight of lamb produced per ewe over a given time period has been used as a useful indicator of overall ewe production efficiency (Nitter 1978). As a composite production trait it includes fertility, prolificacy, maternal ability, and both lamb survival and growth rate. Recent work with traditional breeds in the U.S. has suggested that selection of ewes with high litter size at birth or at weaning and/or litter weight at birth or at weaning will genetically improve total litter weight at weaning per ewe lambing of their offspring (Abdulkhaliq et al. 1989). The National Sheep Improvement Program in the United States includes total litter weight at weaning as a trait in its evaluation of ewe productivity (Wilson and Morrical 1991). For these reasons, the Outaouais Arcott was evaluated on the basis of composite productivity traits. The objectives of the present research were to assess the suitability of the Outaouais as a dam breed, firstly as a pure breed in comparison with the Suffolk, and as a contributor to a commercial crossbred female in comparison with each of the component pure breeds, in a traditional production environment.

Materials and Methods

Livestock

In the 1960's, the Animal Research Centre (now CFAR) in Ottawa developed a specialized sire strain and two dam strains from their foundation stock which was made up from both established and imported germ plasm (Shrestha et al. 1982). During the development of these strains, all sheep were housed indoors in a controlled environment utilising eight-month breeding cycles and artificial rearing of newly-born lambs (Heaney et al. 1980). An outline of the breeding program and observations on early weaning have been presented by Peters (1974a,b).

The Outaouais Arcott breed, one of two dam breeds developed, was derived from the Finnish Landrace, Shropshire and Suffolk breeds. Minor (less than ten percent) contributions were made by several other breeds. Selection was primarily based on reproductive performance with a lesser emphasis on growth rate. An index of lifetime performance of dams and grand-dams (maternal and paternal) was used as the main selection criterion from 1984. The original Suffolk stock used in the trial was drawn from a group of young ewes from the University of Manitoba flock that had been part of the permanent flock at this location for over ten years prior to the trial.

Flock Management

Subsequent to the development of the three Arcott breeds in the total confinement facility at the Animal Research Centre (now CFAR) in Ottawa, two flocks were established in different locations in order to assess the performance of the new breeds in environments that more closely resembled those that would be experienced by sheep in the commercial industry. One of these locations was the University of Manitoba farm facility in Winnipeg, the other being the Bradley Farm at the Experiment Station in Ottawa.

The physical facilities at the University of Manitoba consisted of a metal-clad, fully-enclosed barn and open-front sheds. Pens in these buildings were regularly cleaned and bedded as required. In addition, sheep had access to outdoor pens and to pasture when available. The enclosed barn was designed in such a way that light control could be carried out.

Management prior to breeding followed a procedure under which ewes were initially kept in 18 h light per day for six weeks, followed by a reduction to six h light per day for another six weeks prior to mating. Ewes were treated intravaginally with progestagen-impregnated sponges (Veramix, Upjohn) for 14 days prior to breeding, and if being bred in the non-breeding season, on the day of sponge removal, ewes were injected with 250 IU of pregnant mare serum gonadotrophin (Equinex, Ayerst). Rams were introduced 24 h later and left with the ewes for a period of 25 days. For the matings in which Hampshire rams were used, ewes were bred artificially with fresh, undiluted semen containing a minimum of 500,000 sperm. Insemination was carried out two days after sponge removal using a standard insemination pipette with the semen being deposited immediately posterior to the cervix.

Ewes at lambing time were under constant surveillance, and were handled in a manner similar to that on commercial sheep operations. Immediately post-lambing, ewes were placed in lambing pens to allow the lambs to suckle their dams. Lambs were permanently identified and weighed within 24 h after birth. Weak lambs, lambs abandoned during early life or lambs inadequately provided for by their dams were bottle-fed frozen cow colostrum (a minimum of 75 ml per kg body weight) that had been thawed and warmed to body temperature, and then reared artificially on ad libitum, cold, cow's milk fortified with extra cream to bring the butterfat level to 10%. Artificially-reared lambs were weaned from the milk diet during the week in which they attained 21 days of age. Lambs weighing less than 6 kg at this time remained on milk replacer for an additional week. An 18 percent crude protein creep ration, either pelleted or in meal form, was available free choice to all the lambs from birth to weaning together with hay and water. Prior to weaning, lambs also had access to their dams' ration.

During the week in which they reached 56 days of age, the lambs nursed by their dams were weaned. All lambs were vaccinated at weaning against clostridial disease. Post-weaning, all lambs were fed a high-energy ration containing 17% crude protein to permit maximum expression of genetic potential for growth. These rations contained approximately 90 percent barley, 8 percent hay with the balance being made up of vitamins and minerals, and were fed from weaning to the time lambs were marketed or moved into the main flock as replacements.

The diets for the mature breeding sheep were designed to meet the nutritional requirements according to age and stage of production. The diet was essentially all forage, consisting of hay, plus 5% ground barley as a carrier for supplemental vitamins and minerals. During late gestation and lactation, the grain was increased to 18 percent of the ration to meet the increased nutritional requirements of the ewes. At weaning, the ewes were moved to pasture, when available, or returned to the basic hay-based ration described above until the next breeding season.

Mating Plan

In order to evaluate the reproductive capabilities of the Outaouais Arcott, the Animal Research Centre (CFAR) in Ottawa released 100 ewes and ten rams to the University of Manitoba as a base flock of this breed. During the period from 1984 to 1989, purebred matings of these sheep and the University of Manitoba Suffolk flock were carried out to expand and maintain the purebred numbers. From 1985 to 1989, Suffolk X Outaouais Arcott crosses and the reciprocal cross were produced and from 1986 to 1989, these crosses were bred to one of two terminal breed meat sire breeds, either Hampshire or Canadian Arcott, to produce three-way cross, market-type lambs. No selection was applied to this population and culling was only used as required to maintain a healthy flock free of physical abnormalities.

The breeding protocol at this location was based on a timetable of three lambings in two years. This was carried out in 1984 and 1985. This schedule was modified in 1986, when only a Fall lambing took place. Subsequently, two events disrupted this schedule. Firstly, difficulty in obtaining Hampshire rams and training them for semen collection delayed the breeding originally scheduled for May, 1987 until that fall. Secondly, a fire in the facility at the end of 1987, in which approximately 125 pregnant ewes were lost, required that replacements be obtained from the Animal Research Centre (CFAR) in Ottawa, thus delaying breeding plans for 1988. As a result, from the Fall of 1986 to the fall of 1988, only one breeding per year was carried out. The resulting numbers of lambs produced by each of the breeds or breed crosses over the length of the trial period are shown in Table 1.

TABLE 1. Distribution of lamb births by ewe breed or cross throughout the trial period.

Ewe breed[2]	Season and year of birth[1]								
	1	2	3	4	5	6	7	8	Totals
SU	40	0	49	20	104	99	66	103	481
OU	3	59	83	95	209	211	55	204	919
SUxOU	0	0	0	0	0	53	103	96	252
OUxSU	0	0	0	0	0	0	34	36	70
Totals	43	59	132	115	313	363	258	439	1722

[1]Season and year abbreviations: 1=Spring 1984, 2=Fall 1984, 3=Spring 1985, 4=Fall 1985, 5=Fall 1986, 6 to 8 are Spring lambings in 1987, 1988 and 1989 respectively.

[2] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

Statistical Methods

The objective of this trial was to evaluate the reproductive potential of the Outaouais Arcott, both as a pure breed in comparison with the Suffolk, and as a contributor to an F_1 cross with the Suffolk in comparison with each of the component pure breeds, removing any other factors that affect performance. These four breeding groups, namely the Suffolk, the Outaouais and the two reciprocal crosses of these breeds, constituted a diallel. Through a conventional least squares analysis, this data structure provided the opportunity to examine not only the capabilities of the pure breeds and crosses relative to one another, but also through the development of contrasts, to estimate some of the genetic components of this performance, in particular the direct genetic, maternal genetic and heterosis effects of the two pure breeds involved.

The basic design of the trial and the management procedures prevented any evaluation being made on several traits that are direct measures of reproductive performance. Breeding management included light control, hormone administration, scheduled exposure to rams and automatic removal of ewes from the flock after five parities. As a result, measures of lambing interval, total lifetime productivity, out-of-season breeding ability and even prolificacy under this production system were unlikely to be indicative of genetic merit. Either the ewes were not permitted to express any capabilities they may have had in the trait, or any variation that may have been possible to observe in a trait was masked by the management under which the flock was kept.

Useful indicators of reproductive ability were available, however, by basing the analysis on measures of ewe performance for a particular lambing event. These "lambing-event based" traits included litter size at birth per parity, litter size at 42 days of age per parity, and two composite traits - the total litter birth weight per ewe per parity, and the total litter weight at 42 days of age per ewe per parity. Measurements of performance at first parity and over all parities for these traits were taken. The numbers of ewe lambing-event records available for analysis are shown by breed and age of ewe in Table 2, and the incidence of litter size within each breed group is shown in Table 3.

Lamb birth weights were taken within 24 hours of birth. Six-week weights were taken on the closest Monday or Friday

TABLE 2. Frequency table of lambing-event records by breed and age of ewe.

Ewe age (years)	Breed of ewe				Totals
	Suffolk	Outaouais	SUxOU[1]	OUxSU	
1	56	47	23	5	131
2	100	238	61	9	408
3	76	72	42	5	195
4	37	67	1	0	105
5+	28	5	0	0	33
Totals	297	429	127	19	872

[1] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

TABLE 3. Frequency (and percentage) of litter size at birth by breed over the trial period.

Litter size	Breed of ewe[1]			
	SU	OU	SUxOU	OUxSU
Singles	136 (45.8%)	103 (24.1%)	23 (18.3%)	4 (21.1%)
Twins	145 (48.8%)	205 (48.0%)	73 (57.9%)	8 (42.1%)
Triplets	15 (5.1%)	93 (21.8%)	25 (19.8%)	6 (31.6%)
Quadruplets and over	1 (0.3%)	26 (6.1%)	5 (4.0%)	1 (5.3%)

[1] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

to the day on which the lamb was exactly 42 days of age. The 42-day weights were adjusted for age to a 42-day constant age by calculating the average daily gain from birth to the time the lamb was weighed, and adding this amount, multiplied by 42, to the actual birth weight. In addition, all individual lamb weights were adjusted for sex prior to any litter-weight analysis either at birth or at 42 days by converting all age-adjusted female weight data to a male equivalent weight through the use of additive adjustment factors. The adjustment factor values for weight at birth and at 42 days of age were those calculated through a full animal model analysis of weight data in a concurrent study (described in Manuscript II) and were +0.2325 kg and +0.8582 kg respectively. The numbers in each breed group, and their means, standard deviations, and maximum and minimum values for each trait are given in Table 4.

The underlying mathematical model for the statistical analysis was as follows:

$$Y_{ijklm} = \mu + t_i + d_j + b_k + p(b_k)_l + e_m$$

where:

Y_{ijklm} = the record on the total birth weight (or total 42-day weight) of the mth litter from the lth ewe within breed of the kth breed or breed cross, born in the ith year

TABLE 4. Numbers of lambing events, means, standard deviations, and minimum and maximum values for reproductive traits by breed group.

Breed[1]	N	Mean	Standard deviation	Minimum	Maximum
		Litter size at birth			
Suffolk (SU)	297	1.60	0.60	1.00	4.00
Outaouais (OU)	427	2.11	0.85	1.00	5.00
SU x OU	126	2.10	0.73	1.00	4.00
OU x SU	19	2.26	0.99	1.00	5.00
		Litter size at 42 days of age			
SU	254	1.54	0.55	1.00	3.00
OU	409	1.93	0.79	1.00	5.00
SU x OU	121	1.92	0.68	1.00	4.00
OU x SU	19	2.05	0.85	1.00	4.00
		Litter weight at birth			
SU	297	7.27	2.39	2.20	15.27
OU	427	7.32	2.45	1.43	15.17
SU x OU	126	8.24	2.21	3.43	13.40
OU x SU	19	9.13	2.92	5.60	16.27
		Litter weight at 42 days of age			
SU	254	24.43	7.63	9.36	40.92
OU	409	24.36	8.32	8.56	70.96
SU x OU	121	28.39	7.90	12.36	54.18
OU x SU	19	31.57	10.97	16.76	55.72

[1] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

and season to a ewe in the jth age group;

μ = the overall mean effect;

t_i = effect of year/season at lambing (i = 1, Spring 1984; 2, Fall 1984; 3, Spring 1985; 4, Fall 1985; 5, Fall 1986; 6, Spring 1987; 7, Spring 1988; 8, Spring 1989), considered a fixed effect;

d_j = effect of age of ewe in years (j = 1, 2, 3, 4, or 5), considered a fixed effect;

b_k = effect of breed or breed cross (k = 1 for Suffolk, 2 for Outaouais, 3 for Suffolk X Outaouais and 4 for Outaouais X Suffolk), considered a fixed effect;

$p(b_k)_l$ = effect of ewe within breed, considered a random effect with mean 0 and variance σ_p^2;

e_m = random (residual) error representing variation among lambings of the same ewe.

The models for numbers of lambs in litters at birth or weaning were similar to those used for weight traits except that the age-of-ewe-group factor was removed since it was not significant in a preliminary analysis for these traits. The model for the traits at first parity was less complex and included only factors for lamb breed, year and season of lambing, and ewe age at parity to the nearest month. The type of birth and rearing of the dam was not included in any of the models in which reproductive performance was examined. This data was not available on a large number of ewes, particularly those originating in Ottawa or their offspring. Many ewes produced lambs that were sired by different breeds of sire from parity to parity. Breed of mate could not be included in these analyses due to confounding with breed of dam as a result of the design of the mating plan, and it was assumed in this analysis that breed of mate had little effect on the ewe performance measures studied here. Analysis in the concurrent study (described in Manuscript II) showed that this was a reasonable assumption.

The data for the eight reproductive traits were analyzed using the GLM procedures of SAS (1988). All two- and three-way interactions were considered, but not included in the final model since they were found to be non-significant in preliminary analyses. The error term for the analysis of first-parity performance reflected variation among ewes. However, the standard error values for breed least squares means for all the traits that were measured over more than one parity used the Type III mean square for ewe within ewe breed as the error term. Standard errors for the other factors affecting performance used the within-ewe error term.

Contrasts were developed to estimate direct genetic, maternal genetic and heterosis effects for the eight traits evaluated as described by Dickerson (1969). The assumed genetic model for the breed group mean for purebreds, the Outaouais for example, was:

$$\bar{W}_O = \mu + g_O{}^D + g_O{}^M$$

where:

$\bar{W}_O$ = the mean performance of the Outaouais breed group for the trait of interest;

μ = the mean performance for all breed groups;

$g_O{}^D$ = the direct genetic effect of the Outaouais breed, and

$g_O{}^M$ = the maternal genetic effect of the Outaouais breed.

Similarly, for a crossbred group, the Outaouais X Suffolk crosses for example, the assumed genetic model was:

$$\bar{W}_{OS} = \mu + ½(g_O{}^D + g_S{}^D) + h_{OS}{}^D + g_S{}^M$$

where:

$\bar{W}_{OS}$ = the mean performance of the Outaouais X Suffolk breed group for the trait of interest;

μ = the mean performance for all breed groups;

$g_O{}^D$ = the direct genetic effect of the Outaouais breed;

$g_S{}^D$ = the direct genetic effect of the Suffolk breed;

h_{OS}^{D} = the heterosis effect for the trait in the crossbred Outaouais X Suffolk ewes, and

g_{S}^{M} = the maternal genetic effect of the Suffolk breed.

The contrast to yield the direct genetic effect of the Outaouais versus the Suffolk was therefore as follows:

$$\textit{Direct effect} = g_O^D - g_S^D$$
$$= \bar{W}_O - \bar{W}_S + \bar{W}_{OS} - \bar{W}_{SO}$$

where $\bar{W}$ represents the mean performance of a breed group for the trait of interest, with the subscripts designating the breed group. Similarly, the maternal genetic effect of the Outaouais versus the Suffolk can be calculated as follows:

$$\textit{Maternal effect} = g_O^M - g_S^M$$
$$= \bar{W}_{SO} - \bar{W}_{OS}$$

and the heterosis effect in the crossbred females can be determined by subtracting the mean performance of both purebred groups from that of both the reciprocal crossbred groups, that is:

$$\textit{Heterosis effect} = h_{OS}^D$$
$$= 1/2(\bar{W}_{SO} + \bar{W}_{OS} - \bar{W}_S - \bar{W}_O)$$

Results and Discussion

The design of the trial and the structure of the data restricted the degree to which it was possible to assess performance in individual reproductive traits. The genetic out-of-season breeding ability or lambing interval could not be measured due to breeding management techniques that included light control and hormone treatments. Age at first lambing was a poor indicator of age at which animals reached sexual maturity since breeding of young ewes was induced at a time that may well have been some months after the ewe-lambs were first capable of breeding. Similarly, lifetime productivity could not be measured when most animals were replaced in the flock at an early age and in no case were animals allowed to remain for more than five parities. Even the prolificacy data may have been affected by the management routines at breeding time since pregnant mare serum gonadotropin is recognized as having a superovulatory effect. However, this trial was run under conditions that are similar to those on commercial sheep operations, necessitating the use of assessment techniques that would generate useful information from the kinds of data that would be available on such an operation.

Reproduction Performance at First Parity

The analysis on the number of lambs born at first parity (Table 5) revealed that the Outaouais out-performed ($p<0.05$) the Suffolk (1.61 ± 0.11 vs. 1.24 ± 0.10 lambs). The litter-size at birth for the Outaouais is very close to that reported by Martin et al.(1980) of 1.56 lambs for first-time lambing ABRO dams, a synthetic breed with approximately 50% Finnsheep genes in its background. Similar results were reported by Jakubec (1976), Dickerson (1977), and Vesely and Swierstra (1986 and 1987) in ewes with a high percentage of Finnsheep, a breed known for both prolificacy and early maturity. Each of the two crossbred groups had lambing performance at first parity (1.70 ± 0.15 and 1.69 ± 0.24 lambs for the SUxOU and OUxSU respectively) in excess of the level attained by the Suffolks but not significantly greater than that of the Outaouais. Due to the small size of the OUxSU group and the resulting large size of the error term, this group failed to show a significant difference from any of the groups despite the apparent improvement shown in this group mean above both purebred groups. The breed group ranking for litter size at 42 days did change somewhat from that at birth but the Suffolk group still ranked the lowest. However, differences between breed groups were no longer significant.

TABLE 5. Least squares means and standard errors for reproductive performance for first parity at birth and 42 days of age by ewe breed.

Ewe breed[1]	Litter size (number of lambs ± standard error[2])
	Birth
SU	1.24 ± 0.10[a]
OU	1.61 ± 0.11[b]
SU x OU	1.70 ± 0.15[b]
OU x SU	1.69 ± 0.24[ab]
	42 days of age
SU	0.89 ± 0.10[a]
OU	1.26 ± 0.11[a]
SU x OU	1.16 ± 0.16[a]
OU x SU	1.11 ± 0.25[a]

Ewe breed	Litter weight (weight of litter (kg) ± standard error)
	Birth
SU	5.46 ± 0.28[a]
OU	5.47 ± 0.32[a]
SU x OU	6.03 ± 0.45[a]
OU x SU	6.72 ± 0.70[a]
	42 days of age
SU	18.19 ± 1.22[a]
OU	19.52 ± 1.34[a]
SU x OU	21.97 ± 1.94[a]
OU x SU	22.79 ± 2.69[a]

[1] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

[2] Values within each parity group with different superscripts are significantly different ($p < 0.05$).

Litter weight data for first parity ewe lambs showed that the litter weights at birth were similar among all breed groups. By 42 days of age there was still no significant difference among groups. It would appear that both the lamb losses and the small group size in the crossbred groups contributed to the failure of the differences in crossbred litter weights at 42 days for first-parity ewes to reach levels adequate to show significance at the $p < 0.05$ level overall.

It was considered important to analyze first-parity performance for two reasons. In all but the most extensive operations, young ewes are expected to produce their first lambs as yearlings in the interest of improving overall production efficiency in the sheep flock. In addition, however, the generally-accepted low heritability of reproductive traits and the resulting superior ability of crossbred females to breed earlier (as well as have more lambs) as a result of heterosis was felt to give additional significance to the measurement of the traits at this age. In this analysis, first-lambing ewes as old as 23 months of age at lambing time were included. Had the maximum age been lower, the early-maturing ability of the breeds with Finn background, as described by Vesely and Swierstra (1987), may have been more evident in this analysis.

Reproduction Performance Over All Parities

The least squares means and standard errors for reproduction traits over all parities for the four breed groups are shown in Table 6. When parities at all ages were considered, the litter-size least squares means followed the same general pattern as that shown for litter size at first parity. The Outaouais again out-performed the Suffolk for litter size at birth (1.93 ± 0.06 vs. 1.38 ± 0.07 lambs) and the cross-bred ewes had performance values between those of the purebreds but not significantly different from the Outaouais. The Outaouais X Suffolk cross showed litter-size performance at both birth and 42 days which numerically appeared superior to that of the purebred Suffolks. However, due to their relatively small group size and large variation in the data, this performance level failed to differ significantly from that of the Suffolks ($p < 0.05$).

The breed values for litter weights at birth (Table 6) revealed that the differences in numbers of lambs born was largely compensated for by the weights observed (Manuscript II) for the individual lambs at birth, making the total litter weights at birth more uniform among the breeds and breed crosses. No significant effect of breed group on total litter weight was shown in the analysis of variance

TABLE 6. Least squares means and standard errors for reproductive performance over all parities at birth and 42 days of age by ewe breed.

Ewe breed[1]	Mean litter size (number of lambs ± standard error[2])
	Birth
SU	1.38 ± 0.07[a]
OU	1.93 ± 0.06[b]
SU x OU	1.74 ± 0.12[b]
OU x SU	1.87 ± 0.21[ab]
	42 days of age
SU	1.30 ± 0.08[a]
OU	1.71 ± 0.07[b]
SU x OU	1.58 ± 0.12[b]
OU x SU	1.70 ± 0.20[ab]

Breed	Mean litter weight (weight of litter (kg) ± standard error)
	Birth
SU	6.03 ± 0.80[a]
OU	5.94 ± 0.90[a]
SU x OU	6.18 ± 1.47[a]
OU x SU	7.32 ± 1.49[a]
	42 days of age
SU	21.12 ± 2.95[a]
OU	21.40 ± 3.22[a]
SU x OU	23.19 ± 5.28[a]
OU x SU	27.16 ± 5.36[a]

[1] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

[2] Values within each parity group with different superscripts are significantly different ($p < 0.05$).

for these traits. By 42 days of age, however, the ability to excel in total litter weight started to favour the breed groups that had the higher numbers of lambs at birth. The tendency was for the Suffolk to perform comparably to the Outaouais but neither pure breed was able to match the performance level of either of the crossbred groups for total litter weight at 42 days of age. However, none of the differences among breeds were significant for lambs at this age in this trial.

It was noted that the values for the raw means for both litter size and litter weight were consistently higher than the values obtained from the least squares analysis. Table 1 shows that there were over twice as many lambing records in the last half of the trial as there were in the first half. In addition, there was a highly significant ($p<0.01$) increase in the mean performance of ewes in these traits as the trial progressed (Figure 5). Raw means are effectively weighted, since no consideration is given to the year/season in which the record is made. The least squares means values include a group mean year/season effect and a weighting for the numbers of animals within each group. However, due to lack of fit, the net result is that the group mean values in the least squares means analysis were moved downwards as was observed in this analysis.

Bourfia and Touchberry (1993b) in studies with Moroccan breeds of sheep, found that the mating of the prolific D'man breed to the larger Beni Guil rams resulted in larger litters, higher survival and, most importantly from the standpoint of productivity, larger litter weights at weaning. Similarly, cross-breeding trials with Finnsheep and the synthetic DLS breed (Fahmy and Dufour, 1988) demonstrated that even though the DLS showed heavier weights in the individual lambs at birth, the higher percentage Finn-cross ewes had higher total litter weights by weaning.

Genetic Effects

The contrasts developed to examine the magnitude of the breed additive genetic effects showed that the direct genetic effect of the Outaouais breed was superior in varying degrees over that for the Suffolk in all eight traits examined (Table 7). This effect was not significant ($p > 0.1$) for any of the first parity traits. Averaged over all parities, however, the effect approached significance ($p < 0.1$) for litter weight at birth. For litter weight at 42 days and litter size at birth or 42 days (over all parities), the levels were significant at the $p < 0.05$

TABLE 7. Estimates of component genetic effects[1] and standard errors[2] for reproductive traits.

Trait	Direct effect	Maternal genetic effect	Heterosis effect
		Parameter estimate	
		First parity	
Litter size at birth	0.35 ± 0.26	0.01 ± 0.22	0.28 ± 0.17[a] (19.3%)
Litter size at 42 days	0.32 ± 0.27	0.05 ± 0.27	0.06 ± 0.17 (5.3%)
Litter weight at birth	0.71 ± 0.77	-0.69 ± 0.63	0.91 ± 0.48[a] (16.7%)
Litter weight at 42 days	2.15 ± 2.77	-0.82 ± 2.24	3.52 ± 1.79[*] (18.7%)
		All parities	
Litter size at birth	0.68 ± 0.21[*]	-0.13 ± 0.20	0.15 ± 0.11 (9.1%)
Litter size at 42 days	0.53 ± 0.19[*]	-0.12 ± 0.18	0.14 ± 0.10 (9.0%)
Litter weight at birth	1.05 ± 0.60[a]	-1.14 ± 0.57[*]	0.77 ± 0.30 (12.8%)
Litter weight at 42 days	4.24 ± 2.07[*]	-3.97 ± 1.97[*]	3.91 ± 1.04[a] (18.4%)

[1]Estimates for direct and maternal genetic effects are expressed in terms of Outaouais dams vs. Suffolk dams.

[2]Standard error values for all traits except litter size at first parity were calculated using mean square for dam within dam breed as the appropriate error mean square.

[a]Effect significantly different from zero at $p < 0.1$.

[*]Effect significantly different from zero at $p < 0.05$.

level. The direct genetic ability of the Outaouais to have larger litters resulted, not surprisingly, in a demonstrated superiority in the litter-size traits in this trial. Interestingly, however, the well-recognized genetic merits of the Suffolk in weight traits (as described in Manuscript II) that were contributed directly to the Suffolk offspring, were not sufficient to compensate for the advantage of fecundity in the Outaouais. As a result, the Outaouais continued to show a superiority over the Suffolk in terms of direct genetic contribution to productivity, even in the composite traits that included consideration of offspring weight.

Maternal genetic effects were not significant for any of the traits related to litter size, or for either of the litter-weight traits at first parity. However, Suffolks demonstrated highly significant superiority ($p < 0.05$) for maternal genetic effect in terms of litter weights over all parities at both birth and 42 days.

The direct genetic contributions from reciprocals of a cross between two breeds are expected to be equal. However, since the breed of the dams of each reciprocal is different, differences in the performance of the offspring of the crossbreds may be expected as a carry-over effect resulting from the ability of one of the component purebred dam breeds over the other to raise a ewe which in turn has a superior ability to raise lambs. The superiority in maternal genetic contribution demonstrated by the Suffolks in this trial is noteworthy. However, a determination of the degree to which this is simply a manifestation of the fact that Suffolk dams have relatively fewer lambs to raise would be required (together with other considerations) before any claim is made on the merit of including high levels of Suffolk in a breeding plan for crossbred ewes.

The value of the individual heterosis effect in the crossbreds was positive for all eight reproductive traits measured as shown in Table 7. Generally speaking, heterosis was seen to be a more significant contributor to the overall performance of the crosses in litter traits at first parity, with heterosis values approaching significance ($p<0.1$) being observed for litter size and weight at birth, and litter weight at 42 days being significant at the $p < 0.05$ level. When litter traits over all parities were considered, only litter weight at 42 days of age showed a heterosis effect that approached significance ($p < 0.1$).

Generally, reproductive traits are considered to be the traits in which heterosis is most evident. The fact that performance in the composite traits (litter weight at birth and 42 days of age) included a significant heterosis component indicates the importance of fecundity as a component of litter weight. In practical terms, the level of heterosis is a manifestation of the degree to which a breeder has been successful in combining breed resources so that a maximum number of dominant alleles in a trait are present in the resulting cross. In the present trial, the heterosis values observed would be reduced over what might otherwise be expected by the fact that the 21% of the breed background of the Outaouais is from the Suffolk breed.

Nitter (1978) reported mean heterosis values for litter size at birth of 5% but for litter size at weaning, this figure was 15%. Long et al. (1989), working with Suffolks and Targhees, found values of 7% for prolificacy and 10% for ewe productivity (kilograms of lamb weaned per ewe exposed to breeding per year). However, the heterosis values for litter weight at birth found by Fahmy and Dufour (1988) were small, and in some cases negative, depending on the percentage of Finnsheep in the cross. In his review, Jakubec (1977) reported values for heterosis for litter size born in crosses based on prolific breeds of sheep from -9% to over 30%, and for litter size weaned from -23% to 12%, depending on the breeds involved.

The heterosis value for litter weight at weaning shown by Fahmy and Dufour (1988) for 1/2 cross Finnsheep ewes was 22%, (though crosses with other levels of Finnsheep breeding were as low as 1.5%). Their figure for 1/2 cross Finn ewes corresponds well with that found in this study, and with that (18%) published in Nitter's (1978) review of average heterosis percentages. Their heterosis value in the 1/2 Finnsheep for the number of lambs weaned (13%) is similar in magnitude to that found in this study. Gallivan et al.(1987) found individual heterosis to be 8% for litter weight at weaning, despite a high maternal heterosis value of 33% for this same trait in a rotational crossbreeding system involving Columbia, Targhee, Hampshire and Finnsheep breeds.

The weight of a litter of lambs at weaning is a composite trait that includes litter size at birth, neonatal survival, pre-weaning survival and lamb growth to weaning. As a measure of ewe productivity, it is influenced by the ewe's fertility, fecundity, milking ability, growth rate, and if calculated on an annual basis, the ability to breed out of season. Litter weight at weaning can be considered a biological index, and its importance in any selection program to increase ewe productivity is felt to be considerable (Abdulkhaliq et al. 1989). However, at weaning, the predominant factor influencing litter weight is number of lambs in the litter rather than average lamb weight. Martin et al.(1980) suggests that since heritability estimates for litter weights at birth are higher than those at weaning, selection on litter weight at birth might be more effective in changing total lamb weight weaned than direct selection.

In general, these productivity results support the economic findings of Saoud and Hohenboken (1984) who described the success of Finnsheep-cross ewes in irrigated and non-irrigated pasture environments. In terms of net revenue, the Finnsheep was able to demonstrate its worth in either environment provided the appropriate breed was used for the other portion of the cross (i.e. Finnsheep X Suffolk for irrigated pastures or Finnsheep X Columbia for hill pastures).

Environmental Factors Affecting Ewe Productivity

Neither age of ewe nor year-season of lambing had significant effects ($p>0.05$) on the first parity litter size at birth (Figures 2 and 3). However, both age of ewe and year-season of lambing were significant ($p<0.05$) factors that affected first parity litter size means at 42 days of age and first parity litter weight means at both birth and 42 days of age.

Age of ewe had a significant ($p < 0.01$) influence on litter-weight traits when all parities were considered (Figure 4). Year-season also had a significant ($p < 0.01$) influence on both litter-size and litter weight traits over all parities at both birth and 42 days, and is shown in Figure 5.

In previous studies, environmental influences have been shown to have an important influence on breed evaluation (Dickerson, et al. 1972; Vesely and Peters 1972; Rastogi et al. 1975; Shrestha and Vesely 1986). This was also found to be the case even in an artificial, controlled environment (Shrestha et al, 1992). Included in the influences studied here were year of birth, age of dam, litter size (both at birth and 42 days of age) and sex of

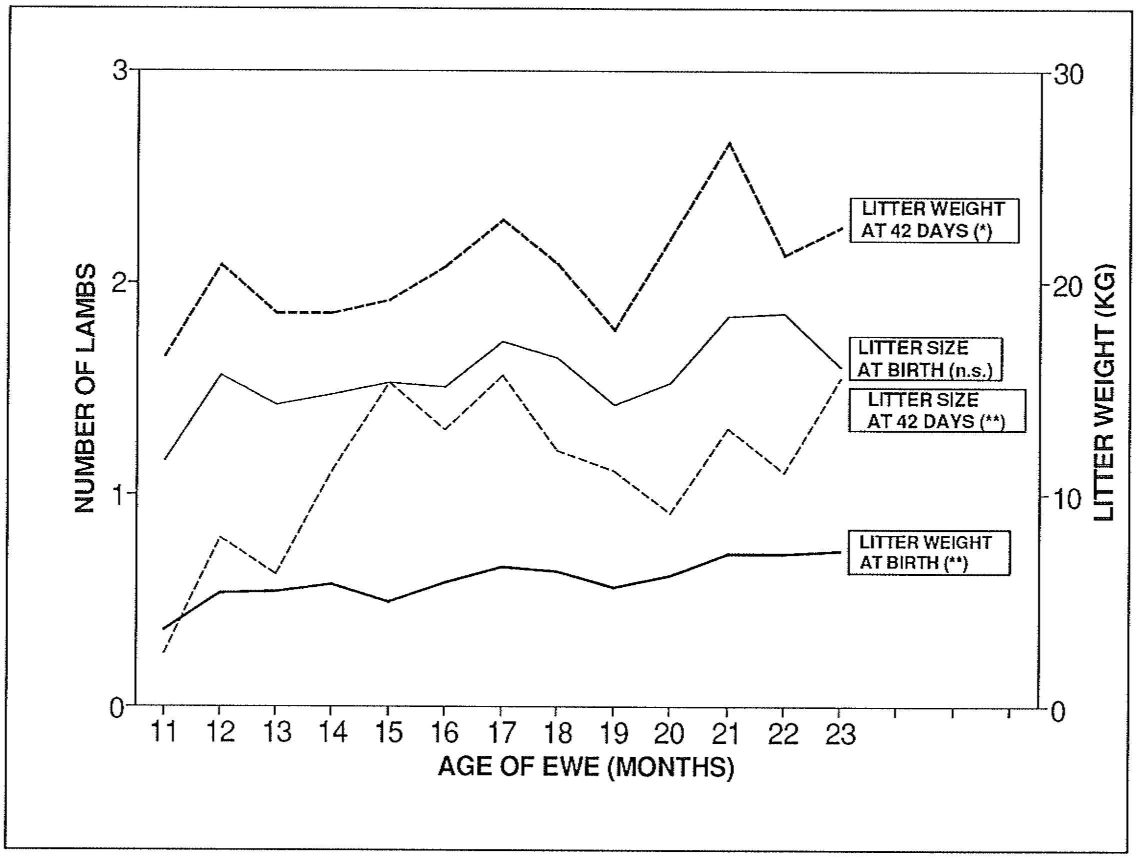

Figure 2. Effect of age of ewe on first-parity litter traits of ewes. (** = effect is significant $p<0.01$; * = effect is significant $p<0.05$; n.s. = effect is not significant)

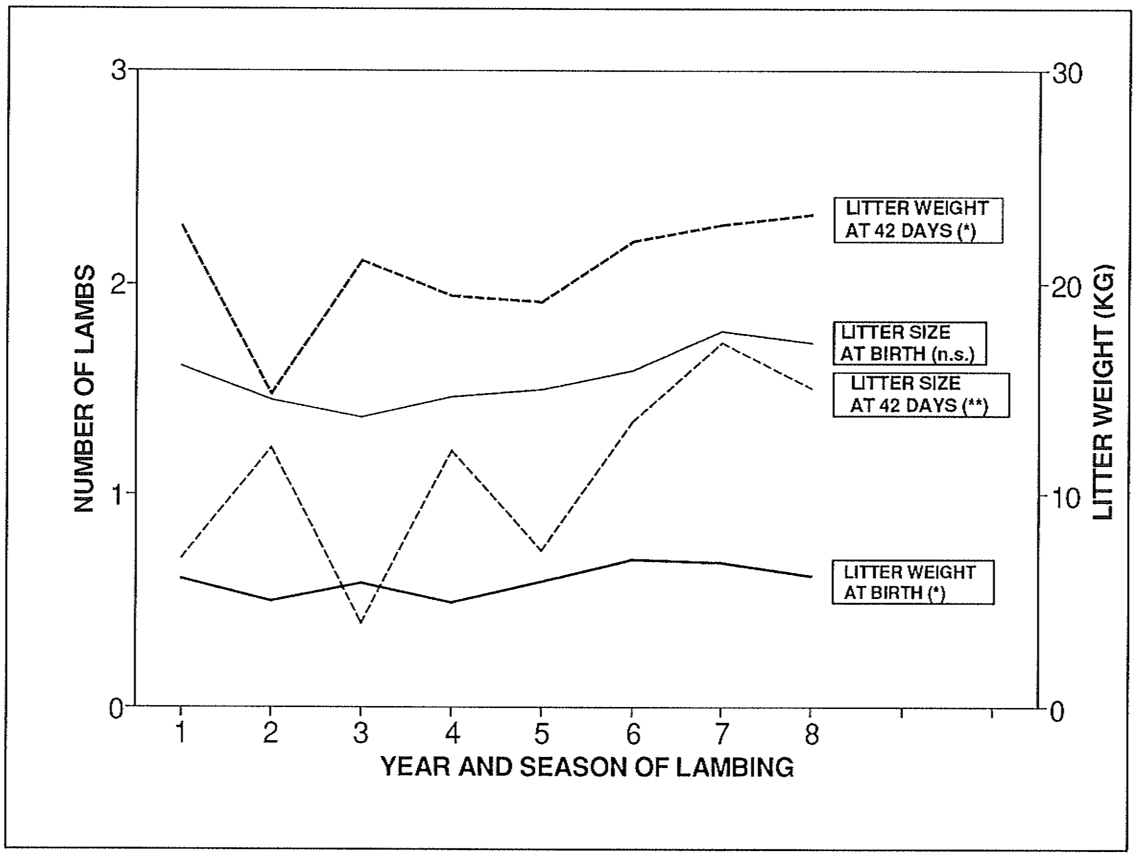

Figure 3. Effect of year/season on first parity litter traits of ewes. (** = effect is significant p<0.01; * = effect is significant p<0.05; n.s. = effect is not significant)

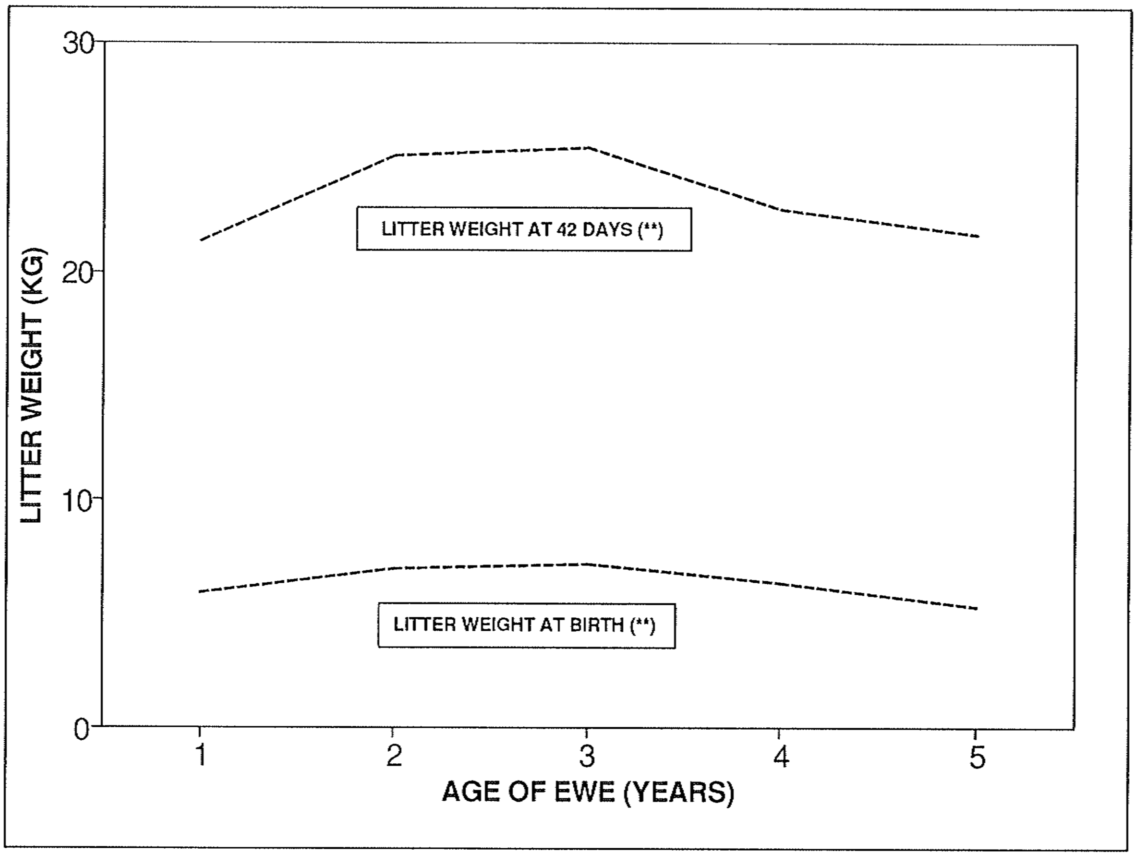

Figure 4. Effect of age of ewe on litter weight at birth and 42 days of age. (** = effect is significant $p<0.01$)

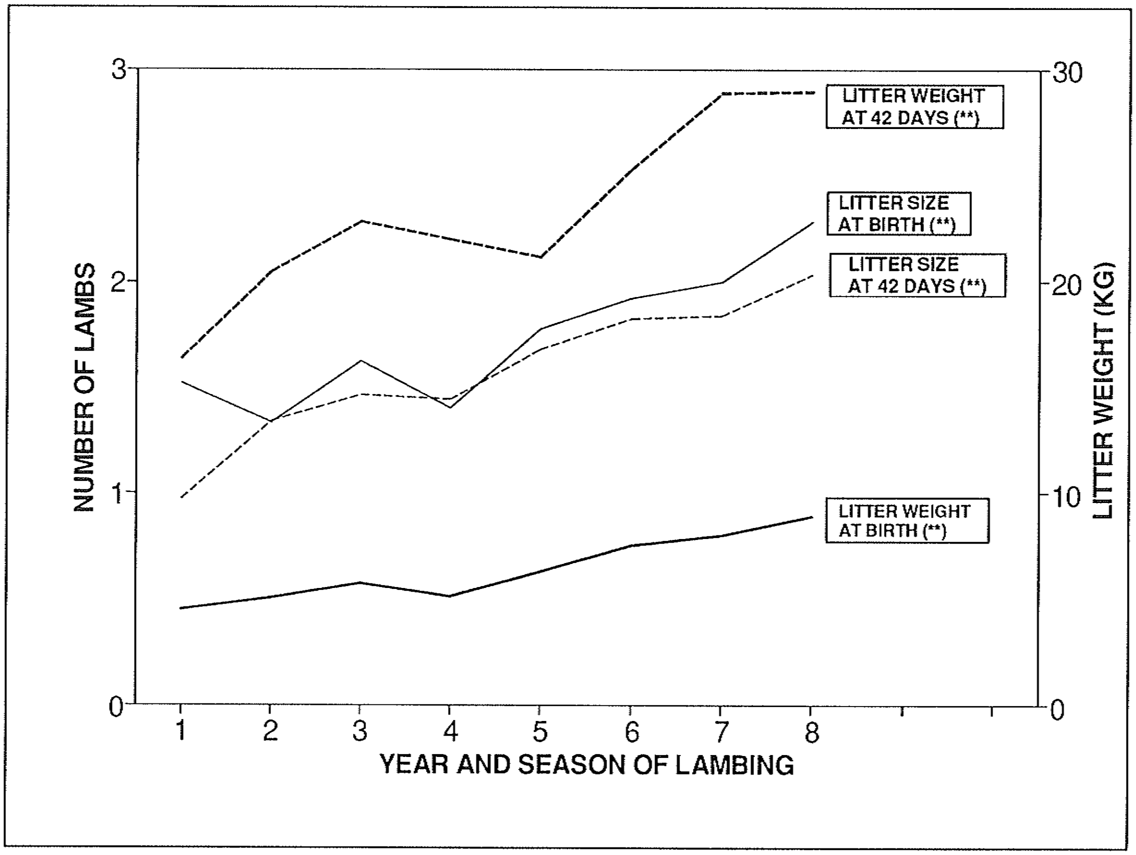

Figure 5. Effect of year/season on litter traits of ewes.
(** = effect is significant $p<0.01$)

lamb. An additional effect of interest in the trial was the litter size in which the ewe was born and reared. However, due to incomplete representation of animals from this data set in some of the classes of this effect (Suffolks born and raised in large litters or Outaouais born and raised as singles, for example), this effect was not possible to isolate. The apparent improvement in mean overall productivity over the years illustrated by Figures 3 and 5 suggests that the level of flock management improved over that period. Further, the farm staff reported difficulty in controlling severe outbreaks of coccidiosis from 1985 to 1987 (year-season periods 4 to 6) in lambs when they were approximately one month of age. The litter weights at 42 days of age during that period show clearly the effect that this had on lamb growth.

Conclusion

In this trial, composite traits were used as a method of breed evaluation in a production environment similar to that on many commercial sheep operations. The newly-developed Outaouais breed demonstrated a superior level of productivity, based on more than simply its ability to produce larger litters. On the basis of litter weight at six weeks of age, the Outaouais as a pure breed and as a contributor to a commercial crossbred ewe, indicated its ability to perform well in a moderately intensive, commercial, semi-confinement operation. The degree to which this level of productivity would be an advantage in more extensive, range-based operations was not evaluated. The superior maternal ability demonstrated by the Suffolk ewes would suggest that an advantage exists in mating OU rams to SU ewes to produce high-performing offspring. Whether the maternal ability for litter weight would compensate for the drop in the number of lambs available as a result of choosing this breeding plan was also not evaluated. However, as a breed for use in farm-based flocks, the Outaouais appears capable of making a significant contribution to the sheep industry in North America.

MANUSCRIPT II

Genetic Evaluation of the Canadian, Outaouais, Hampshire and Suffolk Breeds for Lamb Growth

MANUSCRIPT II

Abstract

A sheep flock, maintained under a semi-confinement management system, was used to evaluate four breeds: the Canadian Arcott (CA), a recently-released terminal sire breed; the Outaouais Arcott (OU), a dam breed, also recently-released; and the Suffolk (SU) and the Hampshire (HA) as representatives of the traditional breeds. Lambs sired by CA rams were compared with those sired by HA rams for birth weight, 42-day weight and 120-day weight. Both of these breeds were bred to Suffolk X Outaouais crossbred ewes. The design of the trial also permitted the comparison of the performance of the resulting three-way cross lambs with that of straight-bred SU or OU lambs and the two-way crosses (SUxOU and OUxSU) between the two breeds. Trial data were analyzed using a traditional least squares analysis and the results were compared with those from a multi-trait animal model analysis of the same data. SU lambs were heavier at birth at 3.8±0.26 kg, though not significantly so over CA-sired or HA-sired lambs which

averaged approximately 3.2 kg. Outaouais lambs were the lightest (2.8±0.32 kg) with the F_1 crosses being between the two. By 42 days of age, the relative ranking of breed groups had not changed with weights ranging from 10.6±1.07 to 12.6±1.20 kg. By 120 days of age, there was no significant difference ($p > 0.05$) among the SU, OUxSU, and CA- and HA- sired groups. The OU and SUxOU groups were significantly lighter at 29.7±1.92 and 28.5±1.93 kg respectively. Of the two terminal sire breeds being tested, the CA-sired lambs were heavier (28.9±3.89 kg) than those sired by the Hampshire rams (28.0±4.32 kg), but the difference was not seen to be significant. Values derived for the breed genetic effects showed Suffolk to excel over the Outaouais in terms of significant direct and maternal genetic effects for birth weight at 0.5±0.10 and 0.5±0.07 kg respectively. By 42 days, there was effectively no difference in direct genetic effect between the breeds, though the maternal effect superiority was still strongly shown by Suffolks (2.0±0.25 kg). By 120 days, the direct genetic effect favoured the Outaouais (3.0±1.03 kg), but maternal effects were still strongly shown by Suffolks. Heterosis effects were generally small (< 3.1%) and were not significantly different from zero ($p>0.1$) at any age. The terminal sire breed effect showed no advantage for either the Canadian or the Hampshire for birth weights.

Interestingly, the Hampshire tended to show an advantage of 0.6±0.38 kg at 42 days indicating better early growth in offspring. By 120 days of age, Canadian-sired lambs showed a superiority of 0.9±1.16 kg. Generally speaking, ranking of groups did not change as a result of animal model analysis. This analysis appeared to give results consistent with the least squares analysis, but tended to demonstrate a superior ability to extract breed effects than traditional least squares procedures when the breed groups were not well represented in all classes of the other fixed effects.

Introduction

The livestock industries in many parts of the world in which the production of red meat is of major importance have traditionally depended very heavily on crossbreeding to maximize productivity. In swine, it has been reported that a specific three-breed cross, developed from females of a single cross which excels in maternal traits, in turn mated to sires of a third breed which excels in bodyweight gain and carcass traits, will approach maximum efficiency of production (Smith, 1964; Shrestha, 1973). A high proportion of total income in sheep operations in North America is derived from the sale of market lambs, and some form of crossbreeding is utilised in most of these farm operations. A number of studies have outlined the genetic resources in various sheep breeds (Sidwell et al. 1962, 1964; Sidwell and Miller 1971; Dickerson et al. 1972; Vesely and Peters 1972, 1979; Eikje 1974; Shrestha and Vesely 1986) and have suggested the selection of the appropriate breeds to utilize in a crossbreeding system or in new breed development to assist in the achievement of maximum efficiency in lamb production.

Crossbred market lambs are preferred firstly because they tend to exhibit an improvement in growth and survival simply as a result of heterosis. Further, crossbreeding presents the opportunity to introduce genes in a terminal cross from a breed known for high rate of gain and superior carcass quality. One such breed is the recently-released Canadian Arcott, developed by the Animal Research Centre (CFAR) in Ottawa.

The management system used at the Animal Research Centre (CFAR) at the time of the formation of these breeds was a highly intensive, total confinement system in which animals were housed indoors in a controlled environment, lambs were weaned almost immediately after birth and raised artificially on milk-replacer diets. Light control and exogenous hormones were used to synchronize estrous cycles of all ewes gred in an 8-mo breeding cycle. Before this breed was to be accepted by the industry, it was necessary that it demonstrate high productivity under more conventional management systems. Trials were therefore designed to place these sheep in different locations, one of which was at the University Farm of the University of Manitoba.

Growth traits are important in the evaluation of the genetic worth of individuals. The national evaluation programs in both the United States and Canada utilize various measures of weight or bodyweight gain. In the U.S. program, producers are offered a total of six weight traits from which they may choose three for inclusion in their flock evaluation (Wilson and Morrical, 1991).

The objectives of this study were firstly to analyze the growth performance of Canadian Arcott-sired and Hampshire-sired lambs in a traditional production environment together with Suffolk and Outaouais lambs and the two reciprocal crosses between the latter two breeds. The second objective was to compare the results of this evaluation obtained from a least squares analysis with those derived from an analysis utilizing animal model techniques.

Materials and Methods

Three New Breeds

In the 1960's, the Animal Research Centre (CFAR) in Ottawa developed a specialised sire strain and two dam strains from their foundation stock which was made up from both established and imported germ plasm (Shrestha et al. 1982). During the development of these strains, all sheep were housed indoors in a controlled environment utilising eight-month breeding cycles and artificial rearing of newly-born lambs. An outline of the breeding program and observations on early weaning have been presented by Peters (1974a,b).

The synthetic sire strain (Canadian Arcott) was developed as a terminal cross meat sire breed, primarily from the Suffolk (37%), Ile de France (28%) and Leicester (14%) breeds with contributions from the North Country Cheviot (7%) and Romnelet (6%). The Outaouais Arcott breed, one of the dam breeds, was derived from the Finnish Landrace (49%), Shropshire (26%) and Suffolk (21%) breeds. Minor (less than ten percent) contributions were made by several other breeds in both Arcott breeds.

Selection was applied to the Canadian Arcott breed to increase lean muscle mass and growth rate, with lesser emphasis placed on prolificacy. Selection of lambs was done according to an index based on the growth performance of full and half-sibs to 91 days of age. During the 1970's, ram lambs were selected for carcass quality based on ultrasonic measurements of loin eye and back-fat adjusted for body weight and litter size. Mature rams were selected for the subsequent breeding primarily on the basis of fertility at the first breeding, based on an ultrasonic pregnancy diagnosis of their mates 60 days after removal of rams from breeding pens.

In the two synthetic dam strain (Outaouais Arcott), replacement ewe-lambs were selected based on growth rate to 91 days of age and the litter size of their parents. As adults, no selection was carried out on ewes during the first breeding season. From the second breeding to the final breeding, selection was based on a ewe productivity index. This index was computed as the weight of lambs produced at 91 days of age summed over previous breedings. Any ewe that failed to produce a live lamb from the second to the fifth breeding was automatically culled. Otherwise, ewes were culled by age group, i.e. 10% were culled after the first breeding, 11% after the second, 13% after the third, 14% after the fourth and 100% after the fifth. An index of lifetime performance of dams and grand-dams (maternal and paternal) was used as the main selection criterion from 1984 onward.

Flock Management

Subsequent to the development of the three breeds in the total confinement facility at the Animal Research Centre (CFAR) in Ottawa, two flocks were established in different locations in order to assess the performance of the new breeds in environments that more closely resembled those that would be experienced by sheep in the commercial industry. One of these locations was the University of Manitoba farm facility in Winnipeg, the other being the Bradley Farm at the Agriculture Research Centre in Ottawa.

The physical facilities at the University of Manitoba, management prior to breeding and the breeding protocol were as described in Manuscript I. The numbers of lambs born within each breed and cross throughout the trial period are shown in Table 8. Over the total trial period, 1,722 lambs from 435 ewes and 74 rams were utilized in the breeding program.

TABLE 8. Distribution of lamb births by breed throughout the trial period.

Lamb breed[2]	Season and year of birth[1]								
	1	2	3	4	5	6	7	8	Totals
SU	40	0	49	9	67	35	38	72	310
OU	3	59	83	37	77	102	38	118	517
SUxOU	0	0	0	58	132	109	17	86	402
OUxSU	0	0	0	11	37	64	28	31	171
CA(SUxOU)	0	0	0	0	0	45	85	91	221
CA(OUxSU)	0	0	0	0	0	8	18	5	31
HA(SUxOU)	0	0	0	0	0	0	31	26	57
HA(OUxSU)	0	0	0	0	0	0	3	10	13
Totals	43	59	132	115	313	363	258	439	1722

[1]Season and year abbreviations: 1=Spring 1984, 2=Fall 1984, 3=Spring 1985, 4=Fall 1985, 5=Fall 1986, 6 to 8 are Spring lambings in 1987, 1988 and 1989 respectively.

[2]Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott, CA=Canadian Arcott, HA=Hampshire. The first breed in a two-way cross is the sire breed. CA(SUxOU)=a Canadian-sired three-way crossbred lamb out of a Suffolk-sired Suffolk x Outaouais two-way crossbred ewe.

Details of the rations, flock management at lambing time and post-lambing, orphan lamb management and weaning procedures were carried out as described in Manuscript I. Lamb weights were taken within 24 hours after birth, then weekly from birth to 42 days of age, and at 60 days and 120 days of age. All weighings were done on the Monday or Friday closest to the day on which the lamb reached the age for that weighing, i.e. the 42-day weight was taken on the Monday or Friday closest to the day on which the lamb was exactly 42 days of age. Weights taken at 42 days and 120 days of age were required for analysis in this trial. The 42-day weights were adjusted for age to a 42-day constant age by calculating the average daily gain from birth to the time the lamb was weighed, and adding this amount, multiplied by 42, to the actual birth weight. Similarly, the 120-day weights were adjusted by calculating the daily gain from 42 days to 120 days of age, multiplying it by 78 and adding the product to the adjusted 42-day weight.

Mating Plan

The objective of this trial at this location was to evaluate the growth performance of lambs produced by mating either Canadian Arcott or Hampshire rams to either of the reciprocal F_1 cross (Suffolk x Outaouais or Outaouais x Suffolk) ewes. With this design, it was possible to compare the Canadian Arcott and the Hampshire as terminal-cross sire breeds. Comparisons were also possible with purebred Suffolks and Outaouais and the reciprocal crosses of these two breeds. The numbers of lambs present at each weighing by breed over the whole trial period are shown in Table 9.

The Hampshire was chosen as a terminal sire breed since it is primarily a meat sire breed, and does not occur in the breed background of the Arcotts. The Suffolk was not evaluated as a terminal sire breed since not only was it used as a crossing breed with the Outaouais Arcott in this trial, but it was also a major contributor (20 to 37%) to the genetic background of the Arcott breeds during their establishment. However, growth data from pure Suffolks and from first cross Suffolk X Outaouais lambs were also available to use for comparative purposes.

To achieve the trial objective, the Animal Research Centre (CFAR) in Ottawa released to the University of Manitoba 100 ewes and ten rams as a base flock of Outaouais Arcotts. During the period from 1984 to 1989, purebred matings of these sheep were carried out to expand and maintain the purebred flock. From 1985 to 1989, Suffolk x

TABLE 9. Numbers of lambs weighed by breed over the total trial period.

Lamb breed[1]	Lambs weighed at birth	Lambs weighed at 42 days	Lambs weighed at 120 days
SU	307	234	199
OU	510	444	376
SUxOU	398	356	337
OUxSU	170	157	149
CA(SUxOU)	212	192	181
CA(OUxSU)	31	29	27
HA(SUxOU)	52	40	34
HA(OUxSU	12	10	10
Total records	1692	1462	1313

[1]Breed abbreviations: SU=Suffolk; OU=Outaouais; SUxOU= crossbred offspring of a Suffolk sire and an Outaouais dam; CA(SUxOU)=a three-way cross, sired by a Canadian ram from a SUxOU crossbred dam; HA=Hampshire.

Outaouais Arcott crosses and the reciprocal cross were produced and from 1986 to 1989, these crosses were bred to either Hampshire or Canadian Arcott sires to produce the three-way cross lambs required for evaluation. Again, no selection was applied to this population and culling was only used as required to maintain a healthy flock free of physical abnormalities.

Statistical Methods

The objective of this portion of the trial was to evaluate the Canadian Arcott as a terminal sire breed. This was achieved through the measurement of birth weights, 42-day weights and 120-day weights of progeny from cross-bred ewes sired by Canadian rams and comparing them with equivalent progeny sired by Hampshire rams, an example of a terminal meat sire breed currently used by the sheep industry. The ewes utilized in the trial were F_1 Suffolk X Outaouais ewes and their reciprocals. Growth data from lambs of this cross and from the purebred Suffolk and Outaouais portions of the flock used to produce the F_1 ewes were also available for comparison. Table 10 shows the number of lambs present, mean performance, and maximum and minimum values for all three weight traits.

TABLE 10. Numbers of lambs, raw means, standard deviations, and minimum and maximum values for weight traits by breed group.

Breed[1]	N	Mean	Standard deviation	Minimum	Maximum
		Birth weight (kg)			
Suffolk (SU)	307	4.45	1.08	0.90	9.00
Outaouais (OU)	510	3.32	0.88	0.90	5.00
SU x OU	398	3.44	0.96	0.40	6.50
OU x SU	170	4.39	0.97	1.80	7.00
CA(SUxOU)	212	3.86	0.98	1.60	6.40
CA(OUxSU)	31	3.96	1.01	1.80	5.60
HA(SUxOU	52	3.74	1.20	1.60	7.40
HA(OUxSU)	12	3.72	0.93	2.40	5.70
		42-day weight (kg)			
Suffolk (SU)	234	15.34	3.75	5.25	25.40
Outaouais (OU)	444	12.52	2.67	6.09	21.33
SU x OU	356	11.83	3.01	3.36	20.53
OU x SU	157	15.60	3.39	8.10	25.03
CA(SUxOU)	192	14.12	3.39	6.60	24.07
CA(OUxSU)	29	14.99	3.01	9.42	22.70
HA(SUxOU	40	15.87	3.55	8.80	24.59
HA(OUxSU)	10	14.36	3.04	10.64	20.97
		120-day weight (kg)			
Suffolk (SU)	199	35.80	7.01	13.21	53.65
Outaouais (OU)	376	33.86	6.45	16.71	53.21
SU x OU	337	32.59	7.64	12.67	57.18
OU x SU	148	38.81	7.50	20.35	58.50
CA(SUxOU)	181	33.12	8.22	16.85	53.87
CA(OUxSU)	27	31.16	8.48	18.31	46.34
HA(SUxOU	34	31.85	7.76	23.04	49.90
HA(OUxSU)	10	34.42	8.39	24.02	48.27

[1]Breed abbreviations: SU=Suffolk; OU=Outaouais; SUxOU=crossbred offspring of a Suffolk sire and an Outaouais dam; CA(SUxOU)=a three-way cross, sired by a Canadian ram from a SUxOU crossbred dam; HA=Hampshire.

The purpose of the analysis was first to estimate the performance of the breeds and their crosses, having removed the effect of other non-genetic factors that influence performance. This can be done through the use of a conventional least squares analysis of variance, as has been done recently by Shrestha et al. (1986) Boujenane and Kerfal (1990), Boujenane et al. (1991a,b), Bourfia and Touchberry (1993a,b), and prior to this by many researchers. Alternatively, an animal model analysis in the form of that developed by Quaas and Pollock (1980) can be used. In this method, a set of simultaneous equations is developed incorporating coefficients to acount for direct genetic correlations, environmental genetic correlations, genetic relationships among animals and maternal environmental effects resulting from some lambs having been raised by the same dam. The coefficients were derived from a series of SAS analyses, and the simultaneous equations were solved using a Gauss-Seidel iterative procedure. Both systems were utilized in this trial and the results were compared.

The underlying mathematical model for the least squares analysis was as follows:

$$Y_{ijklmno} = \mu + t_i + s_j + d_k + r_l + b_m + p(b_m)_n + e_o$$

where:

$Y_{ijklmno}$ = the record of the birth weight of the *n*th lamb from the *o*th dam of the *m*th breed or breed cross, born in the *i*th year and season, of the *j*th sex, to a ewe in the *k*th age group and into the *l*th litter-size group;

μ = the overall mean effect;

t_i = effect of year/season at lambing (i = 1, Spring 1984; 2, Fall 1984; 3, Spring 1985; 4, Fall 1985; 5, Fall 1986; 6, Spring 1987; 7, Spring 1988; 8, Spring 1989), considered a fixed effect;

s_j = effect of sex of lamb (j = 1, male; 2, female), considered a fixed effect;

d_k = effect of age of dam in years (k = 1, 2, 3, 4, or 5 and over), considered a fixed effect;

r_l = effect of the litter size at birth (l = 1, 2, 3, or 4 and over), considered a fixed effect;

b_m = effect of breed or breed cross (m = 1 for Suffolk, 2 for Outaouais, 3 for Suffolk X Outaouais, 4 for Outaouais X Suffolk, 5 for Canadian(Suffolk X Outaouais) and the reciprocal dam, and 6 for Hampshire(Suffolk X Outaouais) and the reciprocal dam), also considered a fixed effect;

$p(b_m)_n$ = effect of dam within breed or breed cross, considered a random effect with mean 0 and variance σ_p^2, and

e_o = random (residual) error, representing variation among lambs from the same dam.

The models for 42-day and 120-day weights were similar except the factor for litter size was changed so that it encompassed not only the litter size into which the lamb was born, but also the litter size in which it was raised as described in Table 11. Lambs that were raised as orphans were not included in the analysis beyond birth, and were subsequently treated as missing. Also, it should be noted that in the least squares analysis, the dam effect term includes the of the maternal environment together with effects of having common genes causing offspring within the same family to perform similarly. In the animal model that follows, the dam effect includes only the effect due to the environment provided to the lamb by the dam.

In the least squares analysis, the data for birth weight, 42-day weight and 120-day weight were analyzed using the GLM procedures of SAS (1988). Since significant numbers of dams produced lambs that were sired by different

TABLE 11. Classes of type of birth and rearing used in analyses of lamb weight performance.

Class	Class description
1	Orphaned lambs, birth data only used in this analysis.
11	Born as a single, raised as a single.
21	Born as a twin, raised as a single.
22	Born as a twin, raised as a twin.
31	Born as a triplet, raised as a single.
32	Born as a triplet, raised as a twin.
33	Born as a triplet, raised as a triplet.
41	Born as a quadruplet[1], raised as a single[2].
42	Born as a quadruplet, raised as a twin.
43	Born as a quadruplet, raised as a triplet.
44	Born as a quadruplet, raised as a quadruplet.

[1]Lambs born to larger litters were included in the quadruplet-born class since no ewes raised more than four lambs.

[2]No lambs were present in the Class of 41.

breeds of sire, it was necessary to use a dam-within-offspring-breed term in the analysis. This forces the model to consider these dams as different dams if the breed of mate is different in the various parities of that dam, but leads to less error than if no action was taken to address this influence on variance. Beyond this, sire effects were ignored since there was no particular type of design used for setting up mating groups. All two- and three-way interactions were considered, but not included in the final model since they were found to be non-significant in preliminary analyses. In the calculation of the standard error values for the least squares means for breed group effects, the Type III mean square for dam within dam breed was used as the appropriate error term.

In addition, the data were analyzed using an animal model which provided simultaneous evaluations on all three traits (birth weight, 42-day weight, and 120-day weight), utilizing all pedigree and repeated record information and accounting for all environmental effects in a manner similar to that developed by Quaas and Pollack (1980). The fixed effects that were included in the model were those included in the least squares analysis, namely breed (six classes), year and season (eight classes), sex (two classes) and dam age at lambing (five classes). Four classes of birth type were included in the analysis of birth-weight data, and nine classes of type of birth and rearing, as shown in Table 11, were included in the analysis of 42-day and 120-day weights. The animal model used for the analysis is shown in Figure 6. In this model:

1) $\boldsymbol{X}$, $\boldsymbol{Z}$ and $\boldsymbol{W}$ are incidence matrices associating lamb weights with fixed effects ***(b)***, the additive genetic merit of the sire, dam and lamb as a deviation from the function of their respective group effects ***(a)*** (considered random with mean 0 and variance σ_g^2), and the non-genetic permanent (maternal) environment effects of dams with multiple reecords ***(p)*** (also considered random with mean 0 but with variance σ_p^2);

2) $\boldsymbol{R}^{ij}$ represents a set of coefficients derived from an inverted matrix of error variance and covariance values to modify all terms in the matrix to account for residual correlations among the traits being analyzed, i and j representing traits;

$$
\begin{pmatrix}
X_1'R^{11}X_1 & X_1'R^{12}X_2 & X_1'R^{13}X_3 & X_1'R^{11}Z_1 & X_1'R^{12}Z_2 & X_1'R^{13}Z_3 & X_1'R^{11}W_1 & X_1'R^{12}W_2 & X_1'R^{13}W_3 \\
 & X_2'R^{22}X_2 & X_2'R^{23}X_3 & X_2'R^{12}Z_1 & X_2'R^{22}Z_2 & X_2'R^{23}Z_3 & X_2'R^{12}W_1 & X_2'R^{22}W_2 & X_2'R^{23}W_3 \\
 & & X_3'R^{33}X_3 & X_3'R^{13}Z_1 & X_3'R^{23}Z_2 & X_3'R^{33}Z_3 & X_3'R^{13}W_1 & X_3'R^{23}W_2 & X_3'R^{33}W_3 \\
 & & & Z_1'R^{11}Z_1+G^{11}A_+^{-1} & Z_1'R^{12}Z_2+G^{12}A_+^{-1} & Z_1'R^{13}Z_3+G^{13}A_+^{-1} & Z_1'R^{11}W_1 & Z_1'R^{12}W_2 & Z_1'R^{13}W_3 \\
 & & & & Z_2'R^{22}Z_2+G^{22}A_+^{-1} & Z_2'R^{23}Z_3+G^{23}A_+^{-1} & Z_2'R^{12}W_1 & Z_2'R^{22}W_2 & Z_2'R^{23}W_3 \\
 & & & & & Z_3'R^{33}Z_3+G^{33}A_+^{-1} & Z_3'R^{13}W_1 & Z_3'R^{23}W_2 & Z_3'R^{33}W_3 \\
 & & & & \mathit{Symmetric} & & W_1'R^{11}W_1+r^{11}I & W_1'R^{12}W_2 & W_1'R^{13}W_3 \\
 & & & & & & & W_2'R^{22}W_2+r^{22}I & W_2'R^{23}W_3 \\
 & & & & & & & & W_3'R^{33}W_3+r^{33}I
\end{pmatrix}
\begin{pmatrix} \underline{b}_1 \\ \underline{b}_2 \\ \underline{b}_3 \\ \underline{a}_1 \\ \underline{a}_2 \\ \underline{a}_3 \\ \underline{p}_1 \\ \underline{p}_2 \\ \underline{p}_3 \end{pmatrix}
=
\begin{pmatrix} X_1'R^{11}\underline{y}_1 \\ X_2'R^{22}\underline{y}_2 \\ X_3'R^{33}\underline{y}_3 \\ Z_1'R^{11}\underline{y}_1 \\ Z_2'R^{22}\underline{y}_2 \\ Z_3'R^{33}\underline{y}_3 \\ W_1'R^{11}\underline{y}_1 \\ W_2'R^{22}\underline{y}_2 \\ W_3'R^{33}\underline{y}_3 \end{pmatrix}
$$

Figure 6. Matrix form of animal model equation for weight trait analysis.

3) G^{ij} represents a set of coefficients derived from an inverted matrix of genetic variance and covariance values used to modify the terms in the $Z_i'R^{ij}Z_j$ portion of the matrix to account for additive genetic correlations among the traits being analyzed, i and j representing traits;

4) A_+ is a matrix of coefficients used to modify the terms in the $Z_i'R^{ij}Z_j$ portion of the matrix to account for relationships among individuals, including consideration of phantom parents, and

5) r^{ji} represents a set of coefficients derived from the inverse of σ_m^2 used to modify the terms in the $W_i'R^{ij}W_j$ portion of the matrix to account for the permanent environmental effects due to dams having more than one lambing in the data set.

The animal model analysis requires genetic parameters (i.e. heritabilities and phenotypic and genetic correlations among traits) that are assumed to be known without error for the group of animals being analyzed. This in fact is seldom the case, and generally the most appropriate estimates, taken from the research literature, are used. These estimates are highly variable in the scientific literature due both to the specific animals (including consideration of their breed background) being used and to the management environment under which the traits of interest are being expressed. Values calculated from data with lambs raised with their dams on pasture (e.g. Wolf et al., 1981) can differ markedly from those calculated from early-weaned lambs raised in a high management level environment (e.g. Osman and Bradford, 1965). For this reason, the estimates of correlations between weight traits used in this study were those calculated from a sheep population similar to the one in the present trial by Shrestha and Heaney (1985), and shown in Table 12. The heritability estimates for these traits required in the calculation of the matrix coefficients were also taken from this paper, and were 0.25 for birth and 42-day weights and 0.26 for final weight.

The phenotypic variance and its components were calculated from the present data. GLM procedures of SAS (1988) were used with a model that included breed of lamb, year and season of birth, sex, type of birth and rearing, dam within breed, and age of dam. VARCOMP procedures of SAS (1988) were used to derive the variance between dams and within dams. Variance among sires was estimated using the same model. The values obtained are shown in Table 13.

TABLE 12. Estimates of correlations used to develop coefficients for animal model analysis (from Shrestha and Heaney, 1985).

	Phenotypic correlations		Genetic correlations	
Trait	49-day weight[1]	Final weight	49-day weight	Final weight
Birth weight	0.54	0.51	0.68	0.66
49-day weight	----	0.93	----	1.00

[1]The parameters for 49-day weight in this trial were considered to be appropriate for use with the 42-day data in the current trial.

TABLE 13. Error variance and its component values calculated from trial data.

Trait	Total σ^2	σ^2 between dams	σ^2 within dams	σ^2 between sires	Adjusted σ_p^2
Birth weight	0.5458[a]	0.1774	0.3648	0.0238	0.5458[s]
42-day weight	5.9889[a]	1.8613	4.4862	0.3215	4.4490
120-day weight	40.7019[a]	7.1624	33.9366	2.0457	35.5852

[a]The sums of the dam variance figures are not exactly equal to these total variance figures due to the figures having been derived from two different analyses on the same data.

[s]This value for total variance was used without adjustment.

In the paper by Shrestha and Heaney (1985), no attempt was made to estimate maternal effects from the birth-weight data. Nor was there in the current trial. Therefore, the calculated phenotypic variance among lamb birth weights was used here without adjustment (for the presence of maternal genetic effects and non-genetic permanent environmental effects) in the calculation of the residual variance for birth weights from the formula:

$$\sigma^2_{e\,(BIRTH)} = (1 - h_b^2)\sigma^2_{p\,(BIRTH)}$$

$$= (1 - 0.25)(0.5458)$$

$$= 0.4093$$

Table 14 shows all the calculated error variance and covariance values used in developing matrix coefficients for the three weight traits.

In the Shrestha and Heaney (1985) paper, lambs were weaned at birth. Since lambs were not weaned until 56 days of age in the current trial, 42-day weights and 120-day weights in this trial would have been affected by maternal environment. In order to more accurately define phenotypic variance at 42 days and 120 days of age so that the heritabilities, and genetic and phenotypic correlations from this paper shown in Table 12 could be appropriately applied,

TABLE 14. Error variance and covariance values calculated for weight traits[1].

Trait	Birth weight	42-day weight	120-day weight
Birth weight	0.4093	0.5766	1.5060
42-day weight	0.5766	3.3368	8.4938
120-day weight	1.5060	8.4938	26.3330

[1]These values were calculated from trial data utilizing genetic parameters from Shrestha and Heaney, 1985.

the variance due to maternal environment had to be subtracted from the phenotypic variance prior to the calculation of the residual variances. The calculation for the 42-day phenotypic variance free of maternal environment effect was therefore calculated as shown below. Since:

$$\sigma_m^2 = \sigma_d^2 - \sigma_s^2$$

then:

$$\textit{Adjusted } \sigma_p^2 = \sigma_p^2 - (\sigma_d^2 - \sigma_s^2)$$

i.e. for the residual variance at 42 days:

$$\textit{Adjusted } \sigma_p^2 = 5.9888 - (1.8613 - 0.3215)$$

$$= 4.4490$$

and:

$$\sigma^2_{e\,(42\ days)} = (1 - 0.25)(4.4490)$$

$$= 3.3368$$

as shown in Table 14. The value for the phenotypic variance for the 120-day weight, calculated in the same way with maternal genetic and permanent environment effects removed, was 35.3832 as shown in Table 13, and the resulting error variance was 26.3330 as shown in Table 14.

The calculation of the error covariance terms (r_e) is possible since the values for the phenotypic correlations and heritabilities are known, the values for e_{ii} can be calculated from the heritabilities, and:

$$r_{p(TRAITS\ 1\ \&\ 2)} = h_1 h_2 r_{g(TRAITS\ 1\ \&\ 2)} + e_1 e_2 r_{e(TRAITS\ 1\ \&\ 2)}$$

That is:

$$0.54 = (\sqrt{0.25})(\sqrt{0.25})(0.68) + (\sqrt{0.75})(\sqrt{0.75})(r_{e(TRAITS\ 1\ \&\ 2)})$$

Therefore:

$$r_{e(TRAITS\ 1\ \&\ 2)} = 0.4933$$

Since this residual correlation value is equal to the covariance of the two traits divided by the square root of the product of the variances of the two traits, the value of the covariance between traits 1 and 2, in this case, was found to be 0.5766 as is also shown in Table 14.

Similarly, the A^{-1} matrix was computed as described by Henderson (1976), and further developed to produce the A_+^{-1} matrix as described by Westell and Van Vleck (1987) to include modifications to relationship values involving phantom parents. The genetic variance and covariance values used to account for the relationships among animals in the data set were calculated. Genetic variance values were available since:

$$\sigma_g^2 = h^2\sigma_p^2$$

and values for h^2 were known from Shrestha and Heaney (1985). Values for σ_p^2 were previously calculated from the current trial data. Similarly, genetic covariance values can be calculated since:

$$\sigma_{g_{12}} = r_{g_{12}}\sqrt{\sigma^2_{g_{12}}}\sqrt{\sigma^2_{g_{12}}}$$

and the genetic correlations are known from Shrestha and Heaney (1985), and genetic variance values were already calculated. The resulting genetic variance and covariance values are shown in Table 15.

Additionally, many ewes lambed more than once during the trial period, and those repeated records were also taken into account in the analysis. Values for the maternal environment effects were calculated from the data shown in Table 13 with the results as shown in Table 16. The inverse of these values were used as coefficients where required.

TABLE 15. Genetic variance and covariance values used in the development of matrix coefficients to account for correlations among traits[1].

Trait	Birth weight	42-day weight	Final weight
Birth weight	0.1364	0.2649	0.7416
42-day weight	0.2649	1.1123	2.8871
Final weight	0.7416	2.8871	9.2522

[1]These values were calculated from trial data utilizing genetic parameters from Shrestha and Heaney, 1985.

TABLE 16. Values of the variance due to the effect of maternal environment and variance component values used in its calculation.

Trait	σ^2 between dams	σ^2 between sires	σ^2 maternal environment
Birth weight	0.1774	0.0238	0.1536
42-day weight	1.8613	0.3215	1.5398
120-day weight	7.1624	2.0457	5.1167

Most of the lambs in the trial were born to parents who themselves were born during the trial. For these parents, the complete pedigree and performance records were known. The animal model analysis requires that the genetic relationships for all animals on the data set be known. Therefore, for those animals for whom either one or both parents are unknown, as is often the case with the base population of a group of animals, "phantom parents" were created and assigned to groups according to the breed and the year their offspring made a record in a manner similar to that described by Westell and Van Vleck (1987). Phantom parents are assumed to be average representatives of all similar animals in their year of birth. Due to differing generation intervals, assumed for the purposes of this trial to be two years for sires and three years for dams, phantom sires and dams were placed in parallel but different phantom parent groups. It has been suggested further that parallel groups should be used depending on the sex of the missing parent (i.e. phantom sires of sires, phantom sires of dams, phantom dams of sires and phantom dams of dams) to correspond to the four selection paths of genetic gain as they exist in the dairy industry (Westell and Van Vleck, 1987) and this recommendation was followed in this analysis. In addition, animals which produced only one offspring and had no record themselves were also assigned to phantom groups according to the same criteria. The phantom groups and the numbers of animals in each are shown in Table 17.

The second purpose of the analysis was to take the breed and breed cross means and derive the component effects. The data structure in this trial permitted the estimation of not only the sire breed effect on growth performance, but since the dam side of the mating plan was a complete diallel, direct, maternal and heterosis effects on weight traits for the component breeds on the dam side are also estimable. Contrasts were developed to estimate these effects as described by Dickerson (1969) and as discussed in Manuscript I. Estimates of individual heterosis from the three-way cross lambs were not possible due to the design of the breeding plan which did not include groups of purebred lambs of the terminal sire breeds. Breed group values from both the least squares and the animal model analyses were used in the calculations of genetic effects and the results compared. The animal model solutions were compared with those from the least squares by examining differences between breed groups. The specific contrasts and the genetic effects that they estimate are shown in Table 18.

TABLE 17. Characterization of phantom groups and the numbers of offspring produced by them.

SIRES:

Year	Suffolk	Outaouais	Canadian	Hampshire
1980	30	0	0	0
1981-82	25	96	0	0
1983-84	9	0	5	0
1985-86	0	41	0	9
1987-88	0	0	0	0

DAMS:

Year	Suffolk	Outaouais	Canadian	Hampshire
1980	0	0	0	0
1981-86	66	96	5	0
1987-88	0	48	0	7

TABLE 18. Genetic effect and method of estimation for direct genetic, maternal genetic, and heterosis effects in the Outaouais and Suffolk breeds, and the sire effect in the Canadian and Hampshire breeds[1] from mean performance values ($\bar{W}$) for breed groups.

Effect	Contrast statement
Direct genetic effect	$\bar{W}_{OU} - \bar{W}_{SU} + \bar{W}_{(OUxSU)} - \bar{W}_{(SUxOU)}$
Maternal genetic effect	$\bar{W}_{(SUxOU)} - \bar{W}_{(OUxSU)}$
Terminal sire breed effect[2]	$\bar{W}_{CA(SUxOU)} - \bar{W}_{HA(SUxOU)}$
Heterosis effect	$1/2(\bar{W}_{(SUxOU)} + \bar{W}_{(OUxSU)} - \bar{W}_{SU} - \bar{W}_{OU})$

[1]Breed abbreviations: SU=Suffolk; OU=Outaouais; SUxOU=crossbred offspring of a Suffolk sire and an Outaouais dam; CA(SUxOU)=a three-way cross, sired by a Canadian ram from a SUxOU crossbred dam; HA=Hampshire.

[2]In the calculation of the sire effects, both reciprocals of the ewe cross are included in the mean.

Results and Discussion

Breed effects

The least squares mean values for the three weight traits for the breeds and breed crosses as derived from the two methods of analysis are shown in Table 19. Generally, the birth weights (2.82 kg to 3.79 kg) are within expected ranges for lambs of this age and of their breed background. Purebred Suffolk lambs had the highest birth weights, but these were not significantly different from the birth weights for the three-way crosses sired by either Canadian or Hampshire rams or the Outaouais X Suffolk crosses. Outaouais and Suffolk X Outaouais lambs were significantly lighter at birth than the Suffolk lambs.

Similar values for birth weight have been published by Oltenacu and Boylan (1981b) on Finnsheep and their crosses with North American breeds, Shrestha et al. (1982) on Suffolk, Finnsheep, Ile de France and East Friesian, (breeds that were all to become contributors to the Arcott breeds), Shrestha and Heaney (1992) and Shrestha et al.
(1992) on the three Arcott breeds, and by Fahmy and Dufour (1988) on Finn crosses. Values approximately 1 kg heavier for traditional, less prolific North American pure breeds

TABLE 19. Least squares means[1] and animal model solutions for weight traits by breed or breed cross.

Breed or breed cross	Least squares solutions	Performance relative to Suffolk: Least squares solutions	Performance relative to Suffolk: Animal model solutions[4]
	Birth weight[2]		
SU	3.79 ± 0.26[a]	0.00[a]	0.00
OU	2.82 ± 0.32[b]	-0.97[b]	-0.76
(SUxOU)	2.96 ± 0.32[b]	-0.83[b]	-0.61
(OUxSU)	3.44 ± 0.35[a]	-0.35[a]	-0.16
CA(SUxOU)[3]	3.18 ± 0.57[ab]	-0.61[ab]	-0.10
HA(SUxOU)	3.20 ± 0.62[ab]	-0.59[ab]	-0.07
	42-day weight		
SU	12.54 ± 0.90[a]	0.00[a]	0.00
OU	10.59 ± 1.07[b]	-1.95[b]	-1.54
(SUxOU)	10.59 ± 1.11[b]	-1.95[b]	-1.83
(OUxSU)	12.57 ± 1.20[a]	0.03[a]	-0.01
CA(SUxOU)	11.57 ± 1.88[ab]	-0.97[ab]	0.05
HA(SUxOU)	12.11 ± 2.04[ab]	-0.43[ab]	0.70
	120-day weight		
SU	30.56 ± 1.59[ab]	0.00[ab]	0.00
OU	29.74 ± 1.92[b]	-0.82[b]	-0.05
(SUxOU)	28.48 ± 1.93[b]	-2.08[b]	-1.58
(OUxSU)	32.31 ± 2.17[a]	1.75[a]	2.59
CA(SUxOU)	28.90 ± 3.89[ab]	-1.66[ab]	0.74
HA(SUxOU)	27.99 ± 4.32[ab]	-2.57[ab]	-0.91

[1]Breed effects were tested for significance through the use of Satterthwaite's Synthetic Mean Squares, using the dam-within-dam-breed term as the error term.

[2]Weights within a column for a given weight trait that are followed by the same letter do not differ significantly ($p<0.05$).

[3]Designations of crossbred ewes in a three-way cross include the reciprocal cross of the ewe.

[4]Animal model solutions include breeding value of individual lambs and breed effect values only.

have been observed by Sidwell et al. (1964), Rastogi et al. (1975), Vesely et al. (1977) and Rastogi et al. (1982). Lighter birth weights (2.4 kg to 3.3 kg) were reported by Bourfia and Touchberry (1993b) for North African breeds and crosses, but these breeds were also reported to have much lighter mature body weights, in the range of 31 kg to 47 kg.

By 42 days of age, the breed-group raankings were similar to those at birth. Purebred Suffolk and the Outaouais X Suffolk cross lambs were the heaviest. The Outaouais and the Suffolk X Outaouais crosses were significantly lighter than the Suffolks and the Outaouais x Suffolk cross lambs. The weights for the three-way cross lambs were between and not significantly different from any of the other groups.

At 120 days of age, the Outaouais X Suffolk lambs were significantly heavier than any of the other groups. The Suffolks no longer out-performed the Outaouais lambs. The Suffolk X Outaouais lambs were the lightest of all the groups. Of the two terminal sire breeds being evaluated, the Canadian-sired lambs tended to out-perform the Hampshire-sired lambs though the result was not significant ($p > 0.05$). Perhaps most significant is the fact that the growth performance of the three-way cross lambs was not significantly different from that of the purebred Suffolks, a result that supports the conclusion of Olthoff and Boylan (1991a) that in a terminal sire production system, using half- or quarter-Finn dams takes advantage of the increased reproductive capacity of the ewe with little or no reduction in lamb performance to market weight.

The 42-day and 120-day weights are not directly comparable to data in other papers due to weights being taken at different ages. However the ranges of weights are comparable to those reported in the papers quoted for birth weights when breed type and management system are taken into consideration. Lambs weaned off pasture (Vesely and Peters 1979) were lighter, but the Suffolk data reported by Shrestha et al. (1985) from the Canadian National Record of Performance database is similar to that in the current trial.

Genetic effects

The contrasts developed to establish direct genetic, maternal genetic, heterosis and sire effects produced the results shown in Table 20. Suffolks demonstrated a clear superiority in direct and maternal genetic effects on birth

TABLE 20. Values from the least squares and animal model analyses for genetic, maternal genetic, heterosis and terminal sire breed effects.

Effect estimate	Least squares solutions	Animal model solutions
	Birth weight	
Direct genetic effect[1]	-0.49 ± 0.10**	-0.34
Maternal genetic effect[1]	-0.48 ± 0.07**	-0.46
Heterosis effect[2]	-0.10 ± 0.06 (3.1%)	-0.01 (0.3%)
Terminal sire breed effect[3]	-0.02 ± 0.11	-0.02
	42-day weight	
Direct genetic effect	0.03 ± 0.35	0.19
Maternal genetic effect	-1.98 ± 0.25**	-1.84
Heterosis effect	0.02 ± 0.20 (0.2%)	-0.08 (0.6%)
Terminal sire breed effect	-0.55 ± 0.38	-0.64
	120-day weight	
Direct genetic effect	3.00 ± 1.03**	3.99
Maternal genetic effect	-3.83 ± 0.74**	-4.02
Heterosis effect	0.24 ± 0.55 (0.8%)	0.61 (1.6%)
Terminal sire breed effect	0.92 ± 1.16	1.51

[1]Direct and maternal genetic effects are expressed in terms of the Outaouais vs. the Suffolk.

[2]Heterosis effects are the individual heterosis effects exhibited by the (SUxOU) and (OUxSU) crosses over the purebred SU or OU, as measured by their weight traits.

[3]Sire effect is expressed in terms of the Canadian rams vs. the Hampshire rams.

**Effects are highly significant ($p<0.01$).

*Effects are significant ($p<0.05$).

weights. Heterosis effects were small (0.3% and 3.1% for least squares and animal model analyses respectively) and non-significant. This differs from results obtained by Rastogi et al. (1982) who found heterosis effects for weight at birth to be as high as 5.4% and 6.9% on Suffolk X Targhee and Columbia X Suffolk crosses respectively, and Vesely et al. (1977) who found significant heterosis effects on birth weight of 2.6% on traditional breeds. Nitter (1978) also reported mean estimates for individual heterosis for birth weight to be 3.2%.

For 42-day weights, the superiority of the Suffolk was not so clearly evident. The direct genetic effect was small and non-significant in favour of the Outaouais. Suffolks still showed a highly significant advantage in maternal genetic effect at this stage.

Individual heterosis effects were very small (0.2% and 1.1% for least squares and animal model analyses respectively). The lambs in this trial were weaned at 56 days of age. Rastogi et al. (1975) finding only non-significant differences at weaning (70 days of age) suggested that heterosis may not be very important for weaning weight, particularly when lambs are weaned at a moderately early age. Bradley et al. (1972) reported heterosis in weaning weight at 120 days of age, as did Vesely et al. (1977) who reported heterosis for weaning weight at 108 days of age of 5.2%. In his review, Nitter (1978) reported a mean heterosis value of 5.0%.

By the 120-day weight, the superiority of the Suffolk in direct genetic effect was no longer evident, and the Outaouais manifested a highly significant advantage of 3 kg. However, the maternal genetic effect was still significantly in favour of the Suffolk. By this stage, the heterosis effect was in favour of the crossbreds, but was small (0.8 or 1.4%). The ages at which lambs are weighed post-weaning vary widely in the literature and it is difficult to compare the present results to other studies. Vesely et al. (1977) reported significant heterosis effects in lambs at about 180 days of age of 5.9%, and Nitter (1978) reported heterosis values for post-weaning growth rate and yearling body weight at 6.6% and 5.2% respectively. In this study, the estimates of heterosis are smaller than most that are reported in the literature. Cunningham (1982) has stated that heterosis estimates tend to be larger in harsher environments. Long et al. (1989) suggest that the Nitter (1978) estimates, incorporating studies from developing countries, may for this reason, be higher than should be expected from trials conducted in the less severe animal environments that are more common in North America. Heterosis values in this trial are smaller also because the Outaouais breed background is 21% Suffolk, thereby reducing the distance between the breeds.

Terminal sire breed effects were found to be small and non-significant for birth weight. By 42-day, the effect was about 0.5 kg in favour of the Hampshire rams. The sire effect became highly significant by the 120-day weight with the Canadian out-performing the Hampshire by 0.92 or 1.51 kg according to least squares means and animal model analyses respectively.

The animal model results appear to be in general agreement with those from the least squares analysis. Theoretically, since the animal model analysis includes consideration of relationships among animals, animal model results could be expected to yield more accurate estimates of the breed effects than the least squares analysis. Calculation of actual standard error terms for the animal model results was not possible to carry out due to the requirement to invert the large matrix, nor was any method of estimating prediction error variances used such as that developed by Greenhalgh et al. (1986). As a result, no evaluation of the accuracy of the animal model estimates can be made.

Environmental effects

Overall, year and season accounted for significant ($p < 0.01$) variation in birth, 42-day and 120-day weights in this trial. The results shown in Tables 21 to 23 indicate that the animal model showed these differences as did the least squares analysis. Interestingly, the least squares analysis yielded results that would appear to indicate a trend of increasing weights for all three weight traits over the trial period, whereas the animal model, while showing differences from year to year, showed no clear trend. Since the use of the terminal Canadian and Hampshire breeds only took place towards the end of the trial, there is a possibility that the animal model was more successful at distinguishing between the year-season effect and breed effects in the case of breed groups that did not appear in all years. This possibility is reinforced by the observation that no trend of increasing weight was shown when the data for the purebreds, which were present for the whole trial period, is considered (shown later in Figure 7).

TABLE 21. Birth weights of lambs by year/season of birth, sex, type of birth and age of dam.

Source[a]	Least squares solutions	Performance relative to the first class of each fixed effect: Least squares solutions	Animal model solutions
	Year/season of birth		
Spring 1984	2.40 ± 0.45	0.00	0.00
Fall 1984	2.81 ± 0.45	0.41	0.35
Spring 1985	2.99 ± 0.36	0.59	0.36
Fall 1985	2.97 ± 0.31	0.57	0.08
Fall 1986	3.16 ± 0.24	0.76	0.15
Spring 1987	3.68 ± 0.16	1.28	0.52
Spring 1988	3.87 ± 0.09	1.47	0.42
Spring 1989	3.96 ± 0.08	1.56	0.34
	Sex		
Male	3.34 ± 0.24	0.00	0.00
Female	3.13 ± 0.24	-0.21	-0.22
	Type of birth		
Single	4.32 ± 0.24	0.00	0.00
Twin	3.45 ± 0.24	-0.87	-0.88
Triplet	2.82 ± 0.25	-1.50	-1.59
Quadruplet	2.34 ± 0.28	-1.98	-2.00
	Age of dam (in years)		
1	3.13 ± 0.08	0.00	0.00
2	3.52 ± 0.14	0.39	0.50
3	3.52 ± 0.24	0.39	0.75
4	3.09 ± 0.33	-0.04	0.64
5 and over	2.89 ± 0.48	-0.24	0.75

[a]All main effects shown were significant ($p<0.05$)

TABLE 22. 42-day weights of lambs by year/season of birth, sex, type of birth and age of dam.

Source[a]	Least squares solutions	Performance relative to the first class of each fixed effect: Least squares solutions	Animal model solutions
		Year/season of birth	
Spring 1984	9.29 ± 1.85	0.00	0.00
Fall 1984	9.60 ± 1.58	0.31	0.51
Spring 1985	12.11 ± 1.26	2.82	1.98
Fall 1985	11.17 ± 1.09	1.88	0.95
Fall 1986	10.40 ± 0.85	1.11	-0.34
Spring 1987	12.18 ± 0.59	2.89	1.17
Spring 1988	14.54 ± 0.34	5.25	2.92
Spring 1989	14.00 ± 0.30	4.71	1.67
		Sex	
Male	12.12 ± 0.87	0.00	0.00
Female	11.21 ± 0.87	-0.91	-0.86
		Type of birth and rearing	
11	16.05 ± 0.98	0.00	0.00
21	13.09 ± 0.98	-2.96	-2.38
22	12.46 ± 0.85	-3.59	-3.74
31	13.51 ± 1.19	-2.54	-3.34
32	11.41 ± 0.93	-4.64	-5.15
33	10.51 ± 0.88	-5.54	-6.03
42	11.06 ± 1.06	-4.99	-5.52
43	10.50 ± 1.29	-5.55	-5.51
44	8.65 ± 1.12	-7.40	-7.20
		Age of dam (in years)	
1	11.60 ± 0.33	0.00	0.00
2	12.35 ± 0.55	0.75	1.53
3	12.47 ± 0.85	0.87	2.00
4	11.41 ± 1.18	-0.19	1.63
5 and over	10.48 ± 1.67	-1.12	1.82

[a]All effects shown were significant ($p<0.05$)

TABLE 23. 120-day weights of lambs by year/season of birth, sex, type of birth and age of dam.

Source[a]	Least squares solutions	Performance relative to the first class of each fixed effect: Least squares solutions	Animal model solutions
	Year/season of birth		
Spring 1985	27.24 ± 3.83	0.00	0.00
Fall 1985	28.04 ± 3.35	0.80	0.82
Fall 1986	29.27 ± 2.59	2.03	-0.33
Spring 1987	32.75 ± 1.82	5.51	3.17
Spring 1988	27.89 ± 1.01	0.65	-2.02
Spring 1989	32.79 ± 0.92	5.55	1.01
	Sex		
Male	31.76 ± 1.96	0.00	0.00
Female	27.57 ± 1.97	-4.19	-4.35
	Type of birth and rearing		
11	37.52 ± 1.89	0.00	0.00
21	28.94 ± 2.43	-8.58	-5.20
22	32.65 ± 1.87	-4.87	-4.19
31	32.61 ± 3.22	-4.91	-7.52
32	32.01 ± 2.24	-5.51	-7.48
33	28.94 ± 2.01	-8.58	-8.66
42	28.66 ± 2.72	-8.86	-9.03
43	25.87 ± 3.34	-11.65	-9.18
44	23.75 ± 2.82	-13.77	-10.94
	Age of dam (in years)		
1	31.18 ± 0.82	0.00	0.00
2	31.03 ± 1.06	-0.15	2.03
3	30.26 ± 1.90	-0.92	2.42
4	28.37 ± 2.88	-2.81	1.52
5 and over	27.47 ± 4.42	-3.71	2.18

[a]All effects shown were significant ($p<0.05$)

Males out-performed females from the standpoint of body weight ($p < 0.01$). The least squares analysis showed that they were significantly heavier than females by 0.21, 0.91 and 4.19 kg for birth weight, 42-day weight and 120-day weight respectively. As shown in Tables 21 to 23, the animal model analysis generated very similar values.

In the birth-weight data, type of birth was seen to be a significant effect ($p<0.01$). As the size of the litter increased, a significant decrease in individual birth weights from 4.32 in single lambs to 2.34 kg in quadruplets was observed, similar to the finding by Shrestha et al. (1992) on a similar population of sheep. Once again, the animal model data, showed similar values.

In the 42-day and 120-day weight data, type of birth and rearing was also seen to have a significant effect ($p<0.01$), with the trend being that larger litters, either at birth or during rearing, have lighter weights at 42 days of age. This effect was still seen by 120 days of age, though post-weaning growth appeared to compensate for some of the earlier poor gain in animals from larger litters. The animal model, while generating values that were not identical, indicated the same trend in this effect, despite the fact that there were very small numbers representing

TABLE 24. Frequency (and percentage) of litter size at birth by breed over the trial period.

Breed[1]	SU	OU	SUxOU	OUxSU
Number of single births	136 (45.8%)	103 (24.1%)	23 (18.3%)	4 (21.1%)
Number of sets of twins	145 (48.8%)	205 (48.0%)	73 (57.9%)	8 (42.1%)
Number of sets of triplets	15 (5.1%)	93 (21.8%)	25 (19.8%)	6 (31.6%)
Number of sets of quadruplets	1 (0.3%)	26 (6.1%)	5 (4.0%)	1 (5.3%)

[1] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

some breed groups in the larger litter type of birth and rearing classes as shown in Table 24.

The effect of dam age on birth weight and 42-day weight was significant ($p<0.01$). Two- and three-year-old ewes were superior for lamb weights at birth and 42 days of age, but by 120 days of age, the differences were no longer significant. Mohd-Yusuff et al. (1992) showed similar production curves for several traits, including litter weight weaned, with Finns and a half-Finn composite breed. However, the apparent decline in productivity in terms of these traits after three years of age in this trial may be an artifact of the data due to missing sub-classes. Most of the three-way cross lambs that contributed performance to the heavier end of the weight ranges were born later in the trial to younger ewes (Table 25) and ewes in the higher age classifications (over three years of age) never had the benefit of this high performance level within their age class. The animal model appeared to be more successful in removing this bias. The comparison between the two analytical methods, in which the animal model produces results in line with literature values, is illustrated with birth- and 120-day weight data for the various age-of-dam categories in Figures 7 and 8.

TABLE 25. Frequency table of lambing-event records by breed and age of ewe.

Dam age	Suffolk	Outaouais	SU x OU[1]	OU x SU	Totals
1 year	56	47	23	5	131
2 years	100	238	61	9	408
3 years	76	72	42	5	195
4 years	37	67	1	0	105
5 years+	28	5	0	0	33
Totals	297	429	127	19	872

[1] Breed abbreviations: SU=Suffolk, OU=Outaouais Arcott. The first breed listed in a two-way cross is the sire breed.

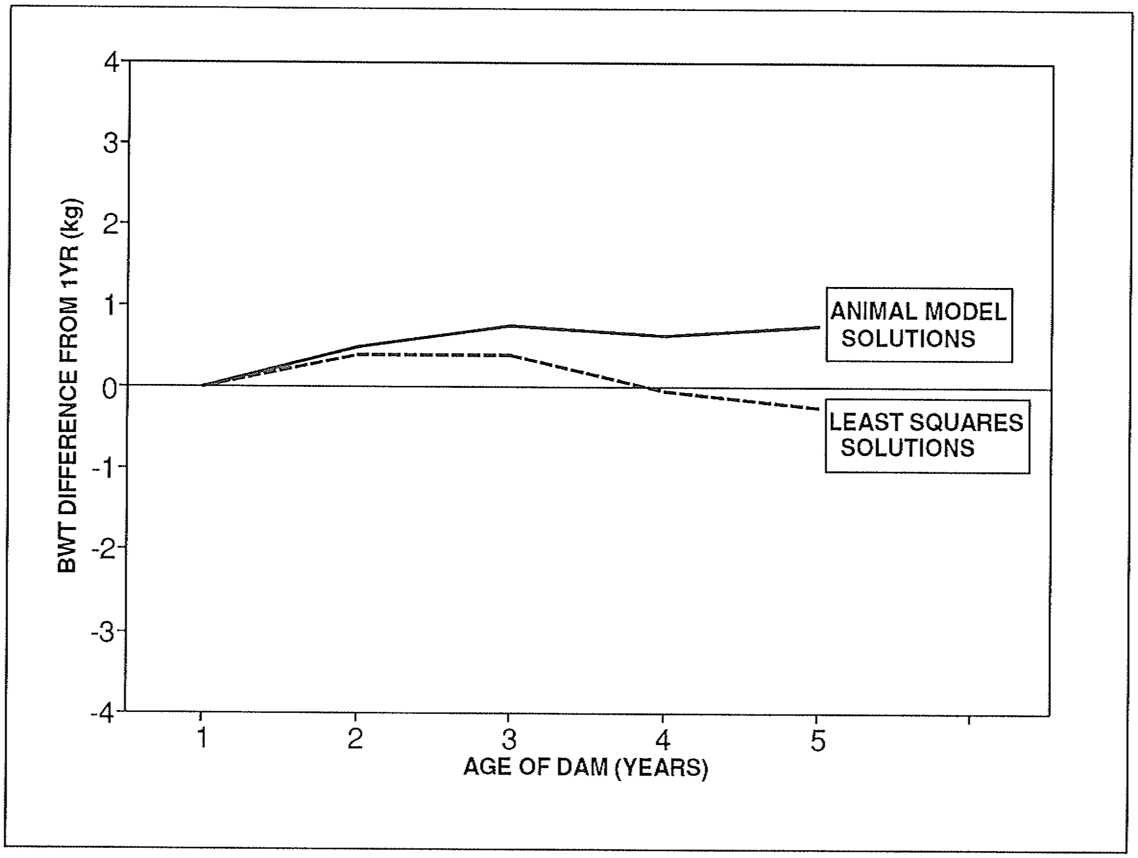

Figure 7. The effect of dam age on lamb birth weight.

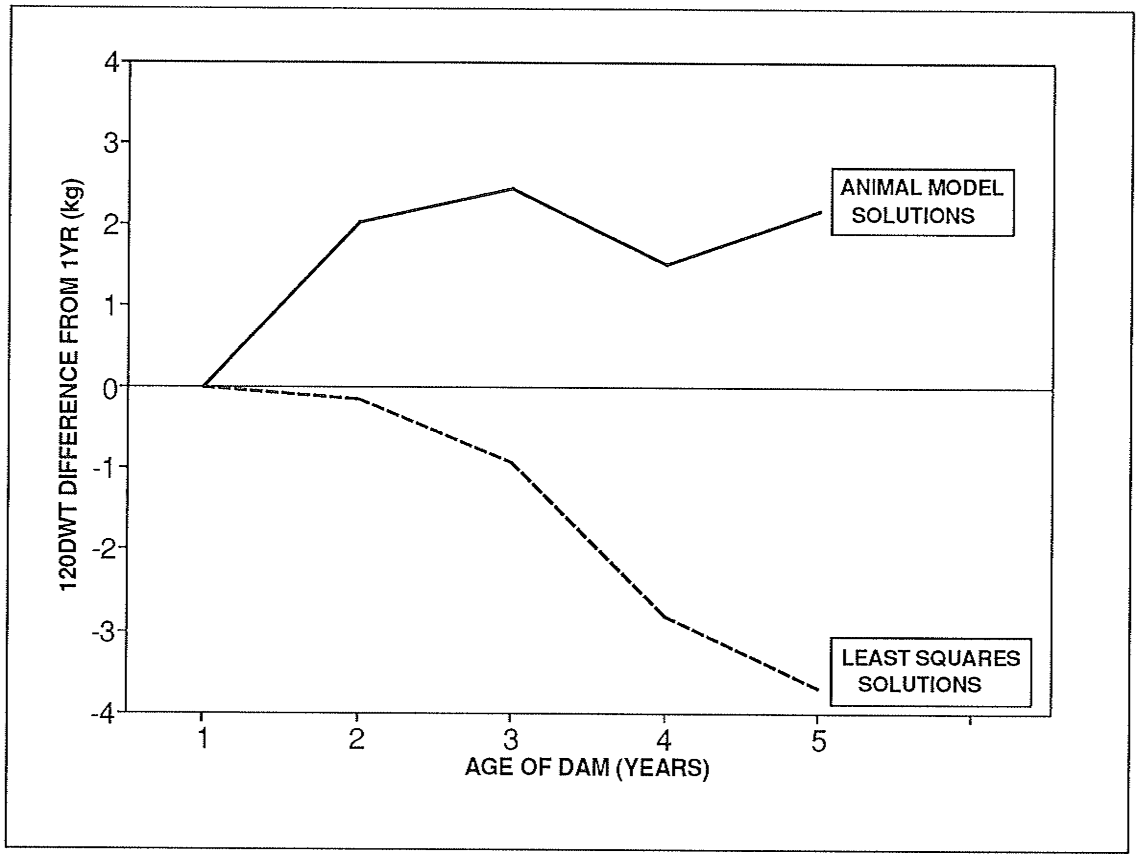

Figure 8. The effect of dam age on 120-day weight of lambs.

The data from this trial essentially agrees with the findings from previous reports (Singh et al. 1967; Sidwell and Miller 1971; Dickerson et al. 1972; Vesely and Peters 1972; Rastogi et al. 1975; Shrestha and Vesely 1986; Shrestha et al. 1992). In all cases it was found that year and season of birth, sex of lamb, type of birth and/or rearing (i.e. litter size into which the lamb is born and/or raised) and age of dam have a major influence on both growth and reproductive performance.

Applications of Results from the Animal Model Analysis

The solutions obtained from the animal model analysis enabled the estimation of various features of the performance of this trial group of animals based on the genetic and environmental components contributing to this performance. Creation of a synthetic record, composed of the individual breeding value and the breed group effect, and analyzing the resulting data set for a trend over time, for example, would provide confirmation that there was no inadvertent selection and thus genetic trend through the trial period in any of the breed groups. This was done for the two purebred groups in the current trial, and as shown in Figure 9, no clearly discernable trend is evident for either of these groups.

An alternate method by which selection over the period of the trial was assessed was by comparing the synthetic records (which contain only the individual breeding values and the breed effect) of those animals that were subsequently retained as replacements with those that were not. In this trial, all animals within the breed groups from which animals were retained for breeding were grouped according to whether their performance fell into the top, middle or bottom third for their breed. The performance groups were determined by designating all animals whose performance fell within the mean plus or minus 0.42 of one standard deviation as part of the middle group. Animals outside that range were placed in the top or bottom group as appropriate.

The results shown in Figure 10 indicate that despite the results shown in Figure 9 and despite the intention not to practice any selection in any of the groups, there was a tendency to pick animals with superior weight performance as replacements. As stated in the mating plans, only those animals that were unhealthy or structurally unsound were intentionally culled. If these individuals were also those

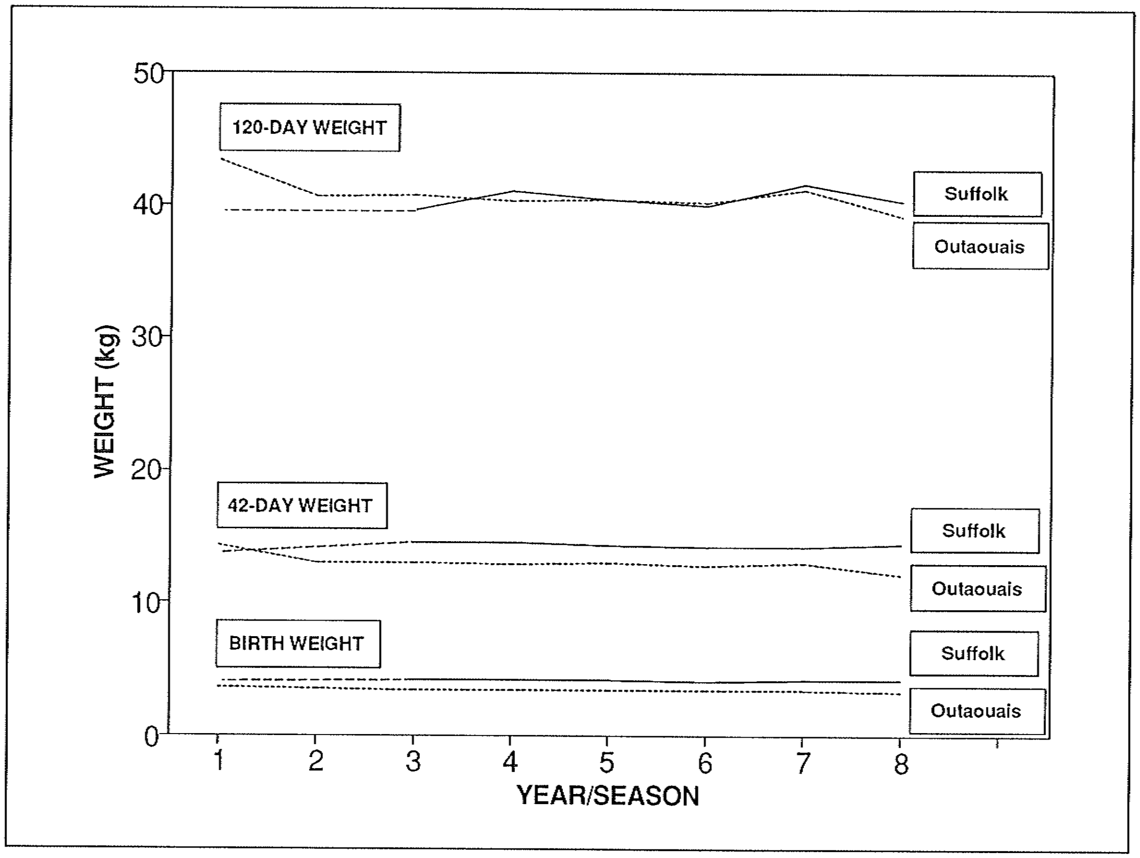

Figure 9. Genetic trends in weight traits in purebred groups over the trial period. (Note: No Suffolk lambs were born in year/season 2. The dashed line is the assumed trend between the values for year/seasons 1 and 3.)

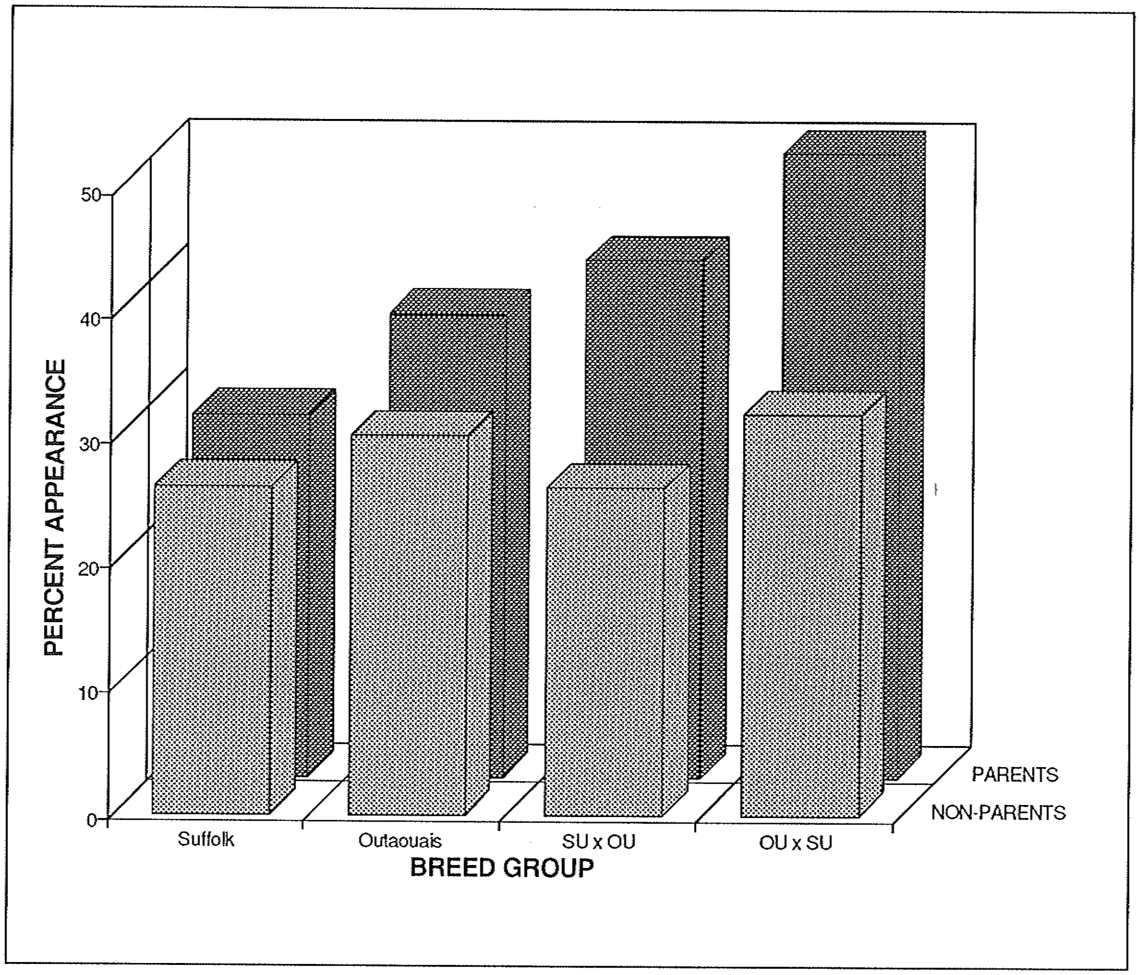

Figure 10. Percentage of top-performing animals appearing in selected parent and non-parent groups.

that were genetically inferior, then the results shown are to be expected. If this was not the case, then the intention to not select was not entirely successful. However, both the range of values in the middle performance classification for each group, and the difference in mean performance between those selected and those not selected was less than 100 grams for weight at 120 days of age. Therefore, while the technique used to produce the data in Figure 10 illustrates quite effectively the results of the selection procedures, the actual genetic trend observed is still considered to be negligible.

Phenotypic trends were also analyzed by adding both breed and year-season effects to the individual animal breeding values and analyzing the resulting data over the period of the trial. The results of the combination of these two effects for the purebred groups are shown in Figure 11. No net phenotypic trend was observed in the data for any of the three weight traits.

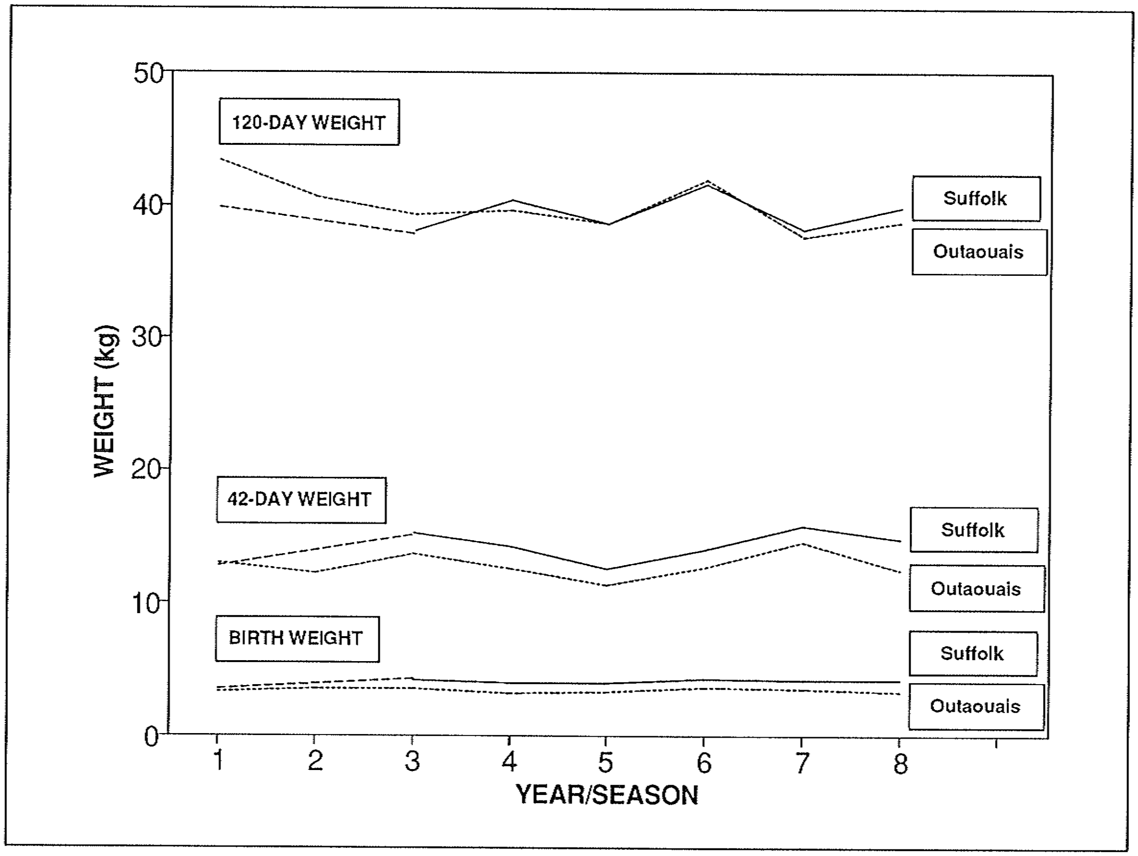

Figure 11. Breed and year effects combined for purebred groups over the trial period. (Note: No Suffolk lambs were born in year/season 2. The dashed line indicates the assumed phenotypic trend between the values for year/seasons 1 and 3.)

Animal model methodology

Solution of the animal model equation involved Gauss-Seidel iterations until the solutions stabilized. Convergence of the equations was monitored in this study by observation of the approximate solutions for breed effects as the number of rounds increased, and by ensuring that the absolute change for solutions decreased as the number of rounds increased. The solutions were examined for the three traits after 1000 iterations, 2000 iterations and 3000 iterations. Convergence was manifested by the decrease in the difference between the successive pairs of values calculated for each breed group for each trait. By 3000 iterations, the changes were becoming minimal and the convergence appeared satisfactory. The breed vector solutions for the traits at all three stages, expressed as differences from the Suffolk value, are shown in Table 26. All data include both the breeding values and the breed vector solutions. These values are used in the comparison with the least squares means analysis values in Table 19.

TABLE 26. Average weight solutions by breed at three stages of the iterative solution process. Values are expressed relative to that for the Suffolk within each trait.

Birth weight

Breed	Number of iterations 1000[a]	2000[a]	3000[a]
Suffolk (SU)	0	0	0
Outaouais (OU)	-0.7569	-0.7569	-0.7568
SUxOU	-0.6135	-0.6136	-0.6135
OUxSU	-0.1609	-0.1608	-0.1607
CA(SUxOU or OUxSU)	-0.1056	-0.1049	-0.1040
HA(SUxOU or OUxSU)	-0.0761	-0.0754	-0.0742

42-day weight

Breed	Number of iterations 1000	2000	3000
Suffolk (SU)	0	0	0
Outaouais (OU)	-1.5386	-1.5387	-1.5387
SUxOU	-1.8250	-1.8255	-1.8252
OUxSU	-0.0120	-0.0115	-0.0116
CA(SUxOU or OUxSU)	0.0485	0.0511	0.0535
HA(SUxOU or OUxSU)	0.6987	0.7010	0.7042

120-day weight

Breed	Number of iterations 1000	2000	3000
Suffolk (SU)	0	0	0
Outaouais (OU)	-0.0465	-0.0471	-0.0471
SUxOU	-1.5807	-1.5806	-1.5808
OUxSU	2.5863	2.5862	2.5873
CA(SUxOU or OUxSU)	0.7250	0.7262	0.7353
HA(SUxOU or OUxSU)	-0.9224	-0.9226	-0.9103

[a]Values in all columns include individual animal breeding values and breed solution vector values.

Conclusion

In terms of body-weight traits, heterosis added little to additive effects of genes from purebred parents to crossbred offspring. The improved performance that was observed resulted largely from the merit of the breeds themselves. Recently-completed studies with the Arcott breeds on lambs raised with their dams on a 12-month breeding cycle (Shrestha and Heaney 1992) and on lambs produced in an 8-month cycle and raised artificially (Shrestha et al. 1992) showed similar results.

Two additional features of the Canadian became apparent in this study. Firstly, the weight advantage manifested at 120 days of age did not include the disadvantage of heavier birth weights which could cause problems at parturition. Also, despite the superiority of the Hampshire in early growth rate, the ability of the Canadian to sustain rapid growth performance indicates a greater overall benefit to commercial lamb producers. In short, this study confirms that the Outaouais and Canadian breeds are capable of superior levels of productivity, not only in intensive systems, but also in a more traditional production environment.

The animal model permitted the simultaneous, multi-trait evaluation of all animals on the database, not only on the basis of their own records but also, through the inclusion of the inverse of the relationship matrix, from the performance of all relatives. In this study, this procedure appeared to be capable of extracting genetic effects more effectively than traditional least squares procedures when the breed groups were not well represented in all classes of the other fixed effects. The additional advantage of being able to evaluate animals for genetic merit that do not have records of their own, (even those that are not yet born) (Henderson 1977), on the basis of the records of their relatives, gives animal breeders a powerful tool indeed.

GENERAL DISCUSSION

The objective of carrying out this trial in an environment similar to that in commercial sheep operations created challenges. Animal management routines limited the traits on which evaluation data could be collected. Relatively simple measurements were made on animals that generally were in the flock for only a short period of time, and on these data, the kinds of data that would be available on a commercial operation, assessments of productivity were made.

Reproductive traits

The analysis of the first-parity traits revealed that the Outaouais and the crossbred ewes out-performed the Suffolk in litter size at birth. Values for the Suffolk, Outaouais, SUxOU and OUxSU ewes for first-parity litter size at birth were 1.24±0.10, 1.61±0.11, 1.70±0.15 and 1.69±0.24 lambs respectively. By 42 days of age, the litter sizes were smaller and no differences were seen among the breed groups. This indicates that at first parity, even though the groups mentioned above have an apparently superior ability to bear lambs, this ability does not extend to being able to raise them. First parity differences in litter weight at birth and 42 days of age were not significant ($p>0.05$). The direct and maternal genetic effects at first parity were small and non-significant. The heterosis value for first-parity litter weight at 42 days of age was significant ($p<0.05$) at 18.7%. Heterosis values at first parity for litter size at birth and litter weight at birth approached significance ($p<0.1$) at 19.3% and 16.7% respectively.

When parities at all ages were considered, the litter-size least squares means at birth followed the same general pattern. The Outaouais again out-performed the Suffolk (1.93 ± 0.06 vs. 1.38 ± 0.074 lambs at birth) and the cross-bred ewes had performance values between those of the purebreds but not significantly different from the Outaouais. At 42 days of age, the differences among the groups were similar to those at birth demonstrating the improved ability of the more mature ewes to raise lambs. Litter weights did not differ among groups at birth or at 42 days of age, indicating that at these ages at least, the lower number of lambs produced by the Suffolk ewes was compensated for by the greater individual weights of those lambs. The direct genetic effect was significant and in favour of the Outaouais for both traits over all parities. The maternal genetic effect was not a factor for litter size, but was highly significant for litter weight at both birth and 42 days. Heterosis, approached significance only for litter weight at 42 days of age at 18.4%.

The breed values for litter weights at birth revealed that the differences in numbers of lambs born was at least partially compensated for by the weights of the individual lambs at birth, making the total litter weights at birth more uniform among the breeds and breed crosses. By 42 days of age, however, the ability to excel in total litter weight started to favour the breed groups that had the higher numbers of lambs at birth. The tendency was for the Suffolk to perform comparably to the Outaouais but neither pure breed was able to match the performance level of either of the crossbred groups for total litter weight at 42 days of age. However, none of the differences between breeds was significant for lambs at this age in this trial. Direct effects still favoured the Outaouais ewes, though Suffolks demonstrated superiority in maternal genetic effects for total litter weights at both birth and six weeks.

Much of this data is very similar to that reported by other workers for ewes with approximately the same percentage of Finnsheep genes in their background and raised in similar environments (Dickerson 1977; Martin et al. 1980). Other researchers (Gallivan et al. 1987; Jakubec 1977; Nitter 1978; Long et al. 1988; Fahmy and Dufour 1988) report values that are both higher and lower, particularly those for genetic effects, when different breeds are involved or environments are less favourable.

The weight of a litter of lambs at weaning is a composite trait that includes consideration of litter size at birth, neonatal survival, pre-weaning survival and lamb growth to weaning. As a measure of ewe productivity, it is influenced by the ewe's fertility, fecundity, milking ability, growth rate, and if calculated on an annual basis, the ability to breed out of season. Abdulkhaliq et al. (1989) suggest that litter weight at weaning can be considered a phenotypic index, and its importance in any selection program to increase ewe productivity is felt to be considerable. However, at weaning, the predominant factor influencing litter weight is number of lambs rather than average lamb weight. Martin et al. (1980) suggests that since heritability estimates for litter weights at birth are higher than those at weaning, selection on this trait might be more effective in changing total lamb weight weaned than direct selection.

Weight traits

Purebred Suffolk lambs had the highest birth weights, but these were not significantly higher than the birth weights for the three-way crosses sired by either Canadian or Hampshire rams. Outaouais and first-cross Outaouais X Suffolk lambs were lighter at birth. The ranges of birth weights were similar to those found by other workers (Oltenacu and Boylan 1981b; Shrestha et al. 1982; Fahmy and Dufour 1988; Shrestha and Heaney 1992; Shrestha et al. 1992).

By 42 days of age, the three-way-cross lambs were heavier, but not significantly so over the Suffolks and Outaouais X Suffolk cross lambs. The Outaouais and the Suffolk X Outaouais crosses were significantly lighter. At 120 days of age, the Outaouais X Suffolk lambs were significantly heavier than any of the other groups. The Suffolks were similar to Outaouais lambs by this stage, and their weights were no longer significantly different. The Suffolk X Outaouais lambs were the lightest of all the groups. No significant differences were seen among the offspring weights at any age of the two terminal sire breeds being evaluated.

Suffolks demonstrated significantly greater direct and maternal genetic effects on birth weights. Heterosis effects were small and non-significant. This differs from results found by Vesely et al. (1977), Nitter (1978) and Rastogi et al. (1982) who found significant heterosis effects for weight at birth ranging from 2.6 to 6.9%.

By 42 days of age, the direct genetic effect was not clearly in favour of either breed. Suffolks still showed a highly significant advantage in maternal genetic effect at this stage. Individual heterosis effects were very small. Rastogi et al. (1975) finding only non-significant differences at weaning (70 days of age) suggested that heterosis may not be very important for weaning weight, particularly when lambs are weaned at a moderately early age. Data from Bradley et al. (1972) and Vesely et al. (1977) reported heterosis in weaning weight from lambs weaned at over 100 days of age. In his review, Nitter (1978) reported a mean heterosis value of 5.0%.

By the 120-day weight, the Suffolk advantage in direct genetic effect was no longer evident, and the Outaouais manifested a highly significant advantage of 3.00±1.03 kg. However, the maternal genetic effect was still significantly in favour of the Suffolk. By this stage, the heterosis effect was in favour of the crossbreds, but was small (1.6%). Other workers report larger heterosis effects for post-weaning gain of 5.9% (Vesely et al. 1977) and 6.6% (Nitter 1978). Cunningham (1982) has stated that heterosis estimates tend to be larger in harsher environments, which would appear to apply to the Vesely et al. (1977) data. Long et al. (1989) suggest that the Nitter (1978) estimates, incorporating studies from developing countries, may for this reason, be higher than should be expected from trials conducted in the less severe animal environments that are more common in North America.

In terms of weight traits, heterosis added minimally to the additive performance of the purebred parents. As in the case of reproductive traits, this may be due in part to the 21% Suffolk background in the Outaouais breed. However, this indicates that the improved performance that was observed resulted largely from the merit of the breeds themselves. Recently-completed studies with the Arcott breeds on lambs raised with their dams on a 12-month breeding cycle (Shrestha and Heaney 1992) and on lambs produced in an 8-month cycle and raised artificially (Shrestha et al. 1992) support the present findings.

Terminal sire breed effects were found to be small and non-significant for birth weight. Similarly, at 42 and 120 days of age, no significant differences were evident between the Canadian- and Hampshire-sired lambs, establishing that the Canadian is capable of performing at a level similar to other terminal sire breeds commonly used in the commercial sheep industry.

Analytical Models

In general, the animal model results appeared similar to those produced by the traditional least squares analysis. Theoretically, the animal model includes and accounts for the effects that influence performance more correctly than least squares analysis does. However, the accuracy of the analysis performed by the animal model is dependent on the accuracy of the genetic parameters for the group of individuals being evaluated. If these parameters were without error, the animal model evaluation solutions should be superior.

Differences between the calculated values from the two analytical methods were noted, however. Further investigation suggested that the animal model did show a superior ability to extract genetic information and isolate non-genetic effects from a data set when breed groups are not well represented in all classes of the fixed effect under consideration. In addition, the animal model permitted the multi-trait evaluation of performance, together with the simultaneous evaluation of all animals in the database not only on the basis of their own records but also, through the inclusion of the inverse of the relationship matrix, from the performance of all relatives. The additional advantage of being able to evaluate animals for genetic merit that do not have records of their own (Henderson 1977), on the basis of the records of their relatives (even those that are not yet born) gives animal breeders a powerful tool indeed.

SUMMARY AND CONCLUSIONS

In this trial, two newly-developed breeds, the Outaouais and the Canadian, were evaluated by comparing them with contemporaries from traditional breeds, in a production environment similar to that on a commercial sheep operation. The Outaouais, a maternal breed, was evaluated on the basis of litter size and litter weight and demonstrated its ability to make a significant contribution to overall productivity as a purebred or as part of an F_1 cross .

The Canadian was developed as a terminal sire breed. Evaluation on the basis of the performance of its offspring indicated its ability to sire lambs with superior growth rate without any complications arising from increased individual lamb birth weights. The favourable comparison with Hampshire rams in this trial, together with its comparable performance with Suffolk rams in previous trials, confirms its merit as a terminal sire breed for use in commercial operations.

The comparison of results from the animal model analysis and the traditional least squares analysis of the growth data in this trial indicated some superiority in the former in extracting breed effect information in situations where breed groups are not well represented in all classes of the fixed effect under consideration. In addition, the ability to utilize the output in various ways, such as examining genetic trends in data that is free of environmental effects, or adding in the year effect to determine phenotypic trends, provides a useful additional tool for developing breed performance profiles and crossbreeding schemes.

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APPENDIX

TABLE 27. Mean squares from the analysis of variance for reproduction traits.

First parity litter traits

		Mean squares			
Source	d.f.	No. of lambs (birth)	No. of lambs (42 d)	Wt. of lambs (birth)	Wt. of lambs (42 d)
Breed	3	1.534*	1.077	4.332	73.822
Year/season	7	0.340	2.526**	8.420	99.835*
Dam age	12	0.337	1.090**	10.451*	87.201**
Error[a]		0.420	0.450	3.607	45.215

Litter traits over all parities

		Mean squares			
Source	d.f.	No. of lambs (birth)	No. of lambs (42 d)	Wt. of lambs (birth)	Wt. of lambs (42 d)
Breed [s]	3	12.694**	6.614**	7.690	198.900
Dam(breed)	418	0.668**	0.533*	5.406**	63.803*
Year/season	7	2.979**	1.640**	34.456**	241.729**
Dam age	4	--	--	12.498**	145.774**
Error[b]		0.462	0.440	4.058	50.872

[a]Error d.f. values for numbers of lambs and litter weights at birth and 42 days of age were 235, 235, 234 and 204 respectively.

[b]Error d.f. values for numbers of lambs and litter weights at birth and 42 days of age were 440, 379, 436 and 375 respectively.

[s]Type III mean square for dam(breed) used as an error term.

*,**Effects significant at $p<0.05$ and $p<0.01$ respectively.

TABLE 28. Mean squares from the analysis of variance for weight traits.

Birth weights

Source	d.f.	Mean square
Breed [§]	5	20.953**
Dam(breed)	560	1.007**
Year/season	7	2.062**
Sex	1	12.738**
Type of birth	3	40.479**
Age of dam	4	5.715**
Error	1111	0.379

42-day weights

Source	d.f.	Mean square
Breed [§]	5	108.946**
Dam(breed)	539	9.240**
Year/season	7	61.477**
Sex	1	191.551**
Type of birth	9	152.924**
Age of dam	4	23.221**
Error	896	3.938

120-day weights

Source	d.f.	Mean square
Breed [§]	5	191.089**
Dam(breed)	523	52.770**
Year/season	5	306.899**
Sex	1	3541.451**
Type of birth	9	360.655**
Age of dam	4	18.873
Error	765	32.061

[§]Type III mean square for dam(breed) used as an error term.

*Effect significant at $p<0.05$.

**Effect significant at $p<0.01$.