A study of two genetic methods for increasing the performance of sheep in New Zealand:

- Crossbreeding between the Romney, Finnish Landrace and East Friesian.

- Use of number of foetuses scanned as a selection predictor.

A thesis presented in partial fulfilment
of the requirements for the degree of:
Master of Applied Science in Animal Science
at Massey University

Georgie J. Walker

1997

Acknowledgments.

Thank you to my family who have been a huge support in so many different ways. Both morally and financially they have got me through my time at Massey, which I do really appreciate Mum and Dad! Here's hoping the financial part stops here though! Thanks also for the phone card, car registration and insurance, clothes (especially linen shirts), school printers, computer breakdown help and Invercargill holidays! To Hamish and Angus - I think your statistic department at Otago needs reviewing!

I would like to thank my supervisor - Professor Hugh Blair for his academic support, and easy to approach and friendly manner. I would also like to express my gratitude for his understanding of my unfortunate and frustrating neck injury. Thank you also to the staff in the Animal Science office.

I would also like to thank Andy and Hamish Ramsden, the studmasters' of DIBO Genetics.

I would like to thank a number of old Lincoln friends, and new Massey friends who were scattered all around the country. They gave me alot of encouragement, support and much valued friendships that will never be forgotten. To Megs, thanks for the endless letters, cards, Northern and Frog'n'Firkin visits, and 2am Saturday night phone calls! To Rach, thanks for all of the holidays and visits - they will be reciprocated in the South Island! To Greg, thanks for the huge support, gear changing in my car (when I hurt my neck), and hot chocolates! To Sue, thanks for the visits, drink therapy, and phone calls! To Craig and Paula, thanks for everything else! Thank-you also to my library friend - Ken.

Thank-you lastly to Krista and Lloyd for their wonderful hospitality at the start of the '96 year. I didn't know a single person when I came to Palmerston North, and they made things so much easier - and possible.

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List of Abbreviations.

B.WT	Birth weight.
D1 -D4	First, second, third, and fourth dams.
DM	Dry Matter
E.FW	Ewe fleece weight.
E.WT	Ewe liveweight
EF	East Friesian sheep breed.
ES	Embryo survival
F	Finnish Landrace sheep breed.
FD	Average fibre diameter of wool.
H.FW	Hogget fleece weight.
H.WT	Hogget liveweight.
HNLB	Number of lambs born to hogget ewes.
kg	kilograms
NFS	Number of foetuses scanned per ewe.
NLB	Number of lambs born per ewe.
NLW	Number of lambs weaned per ewe.
OR	Ovulation rate
P1 - P4	First, second, third, and fourth cross progeny.
R	Romney sheep breed.
S.WT	Slaughter weight.
STW	Survival to weaning.
u	microns
W.WT	Weaning weight.

Chapter One.

INTRODUCTION.

New Zealand's national lamb weaning percentage has been around 100% since 1960 (Walpole, 1995), and as prolificacy is a major determinant of productivity and economic efficiency in sheep production systems (Nitter, 1987 IN: Maria, 1995; Gabina, 1989), the improvement of this trait at a national level is of significant economic importance. The development of more reproductively efficient sheep can be achieved through selection within breeds, by crossbreeding, or by importing new genetic material.

This study examines two ways of improving the prolificacy of sheep; by crossbreeding newly imported genetic material with the New Zealand Romney, and by altering the selection methods for prolificacy by using an alternative selection character.

The Finnish Landrace and East Friesian are both prolific sheep breeds, and their introduction to New Zealand has provided a potential opportunity to increase prolificacy in New Zealand by crossbreeding them with the current New Zealand sheep population. By assessing their performances under New Zealand environmental and management practices, and in relation to and with current New Zealand sheep, their potential may be predicted. It is important to take advantage of both their additive gene effects and their non-additive genetic interactions (or heterosis) with current New Zealand breeds. The aim should be to achieve an ideal breed composition either as a new composite breed or as regularly reconstituted crossbred stock. The additive and non-additive figures can be used to predict the phenotypic performances for different breed composites by simulating the outcomes of crosses between different ram types made up of different combinations of the breeds with current New Zealand sheep.

Direct selection for prolificacy in sheep has been generally accepted as an effective practice (Bradford, 1985; Bradford *et al.*, 1986; Bhuiyan and

Curran, 1995b). However, prolificacy (commonly referred to as litter size) can be so difficult to accurately measure and record for every ewe on a commercial farm as to be impractical. It is also considered to have a low heritability - the average figure reported in the literature is 0.10 (Bradford, 1985: IN: Perez-Enciso *et al.*, 1995). While accepting the relative importance of the trait, this low heritability, coupled with measurement and recording difficulties raises the issue of alternative methods which may provide greater genetic gains. Many farmers in New Zealand are using ultrasound pregnancy scanning as a management tool. They separate their ewes into mobs of single and multiple foetuses, and empties at scanning and applying differential management treatments accordingly. This separation could be taken advantage of by using these scanning results as a replacement selection predictor for numbers of lambs born to increase the genetic gain in sheep productivity, as well as being a useful management tool. This system could be a more accurate form for recording the litter size of ewes (than number of lambs born), and the heritability of the foetal numbers could be higher due to less environmental effects, thus the potential for overall genetic gain could be increased.

The replacement of the number of lambs born by ultrasound pregnancy scanning figures as a selection character is studied to predict the differences in expected genetic gain for a breeding objective and for the three traits in the breeding objective - number of lambs born, liveweight at 8 months and fleeceweight at 12 months.

Chapter Two.

LITERATURE REVIEW.

2.1. Breeding objectives, selection indexes and breeding programmes.

The use of a yardstick or selection index for measuring the net merit of breeding animals was introduced by Hazel in 1943. In practice several or many traits influence an animal's practical value, although they do so to varying degrees. The information regarding different traits may vary widely, some coming from an animal's relatives and some from the animal's own performance for traits which are expressed once or repeatedly during it's life. These factors make wise selection a complicated and uncertain procedure. In addition fluctuating, vague, and sometimes erroneous ideals often cause the improvement resulting from selection to be much less than could be achieved (Hazel, 1943: IN:Harris and Newman, 1994).

2.1.1. Breeding Objectives.

The definition of a breeding objective is the first and most important step in the design of a breeding programme (Ponzoni, 1982). In the past breeding objectives have been based on objective and subjective traits, for example, early attempts at defining selection objectives for the New Zealand Romney concentrated on visual traits and would not have lead to rapid improvement on productivity (Morton, 1932:IN Wickham and McPherson, 1985). A breeding objective is now considered to consist of traits that are of economic importance and that exhibit variation, such as measure(s) of reproductive success (Johnson and Garrick, 1990).

One definition of a breeding objective is a weighted combination of the traits that a breeder wishes to improve by genetic means because they will influence financial costs and returns to the breeder.

The breeding objective should be similar for all breeders and producers involved in the production of a certain type of sheep, therefore the aim should be that stud breeders define their breeding objectives according to their commercial breeder clients own breeding objectives, and to the demands of the respective processors and retailers.

The biggest difference amongst the many definitions of breeding objectives for sheep production, is due to the different production systems of the sheep, e.g. for lean meat production, or wool production. Some examples of different breeding objectives follow.

A breeding objective developed for the Australian Merino sheep based on a profit equation by Ponzoni (1986). The profit equation is defined as :

Profit = Income - Expense, where

Income (I) = lamb's wool x price per kg
+ hogget's wool x price per kg
+ breeding ewe's wool x price per kg
+ surplus offspring x price per individual
+ cull for age ewes x price per individual and,

Expense (E) = offspring (birth to hogget age) feed intake x feed cost per kg
+ breeding ewe's feed intake x feed cost per kg
+ hogget husbandry costs
+ breeding ewe husbandry costs
+ lamb's wool x cost of harvesting and marketing per kg
+ hogget's wool x cost of cost of harvesting and marketing per kg
+ breeding ewe's wool x cost of harvesting and marketing per kg
+ surplus offspring x cost of marketing per individual
+ cull for age ewes x cost of marketing per individual
+ fixed costs

Simm and Dingwall (1989), examined selection indices for terminal sire sheep breeds. The breeding objective was for lean meat production, and the objective traits were carcass lean and fat weight at 150 days of age. They did mention that feed intake should have also been included but because of a scarcity in genetic parameters they did not include it. The selection index characters considered were liveweight, ultrasonic fat depth and ultrasonic muscle depth in the thoracic or lumbar region, at a constant age.

Other breeding objectives can be more simple, where number of lambs and the weight of the lambs produced per ewe can be the objective traits, as efficient production of meat from sheep depend upon these two factors (Oltenacu and Boylan, 1981).

The definition of the breeding objective for purebreeding can be different to that of one for crossbreeding for the following reasons; 1) the percentage of each breeds' genes in the reproduction system depends on the mating programme adopted, therefore crossbred performance aslo depends upon breed fractions, 2) generally when ewes are mated to a ram of another breed all of the offspring are sold, and 3) product prices and means for some traits may change e.g., a crossbred lamb may be heavier and have a greater value. However Morris *et al.,* (1979 IN: Ponzoni, 1982) and Ponzoni and Walkley, (1981) do not agree, saying that as maximising monetary gains is the goal of commercial producers, then there is no difference between the goals of purebreeding and crossbreeding systems, as long as the sources of returns and cost are identified and, the traits influencing the returns and costs are assigned an economic value.

2.1.2. Selection Indexes.

The selection index consists of traits, known as characters that are used for selection to improve the traits in the breeding objective. The characters are genetically correlated with traits in the breeding objective or phenotypically correlated with other characters, which provide a cost-effective increase in accuracy of prediction allowing for measurement difficulty (Johnson and Garrick, 1990).

As it is sometimes not feasible to measure some traits that are defined in a breeding objective in both sexes, traits are selected that are considered more feasible than the objective traits and developed into a selection index. Therefore a selection index is usually considered the next main step in breeding operations. The selection characters can also be chosen because they are considered easier to measure, or can be measured at an early age.

The selection index consists of selection characters and their corresponding weighting factors. The weighting factors indicate the relative importance each trait has for selection based upon their correlations with the objective and economic importance of the objective traits. One of the objectives in developing a selection index is to maximise its correlation with the breeding objective.

There are two other common methods of selection used for animal improvement - independent culling levels and tandem selection. The index selection method has been found to be the most accurate of the selection methods (Young, 1961; Turner and Young, 1969).

2.1.2.1. Ultrasound Pregnancy Scanning.

Direct selection for litter size has been successful in sheep (Bhuiyan and Curran, 1995; Schoenian and Burfening, 1990; Bradford, 1985; Bradford *et al.*, 1986; Bhuiyan and Curran, 1995b), therefore the number of lambs born per ewe is commonly used as a selection predictor for most types of breeding objectives.

The difficulty in measuring litter size, however is thought to contribute to many inaccuracies (Perez-Enciso *et al.*, 1994), and coupled with a low heritability - average of 0.10 (Bradford, 1985: IN: Perez-Enciso *et al.*, 1995) has resulted in a number of other options being studied, including selection on ovulation rate, and embryo survival.

Ovulation rate (OR), embryo survival (ES) and a combination of the two have been studied as possible selection predictors of prolificacy by Perez-Enciso *et al.*, (1995). They found ovulation rate to have a heritability of 0.35 and a positive correlation with litter size, and embryo survival a heritability of 0.11, but a negative correlation with ovulation rate. Simulation studies have shown that an index combining ovulation rate and embryo survival rate can improve upon direct selection for litter size approximately 1.5 times (Perez-Enciso *et al.*, 1994), but the selection experiment by Perez-Enciso *et al.,* found that neither ovulation rate on its own, nor its combination with embryonic survival, provided any advantage over selection using litter size only. Waldron and Thomas (1992) found the expected response in litter size due to indirect selection on ovulation rate was 93% as large as the expected response to direct selection on litter size in Rambouillet sheep. Litter size and ovulation rate combined was estimated to produce 123% as much response to selection for litter size alone.

The use of OR by itself or OR and ES combined may not be acceptable to stud or commercial farmers, due to the method and cost of measurement combined with the large numbers of ewes to measure. Foetal number provides a much more attractive option. It can be determined by ultrasound pregnancy scanning which is already in use by many farmers as a management tool.

Kelly, (1986) found that from the time the ewe is 30 to 40 days pregnant through to lambing, less than 5% of developing foetuses are lost. A study by Kelly *et al.,* (1989) on foetal mortality from day 30 of pregnancy in Merino ewes offered different levels of nutrition found that more foetuses were lost in ewes bearing twins on lower maintenance levels than higher maintenance levels. Kleemann, et al., (1988), found that preferential feeding in late-pregnancy increased the twin-lamb survival of F+ Booroola x S.A Merino ewes. This information shows that ewes carrying multiple foetuses, but then losing 1 or more due to environmental causes before parturition are recorded as having a lower fecundity than ewes not losing any foetuses if prolificacy is based on litter size at birth. This can result in incorrect fecundity and fertility recording and ranking of ewes in a flock.

There have been many techniques available for diagnosing pregnant ewes over the years (Johns, 1986). Real-time ultrasonic scanning of pregnant ewes was pioneered in Australia (Sharp and Robertson, 1985), with real-time B mode transabdominal scanning being the method used in New Zealand.

Ultrasound scanning, used as a management tool can be used to identify:

a) pregnant or non pregnant ewes for culling, re-breeding or differential feeding,

b) the number of foetuses each ewe is carrying,

c) foetal viability (Buckrall, 1988), and

d) the gestational age of the ewes, or week of conception with an accuracy of >90% for an experienced operator (Johns, 1993). The use of scanning for determining the gestational age of the ewes and therefore the estimation of foetal age can be of great practical and economic value. (Aiumlamai, *et al.*, 1992).

There have been various reports publications on the accuracy of the scanning method currently used in New Zealand, and recommendations on the best times to carry it out:

- Sharp and Robertson, (1985) recommend that scanning should be carried out in commercial flocks after the last ewe mated is 45 days pregnant and before the first ewe mated is 105 days pregnant.
- Johns (1986) in a review of pregnancy diagnosis using scanning in Australia reports that by the 25th day of pregnancy, fluid can be detected in the uterus, by the 40th day, pregnancy can be detected with 100% accuracy and the number of foetuses 95% accuracy (or better), and that this degree of accuracy is maintained between the 40th and 120th days of pregnancy. Johns specifies that to achieve this degree of accuracy, operators must learn the correct procedure and gain experience.
- Goel and Agrawl, (1992) and Ishwar, (1995) reviewed pregnancy diagnosis techniques in sheep and goats. They found that ultrasound scanners can diagnose pregnancy at 40-45 days post breeding with over 90% accuracy (Logue *et al.*, 1987 IN: Ishwar, 1995; Buckrall, 1988;IN: Ishwar, 1995; White, *et al.*, 1994), and single versus multiple bearing ewes can be detected at 50 - 100 days of gestation.
- The differentiation between twins and triplets or quadruplets at any stage

is difficult to determine (White and Russel, 1984; Wilkins and Fowler, 1984 IN: Goel and Agrawl, 1992), but Gearhart *et al*, (1988) reported a 100% accuracy for ewes carrying one lamb and 97.3% for ewes carrying two lambs on days 51 to 75 of gestation.

- Fredriksson *et al.*, (1996; IN: Aiumlamai *et al.*, 1992) found that scanning is also useful in the detection of foetal death or abnormality.
- Owens and Armstrong, (1985) assessed the accuracy of real time ultrasound in determining litter size in prolific ewes, particularly those carrying 3 or more lambs. They found that 94.2% of ewes predicted to lamb with 3 or more lambs lambed with 3 or more lambs and of ewes which lambed with 3 or more lambs 21.1% had been accurately predicted to lamb with <3 lambs. The scanning was carried out between 62 and 75 days of gestation. The scanning technique used in New Zealand is therefore considered reliable and relatively easy to carry out under farming conditions.

2.1.3. Formation of breeding systems.

A paper by Harris et al, 1992 lays out the systematic approach to the design of a breeding system. They recommended a 9 step procedure for the designing of comprehensive animal breeding systems, and have reviewed some principles and procedures in designing and implementing co-ordinated breeding strategies in segmented industries.

These 9 steps are briefly described below. The authors state the importance of carrying out the steps sequentially from 1 through 9, while anticipating the requirements of the later steps in the earlier steps.

Step 1. Describe the Production System(s).

Step 1 requires a description of the whole farming operation concerning the available resources, normal management policies and current production figures. For example, the land/farm can be described by the land type, area, location, dry matter production patterns, available shelter, paddock numbers and sizes and labour can be described by the yearly labour unit pattern. The management policies can be described by the approximate timing of events, such as shearing, weaning, selling, and mating times and the management procedures, e.g., whether hoggets are mated (or not), and if they are, is it based on target weights, or are all of them presented to the ram, and when are supplements supplied. The current production figures can include expected fertility, fecundity, weaning, slaughter, hogget, and mature body weights, and wool weights. The complete life cycle of the production animals needs to be described, even if the animals are involved in more than one operating system or ownership during their production cycle.

Step 2. Formulate the objective - both simplified and comprehensive - of the system.

The objective is formulated as a mathematical function or set of functions that describes the contributions of various aspects of the system (especially the genetic aspects) to its productive efficiency. The objective should include the total efficiency of the parental lifetime reproductive performance of an individual, along with the efficiency of production from the offspring. The relative economic importance of all the component traits to the efficiency or profitability of the enterprise must also be considered in the objective. The objective of the system can be described in two forms - a simplified objective for the production units and a comprehensive objective of the complete integrated system. The simplified objective is focused on the performance characteristics for production units of parent females and offspring. If most of the animals in the system are either production animals or parents, then the simplified version will more accurately approximate the other form. But, if there is more than one production system, the comprehensive system, or the average of the comprehensive and simplified systems is used. For example, a breeding objective for a meat animal would involve a female parent and all her offspring, including the fraction of males needed for her production, a dairy animal or hen would involve the animal producing the milk or eggs with a description of the cost of producing that animal (parents' reproductive efficiency). The comprehensive objective allows for the costs of the evaluation and selection programme (steps 5 and 6) and the effectiveness of the purebreeding or crossbreeding programme (step 3). These three steps are important when considering classes of livestock that have low reproductive rates, as only 1/2 - 1/3 of the animals in the total system are described by the simplified objective, whereby the comprehensive objective includes all of the animals involved in the production system.

Step 3 - Choose a breeding system and breeds.

The breed performances for the traits described in Step 2 are stated for the available breeds, and incorporated in an analysis of the breeding systems. The types of breeding systems that can be studied include;

1) a purebreeding system with an established breed or strain,
2) a purebreeding system with a new synthesised population,
3) a rotational crossbreeding system with a specified number of strains,
4) a rotational crossbreeding system to produce parent females to be terminally mated to sires of a different breed, strain or cross, and
5) a specified crossing system with 2 or more breeds.

The choice of breeding system will influence the performance characteristics and costs of the production animals.

Step 4 - Estimate selection parameters and economic weights.

The selection parameters i.e., trait heritabilities, phenotypic variances, additive genetic variances and covariances between the relevant characteristics specified in step 2 and/or potential selection traits, are stated and used to evaluate the potential of the alternative systems in steps 5 and 7. The relative economic weights for the objective characters are the amount by which the profit may be expected to increase for each unit of improvement in that trait. The selection parameters can be found from literature or direct evaluation and the economic weights from the combination of steps 2, the simplified breeding objective, and step 3 to yield the economic weights needed for steps 5 through 7.

Step 5 - Design an animal evaluation system.

An evaluation system is designed to measure and record relevant characteristics, such as weights, age at puberty and fertility at appropriate times for inclusion in the selection criteria (step 6), subject to the constraints of reproduction and longevity. The evaluation system is a detailed life cycle of all the groups involved in the production system and includes data about individuals, test animals, and their siblings or progeny, and when their measurements are taken and used for selection and/or culling. The life cycles are arranged so that appropriate numbers of each sex and breed (if using a crossbreeding system) are available for mating at the appropriate times. If it is a crossbreeding system, the various strains or breeds may require different testing, selecting and mating systems, especially the sire breed in contrast to the dam breeds. All the possible selection options can be evaluated in this step, for example, selecting early in the life cycle, so giving a long reproductive life but limiting the potential for evaluation.

Step 6 - Develop selection criteria.

Selection criteria are an appropriately weighted mathematical function of relevant direct and indicator traits of individuals and near relatives. For each sex, and possibly for each breed or strain selection criteria are developed for each selection point. A selection criterion allows for multistage selection and determines the correlation between selection criterion and selection objectives.

Step 7 - Design matings for selected animals.

Step 7 determines the proportions of animals to be selected at each selection point. The issues of inbreeding, assortive mating and random mating strategies are considered, as well as mating ratios (males to females) and numbers of breeding seasons. The primary goal for breeding population sizes should be to maintain a population large enough to sustain sufficient genetic variability for long term response to selection while reproducing from the selected animals to produce the next generation of test animals. These design decisions affect the intensity of selection that, with accuracy of selection (correlation between selection criterion and selection objective), and the generation interval, will decide the rate of change achieved from the additive genetic variability present.

Step 8 - Design a system for expansion.

Genetic gains can be transferred or expanded upon by crossing improved strains or breeds with other strains or crosses, or within the improved strain or breed, or by using artificial insemination to improve female and male breeding stock. Improvements can be transferred and expanded concurrently with the crossing of the improved strains or breeds to improve female and male breeding stock or by using artificial insemination to sire production animals. The choice of transfer strategy requires consideration of:

- mass, the number of improved animals produced, and
- magnitude, the expected genetic improvement.

The benefits of the mass x magnitude relation relative to the costs of expansion and crossing are of primary concern as an adequate return on investment is required. The generation delays in achieving the magnitude and the required mass must also be taken into account, although the large potential for expansion usually outweighs economic cost of the delay. The poultry industry has developed an expansion strategy by increasing the mass of genetic improvement reaching the production phase, through a 1 generation delay in magnitude (by using grandparent stock). The expansion system for larger meat animals is not as developed as that for poultry, although the use of artificial insemination has helped improve the process. Artificial insemination has allowed greater accuracy of evaluation for sires, greater selection intensity, and has enhanced the expansion system for disseminating genetic improvements to improve production efficiency. The smaller production systems within a production system can be studied as to whether the genetic improvements resulting from the breeding programme are financially viable or whether they should be developed to support the other systems or vica versa.

Step 9 - Compare alternative combined programmes.

Step 9 allows for a comparison of the different options taken in the previous steps. The merits of each option combined with the other steps can be studied in terms of the relative costs and benefits. The benefits reflect the mass x magnitude of genetic improvement of the overall production efficiency, and the costs the combined functions of selection, expanding, crossing, producing and processing.

The authors suggest that future modifications to the breeding programme will probably be needed. There are numerous potentially changeable influences that will affect even the most well designed breeding programme, such as a change in the economic and marketing situation, a change in the availability of outside germplasm, a change in methods and procedures for evaluation, and reproduction technology.

There are a number of people involved in making decisions in an animal industry and this can result in a variety of approaches to the 9 steps. The impact of breeding programmes on commercial production has been quite small considering the potential benefits and increased returns. A lack of an accurate definition of the objectives for an overall breeding programme and the subjective opinions have also thought to have hampered the progress of genetic improvement for financial benefits. In some countries there is centralised control to overcome these problems. An alternative to this for other countries would be the co-operation and co-ordination of many smaller breeders and producers to form breed associations allowing concerted action.

The authors conclude with the statement that improving the efficiency of animal production would benefit not only the developers of that improvement but also all other segments of the industry, including the consumers of animal products.

Steps 1 through to 6 have been used in this study to evaluate the effects of using the Finn and the East Friesian breeds crossed to the New Zealand Romney.

2.2. Crossbreeding.

Crossbreeding is the mating of different breeds, lines or specified groups of a species, or the crossing of different species, eg donkey x horse to produce an ass. It is utilised to take advantage of heterosis and/or breed differences in additive genetic merit (Clarke, 1982a).

In sheep, crossbreeding has been used for many years to combine the attributes of more than one breed into crossbred progeny. The crossbred progeny being more closely adapted to a particular complex of environmental and economic conditions than any readily available pure breed. (Rae, 1952).

In many cases the crossbreeding of a combination of older breeds has led to the formation of new breeds (Mohd-Yusuff *et al.*, 1992). These breeds are known as composite or synthetic breeds and they have continued their existence as some of the common breeds known today, e.g., the Coopworth is a New Zealand breed developed in the 1960's from crossing the Border Leicester with the Romney, the Borderdale in the 1930's from the Border Leicester with the Corriedale, and the Border Leicester thought to be a cross of the English Leicester and Cheviot (New Zealand Wool Board, 1986). Not all crossbreeding leads to the formation of composite breeds though. In New Zealand, breeds such as the Southdown are crossed with the Romney to produce a crossbred lamb for slaughter (New Zealand Wool Board, 1986). This cross occurs at each generation and the crossbred progeny are not used for further breeding.

Once a desired breed combination is found however, it can for a variety of reasons be more practical to develop it as a composite breed. The management of composites is simpler than crossing each generation to maintain desired combinations of breed effects plus part of the maximum crossbreeding heterosis (Mohd-Yusuff *et al.,* 1992). The type of breeding system chosen does depend upon the breeding objectives of the production system, and the type of production system e.g., terminal sire production.

Rae, (1952) reviewed literature on crossbreeding of sheep for the formation of breeds and for lamb and mutton production. The history of sheep farming in New Zealand shows that New Zealand has made some use of crossbreeding to keep abreast of developments in technology and the economy. For example the first breed of sheep in New Zealand was the Merino breed (Rae, 1952). When refrigerated transport allowed the transportation of meat, the emphasis of carcass conformation in sheep was increased, so the Merino was crossbred to improve its carcass conformation. Merino ewes were crossed with the Lincoln breed in 1878 by James Little to produce halfbreds. English Leicester rams were also crossed with Merino ewes to produce a halfbred. The two types of halfbreds have since been crossbred together to form the Corriedale (Rae, 1952). Another example is the South-Suffolk which is a cross between the Southdown and Suffolk.

Clarke, (1982a) reviewed literature on the utilisation of breed resources in the improvement of sheep productivity. Clarke considered recent New Zealand experiments, and concluded that for many production systems it will always be difficult to make effective breed comparisons. This is because conditions vary markedly much from one farm to the next or because so many of the important costs of production are difficult to access and ascribe to appropriate paths in the chain of production leading to the final product. Breed evaluation is a step-wise process which gradually intensifies as information is gained and used to discriminate among alternative breeds, crosses and management systems, (Carter, 1976 IN: Clarke, 1982a). Predictions of Nitter (1978, IN: Clarke, 1982a) showed that the superiority of crossbreeding over straightbreeding would depend largely upon the extent to which crossbreeding strategies were able to exploit heterosis in maternal performance in addition to heterosis in lamb traits. High estimates of hybrid vigour for breeding ewes have suggested a future for rotational crossbreeding for better exploiting heterosis and perhaps also better avoiding the effects of recombination loss. Clarke stressed that research studies on the comparative feeding costs of different genotypes would be particularly valuable.

Crossbreeding enables the additive genetic effects of each breed to be combined and the non-additive genetic interactions to produce heterosis or hybrid vigour. The impact of additive genetic effects in crossbred animals can be calculated as the mean phenotypic value of the two breeds. The heterosis expressed in the progeny can be calculated by the difference in the measurement of the trait between the actual measurement in the crossbred progeny and the expected measurement based on the mean additive genetic values of the parental breeds, expressed as a percentage of the mean additive genetic values of the parental breeds.

2.2.1. Crossbred Sires

In 1963, Bradford *et al.,* discussed the performance and variability of the offspring of crossbred and purebred rams. They indicated that there was infrequent use of crossbred males by livestock producers and little experimental information on the effects of using crossbred sires. They conducted a study using the Hampshire and Suffolk sheep breeds, crossing purebred and crossbred rams over purebred ewes. The mean performances of the crossbred offspring was found to be at least equal to, and with variability no greater than that of the purebred offspring. They also found that survival and finishing ability of the purebred offspring may be superior to that of the crossbred, but this aspect was not significent.

The effect of paternal heterosis on lamb production traits of the ewe was studied by Ch'ang and Evans (1986). Purebred, F1, and F2 rams were mated to F1 ewes to study the effect of paternal heterosis on lamb production traits and to investigate the retention of paternal heterosis based on the dominance model. They found an impact of paternal heterosis, and, while it was retained, it was considered unlikely to have the same practical impact as the rentention of maternal heterosis.

2.2.2. Heterosis

Heterosis was reported by Mendel in his plant experiments when he reported that hybrid plants revealed vigour in excess of either parents (IN: Bowman, 1959). The same phenomenon was also noted in animals, prompting further study of heterosis in animals, (Sang 1956 IN: Bowman, 1956 IN: Bowman 1959; Bowman, 1956 IN: Bowman 1959).

Heterosis is the non-additive gene interaction that is thought to be the genetic cause of the difference in progeny performance from the mean of two parents. The bigger the non-additive gene frequency differences between the breeds, the greater the amount of heterosis that will be expressed. Therefore, crosses between different breeds and different traits show different degrees of heterosis. Traits of low heritability, such as fertility, show the most heterosis while those of high heritability, such as milk fat percentage, show little or none (Donald, *et al.,* 1977).

The word heterosis was introduced by Schull in 1914 (Bowman, 1914 IN: Bowman 1959; Sheridan, 1981), to describe the increased vigour of hybrids relative to their parents. It had originally been referred to as hybrid vigour and heterozygosis (Bowman, 1914 IN: Bowman, 1959), and today is referred to as both heterosis and hybrid vigour.

There have been many theories postulated on the causes of heterosis, with more than one cause thought to contribute to the overall heterosis effect. (Rendel, 1953). Today, the most commonly accepted reason is the dominance theory, and the effects of epistasis. Heterosis is generally considered the reverse of inbreeding depression. In 1912, East (IN: Bowman, 1959), postulated that the decline in vigour due to the inbreeding of naturally cross-fertilised species and the increase in vigour due to crossing such species were evidence of the same phenomenon. With inbreeding, the degree of homozygosity in a population is increased as the population (line or breed) becomes more inbred, thus increasing the number of undesirable homozygous recessive alleles. By crossing genetically separated populations the recessive alleles are (on average) covered up and the greater the proportion of dominant alleles that are expressed by the crossbred progeny, thereby increasing performance. However the same theory can also be applied to co-dominance, incomplete dominance, and overdominance and epistasis effects. Thus, heterosis can be considered to be caused by all the various types of gene interactions except additive gene action.

Some theories postulated throughout the last century can be related to today's theories.

Amongst the more common 'explanations' of the past are:

(1) Harmful mutation theory. This theory proposes that the frequency of a gene in a closed population can be increased by mutation, and in the absence of selection or reverse mutation it will eventually reach unity. If the gene is harmful the overall 'fitness' of the population is reduced and if the gene is completely recessive, selection will act on the homozygotes. By crossing non-inbred lines, the recessive genes can be masked for a generation so that no individuals are produced with reduced fitness. An estimate based on a reasonable guess at mutation rates and gene numbers puts the increase in fitness possible by this means at not more than 5% (Rendel, 1953).

(2) Euheterosis theory. Heterosis is considered by Dobzhansky (1950) to be the result of the interaction of polygene complexes carried in the chromosomes with different gene arrangements. The heterozygotes had higher adaptive values to the environment than homozygotes.

Two explanations that today can both be referred to as the overdominance theory are:

3) Overdominance theory. The heterozygote is considered to be better than either of the two homozygotes, with the qualities of the homozygotes combining into what is considered a better individual. 'The two alleles are

considered to both do something different in the heterozygote form' (Rendel, 1953).

4) Biochemical versatility. Described by Reeve and Robertson (IN: Sang, 1956), the hybrid is considered to be better and more adaptable to the environment, as it has more different kinds of genes, and thus can cope more successfully in the non-static environment.

5) Genetic-Environment Interaction Theory. Griffing and Zsirosis (1971) postulated this theory that heterosis is the result of the interaction between genetic and environment stimuli. They studied the flowering plant *Arabidopsis thaliana,* and found that the different kinds of heterosis were definable depending on how the heterotic phenomenon was influenced by facets of the physical as well as biotic environment. Thus, nutrient-dependent and temperature-dependent forms of heterosis were observed.

2.2.2.1. Types of heterosis.

Heterosis has been divided into three types of heterosis - individual, maternal, and paternal. These three types can be explained as summarised in a paper by Sheridan (1981):

(a) Individual heterosis, is the improvement in performance or vigour in an individual animal (relative to the mean of the parents) that is not attributable to either maternal, paternal or sex-linked effects,

(b) Maternal heterosis, refers to heterosis in a population attributable to using crossbred instead of purebred dams (eg increased milk production, improved prenatal environment, larger litter size),

(c) Paternal heterosis, refers to heterosis in a population attributable to using crossbred instead of purebred sires.

These three types of heterosis were reviewed for their contribution to breed utilisation for meat production in sheep by Nitter (1978). Nitter summarised the available literature to produce averages for crossbreeding effects which were compared to straightbreeding performances. The crossbred values were also used to study the efficiency of different systems of breed utilisation. The summaries included:

1) On average crossbred lambs had a 5% higher weaning weight at 100-120 days than purebred lambs due to individual heterosis and individual lambs born from crossbred ewes had about a 6 - 7% higher weaning weight at 100 - 120 days than those from purebred ewes. Similar values were found for individual heterosis in pre-weaning and post-weaning growth rates, with the improved growth rate due to an association of individual and maternal heterosis for birth weight (about 3 and 5% respectively),
2) The estimates for single reproductive traits were found to be more variable than those for growth. Fertility was improved more by using crossbred ewes (h^M = 9%) than by generating crossbred lambs out of purebred dams ($h^I = 2-3\%$). Individual and maternal heterosis for prolificacy (litter size) were found to be 3% each, with no heterosis on average found for ovulation rate. Lamb survival was found to be improved by producing crossbred lambs ($h^I = 10\%$) and by using crossbred dams ($h^M = 3\%$). There were few reports found on the possibility of improving reproductive performance by using crossbred rams.
3) The effects of heterosis were cumulative, for example, the total weight of lambs reared per ewe mated to the ram is a product of fertility, prolificacy, lamb survival and individual weaning weight and these combined effects accounted for an 18% advantage of crossbred progeny over purebred lambs (h^I) and an additional 18% for maternal heterosis (h^M). Combining the average estimates for each of the traits individually would provide similar overall effects.
4) Rotational breeding was found to be the most efficient form of crossbreeding.

2.2.3. Crossbreeding Systems

There are a number of regular crossbreeding systems available to breeders. The potential success of each system depends upon the additive genetic effects, the non-additive genetic interactions or heterosis, and the management required to maintain the particular system and the effects of the systems, e.g., increased fecundity may result in an excess number of progeny that the breeder is unable to manage in labour, capital, land, and resource terms. The utilisation of the heterosis in crossbreeding systems also depends upon the selection applied either during the inbreeding or at the crossing of the inbred lines (Bowman and Falconer, 1960).

The more common crossbreeding systems are:

- Specific Crossing. Specific crosses also referred to as fixed percentage crosses and can involve 2 or more 'straightbred' parent lines, known as two, three or four breed specific crosses. In a two breed specific cross the two different parent lines, e.g., Romney breed and Finn are crossed to produce crossbred progeny that are 1/2Romney and 1/2Finn. The progeny exhibit 100% individual heterosis (of the original heterosis from the two different breeds). A three breed specific cross involves crossbred progeny from a two breed cross crossed to a third breed, e.g., 1/2R1/2F x East Friesian. The resulting crossbred progeny have a breed composition of 1/4 of the two first breeds and 1/2 of the third breed, e.g., 1/4R1/4F1/2EF. The progeny express 100% individual heterosis from the three different breeds, and dams express 100% maternal heterosis if the dam is a crossbred and the sires express 100% paternal heterosis if they are crossbreds.

- Rotational Crossing. Rotational crosses are also known as variable percentage crosses. They can involve 2 or more breeds and follow a repeatable series of steps. For the two breed rotational cross, two breeds are crossed to produce crossbred progeny (F1), as in a two breed specific cross. The F1 progeny are then backcrossed to one of the original parent breeds to produce F2 progeny. The F2 animals are backcrossed to the other of the original parent breeds, and these crossbred progeny backcrossed to the first breed (their grandsire breed). Equilibrium is reached where the breed composition of the progeny is 2/3 of the sire breed and 1/3 of the maternal sire breed. At equilibrium, 2/3s of both maternal heterosis and 2/3 individual heterosis is expressed. A three breed cross involves three breeds in a rotation similar to the two breed rotation. The three different equilibrium compositions are 4/7 of the sire breed, 2/7 of the maternal grandsire breed, and 1/7 of the maternal great-grandsire breed. There is 6/7 of both the maternal and individual heterosis expressed. An alternative to the standard rotational cross is the periodic rotation cross, where the sire breeds are used 'unequally' in the rotation, i.e., instead of using sire A then sire B, then sire C, it could be sire A-C-A-B-C-C. This allows less variation in performance between generations, and can allow for some breeds to be used less. There is generally less heterosis expressed in periodic rotations than the standard rotations. Under certain conditions where the additive effects are more beneficial than the non-additive genetic interactions, some periodic rotations are more suitable than conventional rotations, (Falconer, 1960).

- Composite (or synthetic) breeds. Composite breeds are 'new' breeds that have been established by interbreeding the crossbreds from other crossbreeding systems. A specific or rotational cross is halted at a certain breed composition and the crossbred animals *inter se* mated with each other to form the new breed. The production system is then managed as a straightbred production system. In a two breed synthetic system 1/2 of the original heterosis is retained, and in a three breed 2/3 of the heterosis is retained, this can be calculated by the formula:

$$heterosis\ retained = \frac{(m-1)}{m},$$

where m is the number of parent breeds involved.

2.2.4. Crossbreeding in Australia and the United Kingdom.

Crossbreeding plays a large part in sheep production in Australia and the United Kingdom. Aged ewes from the hill flocks are mated to specialised breeds such as the Border Leicester to produce F1 ewes which in turn are mated under better conditions to special purpose terminal sires for production of three-way cross lambs for slaughter (Bichard, 1974; Fogerty, 1978: IN Clarke, 1982). Accordingly, the Suffolk and Border Leicester breeds have developed from original localised types to breeds having a major role as special-purpose male lines in an industry-wide crossbreeding programme. A study of breeding in the U.K. showed that 43% of ewes were mated to Down rams - nearly 80% of them being Suffolks, which also sired 27% of crossbred ewes compared with the 33% sired by Border Leicesters. Hill breeds comprised 38% of all ewes and directly contributed only 18% of carcass meat, but indirectly through crossbreeding their total genetic contribution to lamb meat supply was 63% and to the dams of slaughter lambs it was 57%.

2.3. History of the Finn and East Friesian in New Zealand.

In 1972 the Finnish Landrace and East Friesian breeds were among four breeds of sheep imported to New Zealand from Britain (Meyer *et al.*, 1977) with the aim of increasing fertility and/or growth attributes of the New Zealand Romney.

A report about the progress of these new exotic breeds was published by Meyer *et al.,* (1977) highlighting their introduction to the country and subsequent preproduction and production performances under experimental conditions. 46 ewes and 4 rams of the Finn breed and 5 ewes and 1 ram of the East Friesian breed were held at Somes Island Maximum Security Quarantine Station for six months. They were then transferred to Mana Island Research Station, where their numbers were rapidly increased using artificial breeding techniques. In 1976, the crossbred stock born at Mana Island were transferred to Crater Research Station near Rotorua for breed evaluation.

The breed evaluation programme consisted of a comparison of the progeny from the crossbreeding of the exotic breeds and some current New Zealand breeds with Romney ewes. The Romney ewes were a flock made up of a wide selection of Romney ewes from throughout New Zealand.

All of the exotic halfbreds had a mean lamb survival rate equal to or better than any of the local breed crosses, despite the Finn cross having the lowest mean birth weight (averaging 0.3kg lighter than the straightbred Romney at birth).

The East Friesian half cross was found to have a higher average weaning weight than the Finn half cross, Finn and East Friesian quarter breeds (3/4 Romney) and straightbred Romney.

The ewe hogget fleece weights of the East Friesian crosses were found to be comparable to the straightbred Romney and local breeds, with the Finn (and one local breed) fleeces slightly lower in weight and with a higher incidence of wool break than the other breeds. The authors commented that with the high selection intensity possible in a breed as prolific as the Finn, it may be possible to put more emphasis on selection for fleece weight and wool break.

Finn and East Friesian ewe crosses were found to have an extremely low incidence of bareness, high litter size, and good lamb survival, despite the high frequency of multiple births. The combination of these factors resulted in lambs docked/ewe mated of 1.36 and 1.29 respectively as compared to 0.67, 1.03, 0.83, for the Cheviot, Dorset, and German Whiteheaded Mutton crosses and 0.53 for the straightbred Romney.

The authors concluded that the high performance of the East Friesian and Finn exotic breed crosses made them look very useful for potential incorporation into the national sheep population, although the optimal breeding system for their incorporation and needed to be determined.

Unfortunately, all of the newly introduced and derived crossbred stock were destroyed after one of the East Friesian ewes was suspected of carrying scrapie. Scrapie is a neurological disorder, with a long incubation period and apparent hereditary influence, so the sheep were destroyed as part of the continuing quarantine safeguards to the national flock.

The East Friesian was reintroduced into New Zealand in 1992 with 11 pregnant ewes and 4 rams from Sweden. They were first released within New Zealand in April 1996 via artificial insemination. Allison, (1995) considers the East Friesian with large body size, high fecundity and milk production, leanness, and moderate wool production will likely prove the catalyst for a sheep milking industry, and will be a valued component of a productive meat and wool dam.

2.4. Performance data on the Finn and East Friesian.

A review of available data on Finn sheep throughout the world by Maijala and Osterberg, (1977) has summarised a general description of the breed.

The reproductive traits of the Finn show it to be an early sexually maturing breed, with both sexes being able to be used for breeding at 6-8 months of age. The conception rates are averaged at 94% for ewe lambs and 95-98% for adult ewes, with fecundity or litter size for 1 year old, 2 year old and adult ewes at 1.8, 2.4, and 2.7, respectively. There was a considerable range in reports for lamb mortality, 7 to 40 %, due to litter size (larger litter sizes produced smaller lambs and lower survival rates, and the age of the dam affected their ability to raise the larger litter sizes). Assistance was reported to be needed at lambing in 10-12% of cases. The majority of ewes were found to be able to conceive out of season. The rams were reported to show high libidos and good fertility, although there was no mention about their out of season performance.

In the review of body weights, the average birth weight was found to be about 2.4kg, but varied with litter size. The mean 150 day weight in Finland is 30kg and daily gain 187g. The weight gain during the first 6 weeks was found to depend upon litter size - with total litter weight at 150 days around 71kg, (litters of 4-5 lambs were three times as heavy as single litters).

The carcass yield of the lambs was reported to be competitive with other breeds, but carcass quality (percentage of muscle and subcutaneous fat) was 5-10% poorer. Fat was found to be located mainly in body cavities, not subcutaneously.

Fleece weights were reported to be inferior to most other breeds, being about 2kg as greasy and 1.5kg as clean. The wool was between 35-28 microns for average fibre diameter, white, semi- illustrious, soft and silky and with rare medullation.

An independent study by Branford Oltenacu and Boylan, (1981), was conducted on the performance of pure and crossbred Finnsheep with the Suffolk, Targhee and Minnesota 100 breeds. The average recordings for birth weight, weaning weights, fleece weights and total weaning weight of lamb per ewe for different age groups have been summarised in table 2.4.1.

A study by Olthoff and Boylan, (1991) considered the potential of the Finn breed as part of a composite ewe for use in a terminal sire production system. The Finn ewes were crossed with terminal sires (Suffolk, Targhee, Dorset and Lincoln) to evaluate their performance. They recommended the use of 1/2 or 1/4 Finn crossbred ewes in a terminal sire production system to increase the reproductive capacity in the ewe, with little or no reduction in lamb performance to market weight.

The use of Finn sheep to improve reproductive performance is recognised to be due to both additive and non additive genetic effects (Snowder *et al*, 1996). The reproductive performance can decrease due to genetic recombination and loss of heterotic effects, however Snowder *et al*, (1996) found that selective *inter se* breeding of Finn crossbred ewes can recover the lost reproductive performance within three generations of selection for total litter weight of lamb weaned.

Table 2.4.1 Average trait performances for Finn crosses. (Branford Oltenacu and Boylan, 1981)

	Purebred Finn	**1/2 Finn (1st cross)**	**1/2 Finn (backcross)**	**3/4 Finn**	**1/4 Finn**
Birth Weight - breed of lamb (kg)	2.60±0.04	3.34±0.02	3.19±0.04	3.10±0.04	3.34±0.04
Weaning Weight - breed of lamb (kg)	17.6±0.30	17.8±0.16	18.0±0.28	18.0±0.27	18.4±0.31
1 year ewe weight (kg)	42.9±0.9	48.6±0.4	44.0±0.8	43.2±0.7	45.3±0.8
2 year ewe weight (kg)	51.2±1.1	56.9±0.4	52.2±1.4	51.5±1.0	55.5±1.4
3 year ewe weight (kg)	57.7±1.4	63.4±0.7	60.7±2.4	56.7±1.7	No figure available
Total adjusted weight of lamb weaned per 1 year old ewe (kg)	19.8±1.7	15.6±0.8	12.0±1.4	15.9±1.4	10.8±1.5
Total adjusted weight of lamb weaned per 2 year old ewe (kg)	38.4± 2.2	27.8± 0.9	23.5± 2.7	26.5± 2.0	22.4± 2.6
1 year fleece weight (kg)	2.0 ± 0.08	2.8 ± 0.04	2.4 ± 0.07	2.4 ± 0.07	2.8 ± 0.08
2 year fleece weight (kg)	2.2 ± 0.10	3.0 ± 0.04	2.5 ± 0.13	2.6 ± 0.10	3.0 ± 0.14
3 year fleece weight (kg)	2.2 ± 0.13	3.0 ± 0.06	2.6 ± 0.22	2.5 ± 0.16	No figure available

The East Friesian is known as a milking sheep internationally. It is regarded as the most productive milking breed with production at 500- 600 litres per lactation (Allison, 1995).

The breed has a large body size, ewes averaging about 85kg, and a fleeceweight of about 4 - 4.5kg, and average wool fibre diameter of 37 microns. The lambing percentage (at birth) is 230% for mature ewes. The breed is considered to be lean, with low subcutaneous fat but good internal fat reserves (Allison, 1995).

Chapter Three.

MATERIALS AND METHOD.

3.1. Finn and East Friesian analysis.

The effect of the two breeds when combined with the New Zealand Romney were predicted by crossing ram types made up of different combinations of the breeds (Finn, East Friesian and Romney) with commercial Romney ewes in a simulation study. The performance on ten traits was studied, including weaning percentages.

The study was carried out in 3 parts:

Part 1 - 23 Ram types crossed to commercial Romney ewes.
Part 2 - Effect of 8 ram types on a breeding flock.
Part 3 - Analysis of lamb and wool production rate per kilogram of ewe liveweight

Some of the methodology used in this study was based upon the ideas of the studmasters' of a Sheep Stud in Southern Hawke's Bay (DIBO Genetics). The DIBO flock was straightbred Romney until the Finn breed was introduced in 1991, and the East Friesian breed in 1996.

The studmasters' aim is to breed a crossbred ram composed of the three breeds to ' produce ewes that will raise 2 fast growing lambs (weaned at 12 weeks, each weighing 30 kg) from the 1 year hogget stage'.

3.1.1. Part 1: 23 Ram types crossed to Romney ewes.

Twenty three different 'ram types', made up of different percentages of the Romney, Finn and East Friesian sheep breeds, were crossed to what was considered a standard Central North Island Romney ewe. The predicted phenotypic measurements for ten traits were generated for 4 'crosses' of each ram type.

3.1.1.1. Ram types

The twenty three ram types used for part one of the study, (numbered from Ram 1 to Ram 23) were generated by using different breeding systems. The systems used were considered to be the quickest ways to produce the specified ram type.

The ram type, identification number and method of production are shown in table 3.1.1.1.1. where; Column 1: shows the ram type identification number,

Column 2: shows the breed composition of each ram type,

Column 3: shows the breeding system used to produce the corresponding ram type.

Column 4: shows the number of generations and crosses required to produce the ram type based on their respective breeding system, and,

Column 5: the actual crosses of breeds to produce the ram type based on the breeding system.

Table 3.1.1.1. 1. Twenty three ram types and methods of production.

RAM TYPE	COMPOSITION	BREEDING SYSTEM	NUMBER OF GENERATIONS AND CROSSES	ACTUAL CROSSES
1	Romney	Straightbred	0 Generations 0 Crosses	none required
2	Finn	Straightbred	0 Generations 0 Crosses	none required
3	1/2Romney 1/2Finn	Two breed fixed cross	1 Generation 1 Cross	1)R x F
4	East Friesian	Straightbred	0 Generations 0 Crosses	none required
5	1/2Romney 1/2East Friesian	Two breed fixed cross	1 Generation 1 Cross	1)R x EF

table 3.1.1.1.1. continued........

6	1/2Romney 1/4Finn 1/4East Friesian	Three breed fixed cross	2 Generations 3 Crosses	1)R X F 2)R x EF 3)1/2R1/2F x 1/2R1/2EF
7	1/4Romney 1/2Finn 1/4East Friesian	Three breed fixed cross	2 Generations 2 Crosses	1)R x EF 2)1/2R1/2EF x F
8	1/4Romney 1/4Finn 1/2East Friesian	Three breed fixed cross	2 Generations 2 Crosses	1)R x F 2)1/2R1/2F x EF
9	1/2Finn 1/2East Friesian	Two breed fixed cross	1 Generation 1 Cross	1)F x EF
10	1/2Romney 3/8Finn 1/8East Friesian	Three breed crossbred cross - two breed backcross x two breed backcross	3 Generations 5 Crosses	1)R x EF 2)1/2R1/2EF x R 3)R x F 4)1/2R1/2F x F 5)3/4R1/4EF x 1/4R3/4F
11	2/3Romney 1/3Finn	Two breed rotational cross	4 Generations 4 Crosses	1)R x F 2)1/2R1/2F x R 3)3/4R1/4F x F 4)3/8R5/8F X R
12	2/3Romney 1/3East Friesian	Two breed rotational cross	4 Generations 4 Crosses	1)R x EF 2)1/2R1/2F x R 3)3/4R1/4EF x EF 4)3/8R5/8EF X R
13	1/3Romney 2/3Finn	Two breed rotational cross	4 Generations 4 Crosses	1)R x F 2)1/2R1/2F x R 3)3/4R1/4F x F 4)3/8R5/8F X R
14	1/3Romney 2/3East Friesian	Two breed rotational cross	4 Generations 4 Crosses	1)R x EF 2)1/2R1/2EF x R 3)3/4R1/4EF x EF 4)3/8R5/8EF X R

table 3.1.1.1.1. continued.........

15	4/7Romney 2/7Finn 1/7East Friesian	Three breed rotational cross	4 Generations 4 Crosses	1)R x F 2)1/2R1/2F X EF 3)1/4R1/4F1/2EF X F 4)1/8R5/8F2/8EF X R
16	4/7Romney 1/7Finn 2/7East Friesian	Three breed rotational cross	4 Generations 4 Crosses	1)R x EF 2)1/2R1/2EF X F 3)1/4R1/2F1/4EF X EF 4)1/8R2/8F5/8EF X R
17	2/7Romney 4/7Finn 1/7East Friesian	Three breed rotational cross	4 Generations 4 Crosses	1)R x F 2)1/2R1/2F X EF 3)1/4R1/4F1/2EF X R 4)5/8R1/8F2/8EF X F
18	2/7Romney 1/7Finn 4/7East Friesian	Three breed rotational cross	4 Generations 4 Crosses	1)R x EF 2)1/2R1/2EF X F 3)1/4R1/2F1/4EF X R 4)5/8R2/8F1/8EF X EF
19	1/7Romney 4/7Finn 2/7East Friesian	Three breed rotational cross	4 Generations 4 Crosses	1)F x EF 2)1/2F1/2EF X R 3)1/2R1/4F1/4EF X EF 4)2/8R1/8F5/8EF X F
20	1/7Romney 2/7Finn 4/7East Friesian	Three breed rotational cross	4 Generations 4 Crosses	1)F x EF 2)1/2F1/2EF X R 3)1/2R1/4F1/4EF X F 4)2/8R5/8F1/8EF X EF

table 3.1.1.1.1. continued.........

21	3/4Romney 1/8Finn 1/8East Friesian	Three breed crossbred cross - two breed backcross x two breed backcross	3 Generations 5 Crosses	1)R x F 2)1/2R1/2F x R 3)R x EF 4)1/2R1/2EF x EF 5)3/4R1/4F x 3/4R1/4EF
22	3/4Romney 1/4Finn	Two breed backcross	2 Generations 2 Crosses	1)R x F 2)1/2R1/2F x R
23	3/4Romney 1/4East Friesian	Two breed backcross	2 Generations 2 Crosses	1)R x EF 2)1/2R1/2EF x R

3.1.1.2. Crosses.

Each of the 23 ram types were crossed with the 'average Romney ewe' and then their respective progeny, grand-progeny and great-grand-progeny for a total of 4 crosses.

Cross 1 for each ram type involved the ram and the Romney ewe labelled as Dam 1 (D1), to produce crossbred progeny - Progeny 1 (P1). The P1 ewe hoggets from each cross then became the D2s and were backcrossed to their respective sire breed types in cross 2 to produce the P2s. The P2 ewe hoggets were backcrossed to their respective sire breed type as D3s for cross 3 to produce the P3s and finally the P3 ewe hoggets as D4s backcrossed to their respective sire breed types for cross 4 to produce the P4s. Therefore, 4 different types of progeny were produced for each of the 23 ram types. In total 92 (23 ram types * 4 crosses/ram type) crosses were simulated.

An example of the 4 cross procedure for each ram can be demonstrated by detailing the four crosses of one ram type.

e.g., The 4 crosses of Ram type 6 -1/2R1/4F1/4EF:

<u>Cross 1:</u>

Romney ewe	x	1/2R1/4F1/4EF ram	=	3/4R1/8F1/8EF progeny
D1	x	R6	=	P1

Cross 2:

3/4R1/8F1/8EF ewe x 1/2R1/4F1/4EF ram = 5/8R3/16F3/16EF progeny
D2/P1 x R6 = P2

Cross 3:

5/8R3/16F3/16EF ewe x 1/2R1/4F1/4EF ram = 9/16R7/32F7/32EF progeny
D3/P2 x R6 = P3

Cross 4:

9/16R7/32F7/32EF ewe x 1/2R1/4F1/4EF ram ewe = 17/32R15/64F15/64EF progeny
D4/P3 x R6 = P4,

where R6 is ram type 6,
D1, D2, D3 and D4 represent dam types 1, 2, 3, and 4 and,
P1, P2, P3 and P4 represent progeny types 1, 2, 3, and 4.

3.1.1.3. Traits studied.

Ten traits were studied to establish possible parameters of production from each cross. The parameters established are based upon breed and flock averages.

The ten traits studied were:

1 and 2) Weaning Percentage for MA and hogget ewes.

Weaning percentage was based on number of lambs born (**NLB**) and survival rate to weaning (STW) for the number of ewes at mating. Weaning percentage was considered important to derive information for:

- number of animals available for slaughter
- number of animals available for flock replacements by selection
- number of animals to include for budgeting of resources, e.g., Dry Matter (DM).

3) Birth Weight.

4) Weaning Weight.

Although weaning weight can be dependent upon different management policies, weaning weight gives an indication of:

- daily growth rate from birth, and therefore resources used (by ewe)
- total litter weight produced per ewe when multiplied by weaning percentage information
- indication of how much DM and time required for lambs to be ready for slaughter.

5) Slaughter weight.

Slaughter weight is an important consideration for breed evaluation, in particular to obtain an indication of how much DM is required (along with number of days from weaning).

6) Hogget ewe liveweight.

The weight of the hogget ewes was estimated to provide information for;

- feed budgets.

7) Mixed age ewe liveweight.

The weight of the mature ewe was included to:

- calculate the required DM for maintenance and reproduction
- assess the practicality of carrying those ewes in terms of resources required compared to what they produce i.e., total litter weight -(weaning percentage x weaning weight), and wool production.

8) Hogget fleece weight.

Hogget fleece weight was included as it is a part of the sheep income equation.

9) Ewe fleece weight.

Ewe fleece weight is included as it is part of the sheep income equation.

10) Average fibre diameter.

The average fibre diameter was considered to study the change in quality of the wool.

These 10 traits were selected for inclusion in this study, as they are integral components of most sheep system profit equations. As a consequence, they are potential breeding objective traits and/or selection index characters.

3.1.1.4. Calculations of expected phenotypic performances.

The predicted phenotypic measurements were calculated using the additive genetic and non-additive genetic figures for the breeds. The Romney breed was divided into two lines - Original Romney (commercial Romney), and Stud Romney, as they were considered to be genetically different for additive effects. The heterosis figures were assumed to be the same for all of the breed interactions, i.e., R x F and 1/2R1/2EF x F had the same heterosis figures, and there was no heterosis assumed between the Original Romney and Stud Romney lines. The figures used for each of the 10 traits, guesstimated from performance information provided by DIBO Genetics and from published literature, are in tables 3.1.1.4.1. and 3.1.1.4.2.

Table 3.1.1.4.1. Additive gene effects of the breeds.

Breed: Trait:	**Original Romney**	**Stud Romney**	**Finn**	**East Friesian**
NLB (lambs)	1.18	1.4	2.75	2.3
STW (%)	0.85	0.85	0.75	0.85
H.NLB (lambs)	1	1.3	2.4	2
H. STW (%)	0.8	0.8	0.75	0.85
B.WT (kg)	4	4	3	5
W.WT (kg)	20	25	26	35
S.WT (kg)	27	29	32	35
H.WT (kg)	40	46	46	65
E.WT (kg)	55	58	58	80
H.FW (kg)	3	3.4	2.8	3.7
E.FW (kg)	3.4	4	3.5	4.5
FD (microns)	35	34	28	36

Table 3.1.1.4.2. Non-additive genetic interactions between the breeds.

Type of heterosis:	INDIVIDUAL	MATERNAL	PATERNAL
Trait:	HETEROSIS	HETEROSIS	HETEROSIS
NLB	/	5%	1%
STW	5.5%	4%	/
H.NLB	/	5%	1%
H.STW	5.5%	4%	/
B.WT	10%	5%	2%
W.WT	15%	14%	2%
S.WT	25%	5%	2%
H.WT	18%	5%	2%
E.WT	18%	5%	2%
H.FW	18%	10%	2%
E.FW	17%	5%	2%
F.D	16%	5%	2%

A Microsoft Excel programme was used to calculate the expected phenotypic performances for each cross and each trait.

A worksheet was established for each trait, with each sheet comprising 6 tables: Table 1: Heterosis effects - for trait.

Table 2: Additive effects - for trait.

Table 3: Total heterosis for each component of trait.

Table 4: Percentage of heterosis expressed by each individual involved in analyses.

Table 5: Breed composition breakdown of every individual involved in analyses.

Table 6: Results table for trait.

The formulae used in the tables for one of the ram types is shown in Appendix I. A general explanation of each of the tables has been summarised in the following paragraphs:

Table 1: Heterosis effects - for trait.

Table 1 shows the heterosis figures for the breed crosses. The heterosis effects have been divided into individual, maternal and paternal effects for each trait (where appropriate), and the figures are in decimal form as a percentage of the unit used to measure the particular trait. There is also another column in the table of '1's that are required as part of the final equation.

Table 2: Additive effects - for trait.

Table 2 shows the raw data for the additive effects for each of the breeds, Finn, East Friesian, Original Romney (the commercial Romney flock figures) and Stud Romney (the stud Romney figures).

Table 3: Total heterosis for each component of trait.

Table 3 shows the actual heterosis percentage expressed for each of the different genotypes of the progeny. The heterosis has been divided into the maternal heterosis from its dam (based on it's dams genotype, paternal heterosis from its sire (based on it's sires genotype) and individual heterosis (based on its own genotype). The percentage figure is calculated by multiplying the percentage of original heterosis expressed by each genotype (in table 4) with the original heterosis for each trait (in table 1).

Tables 4a, 4b, and 4c: Percentage of heterosis expressed by each individual involved in analyses.

These sub-tables show the percentage of original heterosis expressed as an individual (individual heterosis), and as a parent i.e., maternal and paternal heterosis, based on the breed composition or genotype of the individual. Table 4a shows the individual heterosis expressed or retained by each individual genotype, Table 4b, the maternal heterosis expressed by the dam of each individual genotype, and Table 4c, the paternal heterosis expressed by the sire of each individual genotype.

The tables are identical for all of the traits, as the percentage of original heterosis expressed is the same for all of the traits.

The method used to calculate the percentage of original heterosis expressed is the Heterosis Fraction Method, that can be referred to in Appendix II.

Table 5: Breed Composition breakdown of every individual involved in analyses.

Table 5 shows the fractions of each breed in the composition of all of the rams, dams and progeny involved in the analyses. The table is structured to show a ram identification number, then the fractions of his breed composition (breed fractions), then the breed fractions of the first dam D1, then that of the P1, P2, P3, and P4s across the same rows. Each ram and his respective dam and progeny breed compositions are on rows identified by the ram type identification number.

The order of the breeds for the ram types is Romney, Finn, East Friesian. The order for the dams involved in the first cross (D1s) is Original Romney (OR), Finn and East Friesian and the order for the all of the progeny (and remaining dams) is Total Romney, Original Romney, Stud Romney, Finn and East Friesian.

The fractions are formatted to take up two rows, with the numerator in the row above its respective denominator, in order to use the figures to calculate the percentage of original heterosis for table 4. The fractions for the Original Romney are entered into one box, as they are not required for the heterosis calculations, i.e., it is assumed in this study that there is no heterosis between the Stud Romney and Original Romney, therefore only the total Romney figures are required.

These figures in this table are also used to calculate both the additive effects in table 6.

Table 5, like table 4 is also identical for all of the traits.

Table 6: Results table for trait.

Table 6, the results table, shows in column 1, the ram type, column 2 the dam genotype, and column 3 the resulting progeny genotypes from the cross of the sire and dam in columns 1 and 2 respectively. Column 4 shows the total heterosis percent for the trait, column 5 the total additive effect for the trait (from tables 2 and 5). The expected phenotypic performance is in column 6 and is calculated by multiplying the heterosis and additive figures effects in columns 4 and 5.

3.1.2. Part 2: Effect of 8 ram types on a breeding flock.

Based upon the thoughts of the studmasters of DIBO, and the results from part 1, (in Appendix IV), 8 ram types were selected for further analysis. Each ram type was assigned an option number for parts 2 and 3.

The 8 ram types selected were: Ram type 6 - 1/2R 1/4F 1/4EF (Option 1)
Ram type 7 - 1/4R 1/2F 1/4EF (Option 2)
Ram type 8 - 1/4R 1/4F 1/2EF (Option 3)
Ram type 19 - 1/7R 4/7F 2/7EF (Option 4)
Ram type 3 - 1/2R 1/2F (Option 5)
Ram type 1 - R (Option 6)
Ram type 11 - 2/3 R 1/3 F (Option 7)
Ram type 17 - 2/7R 4/7F 1/7EF (Option 8).

The ram types were crossed to the ewe flock for 4 consecutive years, and the predicted phenotypes averaged to calculated the flock averages for a 5 year period.

3.1.2.1. Ram types chosen.

The 8 ram types were chosen for a number of reasons. Types 7, and 17 represented a ram type with a majority Finn genes, then Romney and 1/4 or less of East Friesian. Types 3, 6, 8 and 19 were chosen as a variation on 7 and 17. Ram 1 was chosen to provide a comparison of the various crossbred rams to the purebred Romney, and ram type 11 was chosen as a variation on this. DIBO Genetics also expressed an interest in ram types similar to ram types 6, 7, and 17.

3.1.2.2. Annual calculations.

The phenotypic performance figures calculated in part 1, for each of the selected 8 rams were used to calculate the overall flock performance, based on the age structure of the flock for each year.

Two different flock age structures, option a and option b, were used to calculate the effect of rate of replacement of hogget ewes into the flock. Option a is considered to be a 'base' structure, where the breeding flock consists of all age groups from hogget up to 6 years. Option b has a higher percentage of hoggets selected for the breeding flock, and the 5 year old age group is the oldest age group in the breeding flock, this lowers the generation interval.

Both of the age structures options were expressed in two forms:

- % of hoggets and % of MA flock, where the % of hoggets figures was used to calculate the figures for the hogget traits - hogget weaning percentage, hogget liveweight and hogget fleece weight, and the % of MA flock used to calculate the MA ewe traits - weaning percentage, ewe liveweight, and ewe liveweight.
- % of breeding flock, to calculate the birth, slaughter, and weaning weights, and average fibre diameter of the wool.

The performances for each trait in each year are calculated, based on the proportion of each age group and their respective performances. In option a, all of the calculations have been based upon the age structure in option a. In option b, the first two years - years 0 and 1 are based upon the age structure of option a and then for years 2, 3, 4 and 5, the selection rate is changed to that of option b.

Table 3.1.2.2.1. shows the percentages of each age group for each option.

Table 3.1.2.2.1. Standard age structure of flock for options a and b for each ram type.

	Option a		Option b	
Age	% of hoggets and % of MA Flock	% of Breeding Flock	% of hoggets and % of MA Flock	% of Breeding Flock
Hoggets	100%	22%	100%	30%
2T	27%	21%	36%	25%
3 yrs	26%	20%	29%	20%
4 yrs	19%	15%	21%	15%
5 yrs	14%	11%	14%	10%
6 yrs	14%	11%	0%	0%

The details of what happens in each year have been summarised in the following paragraphs, and the genotypes in each year and age group in the tables 3.1.2.2.2, and 3.1.2.2.3.

Year 0 - the base year, where all of the phenotypic measurements for all of the traits are from the base flock genotypes or the Original Romney figures.

Year 1 - is the year that the ram type is first crossed to the breeding ewes in the flock, therefore the individual traits - hogget and ewe liveweights, fleece weights and fibre diameters will remain the same, but the weaning percentages, birth, weaning and slaughter weights of the lambs produced in year 1 and measured in year one will be based upon the genotypes from cross one.

Year 2 - is the second year the ram type is crossed to the breeding flock. The weaning percentage from the hogget ewes will be based on cross 2, as the hoggets are the first year lambs that were produced from cross 1, therefore making them P1/D2 classification. The weaning percentage from the 2 years and older ewes are based upon the performances from cross 1, as all of the ewes are the original genotype (D1). The birth, weaning, and slaughter weights of the lambs from the hogget ewes in year 2 are based on the phenotypic results from cross 2, and from the 2 years and older ewes from the phenotypic results in cross 1, as the ewes are all the original genotype (D1). The hogget liveweights and fleece weights for year 2 are based upon the phenotypic results from cross 2, as the genotypes of their dams D2 are from cross 1, i.e. they are P1s. The MA ewe live weight and fleece weights are the same as years 0 and 1, as they have the same base genotype.

Year 3. The weaning percentage from the hogget ewes is from the phenotypic results from cross 3, as the dams are P2s/D3s, the weaning percentages from the 2 year old ewes is based upon the phenotypic results from cross 2, as the dams are P1s/D2s. The older ewes are still of the original genotypes, therefore their weaning percentages are based on cross 1. The birth, weaning and slaughter weights are measured from P3's from the hogget ewes, P2's from the 2 year old ewes and P1's from the three year old and older ewes.

Year 4 - is the last year the ram is crossed to the flock. The progeny in year 4 are made up of 4 different genotypes, as there are 4 types of ewes in the breeding flock. There are 3 different genotypes for hogget and ewe liveweights and fleece weights and fibre diameter.

Year 5 - is the first year the P4s are included into the breeding flock. Two different age groups of ewes have produced P4s.

Table 3.1.2.2.2. Type of progeny in each age group in each year for the traits; Weaning percentage for hogget and MA age ewes, birth weight, weaning weight, and slaughter weight.

AGE	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Hogget	P0	P1	P2	P3	P4	P4
2 years	P0	P1	P1	P2	P3	P4
3 years	P0	P1	P1	P1	P2	P3
4 years	P0	P1	P1	P1	P1	P2
5 years	P0	P1	P1	P1	P1	P1
6 years	P0	P1	P1	P1	P1	P1

Table 3.1.2.2.3. Type of progeny in each age group in each year for the traits; Hogget and MA ewe liveweights, hogget and MA ewe fleece weights, and average fibre diameter

AGE	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Hogget	P0	P0	P1	P2	P3	P4
2 years	P0	P0	P0	P1	P2	P3
3 years	P0	P0	P0	P0	P1	P2
4 years	P0	P0	P0	P0	P0	P1
5 years	P0	P0	P0	P0	P0	P0
6 years	P0	P0	P0	P0	P0	P0

3.1.2.3. Traits studied.

The traits studied were the same as in part 1, except the two weaning percentage traits (weaning percentage for MA ewes and weaning percentage hogget ewes), were joined together to obtain an average weaning percentage for the flock.

The birth, slaughter, and weaning and slaughter weights of lambs from hogget ewes are normally different to that from when the ewes of the same genotype are 2 years and older, and under the same environmental conditions. However, in this study they were assumed to be the same, as the figures were calculated as averages. It was also assumed, for the purpose of this study, that the effect of the simplification was insignificant.

3.1.3. Part 3: Predicted changes in flock performances and analysis of lamb and wool production rate per kilogram of ewe liveweight

The expected changes for years 1 to 5 from the base year 0 for the traits in part 2 were calculated and tabulated. The figures were calculated by subtracting the base year performances from the annual performances for each trait, using the figures calculated in part 2.

The efficiency of production for ewe liveweight was calculated for:

- Total lamb weight weaned, (measured as kilograms of lamb per kilogram of ewe liveweight), and
- Total fleeceweight produced, (measured as grams of wool per kilogram of ewe liveweight).

Both efficiencies were calculated by dividing the total production of each trait by the ewe liveweight. The calculations were done for Years 0 to 5.

3.2. Number of foetuses scanned as a selection predictor.

To use ultrasound pregnancy results as a selection predictor, the number of foetuses scanned (NFS) is used as a replacement selection predictor for number of lambs born (NLB) in a set breeding objective.

A breeding objective, and two selection indices - the NLB selection index and the NFS selection index, were simulated to calculate the genetic changes of the two predictor options and the expected differences in index ratings of individuals in a flock.

3.2.1. Calculation of the figures used for the analysis.

The breeding objective and NLB selection index were those used for the default Romney option used in Animalplan (Sherlock, 1996). Animalplan economic values were also used.

The breeding objective was:

$$T = 10.5G_{NLB} + 0.55G_{LW8} + 3.0G_{FW12},$$

where: T is the breeding objective,

G_{NLB} is the genotypic value of the dam for the trait number of lambs born,

G_{LW8} is the genotypic value for the trait liveweight at 8 months of age,

G_{FW12} is the genotypic value for the trait fleece weight at 12 months of age,

10.5 is the relative economic value for the trait number of lambs born,

0.55 is the relative economic value for the trait liveweight at 8 months and,

3.0 is the relative economic value for the trait fleece weight at 12 months of age.

The two selection indexes referred to as the NLB index and NFS index are:

1)The NLB selection index:

$$I_{NLB} = b_{NLB}X_{NLB} + b_{WWT}X_{WWT} + b_{LW12I}X_{LW12I} + b_{LW12PHS}X_{LW12PHS} + b_{FW12I}X_{FW12I} + b_{FW12PHS}X_{FW}$$

where: I_{NLB} is the selection index,

b_{NLB}, b_{WWT}, b_{LW12I}, $b_{LW12PHS}$, b_{FW12I}, and $b_{FW12PHS}$ are the weighting factors for the phenotypic deviations, and

X_{NLB}, X_{WWT}, X_{LW12I}, $X_{LW12PHS}$, X_{FW12I}, X_{FW12I}, $X_{FW12PHS}$ are the adjusted (for systematic environmental effects) phenotypic deviations for the selection characters number of lambs born to the dam, weaning weight, individual liveweight at 12 months, paternal half-sib liveweight at 12 months, individual fleeceweight at 12 months, and paternal half-sib fleeceweight at 12 months, respectively.

2) The NFS index is the same as the NLB index, except $b_{NLB}X_{NLB}$ is replaced by $b_{NFS}X_{NFS}$, e.g.,

$$I_{NFS} = b_{NFS}X_{NFS} + b_{WWT}X_{WWT} + b_{LW12I}X_{LW12I} + b_{LW12PHS}X_{LW12PHS} + b_{FW12I}X_{FW12I} + b_{FW12PHS}X_{FW12P}$$

where: I_{NFS} is the selection index,

b_{NFS} is the weighting factor the NFS phenotypic deviations, and

X_{NFS} is the adjusted (for systematic environmental effects) phenotypic deviations for the selection character number of foetuses scanned of the dam.

Calculations:

- The 'b' weighting factors for each adjusted phenotypic deviation in the two selection index equations were derived as best linear predictors (BLP), so the prediction error variance (PEV) was minimised between the objective and index i.e., $Var(I-T) = Var(I) + Var(T) - 2Cov(I,T)$.
- The prediction error variance equation was differentiated with respect to each of the b factors and each equation set equal to zero. The two sets of normal equations are shown to in appendix III, 3.1.
- The genetic and phenotypic parameters required to solve the normal equations are given in table 3.2.1.

Table 3.2.1. Genetic and phenotypic parameters for traits in the objective and selection indices.

TRAIT	Phenotypic SD	NLB	LW8	FW12	NFS	WWT	LW12I
NLB	0.57	**0.15**		-0.2		0.05	0.12
LW8 (kg)	3.5	0.15	**0.35**				
FW12 (kg)	0.45	0.04	0.3	**0.56**	-0.2	0.2	0.4
NFS	0.5	0.88	0.15	0.04	**0.25**	0.1	0.13
WWT (kg)	3.0	0.1	0.8	0.2	0.15	**0.2**	0.65
LW12 (kg)	4.9	0.25	0.8	0.4	0.27	0.8	**0.29**

Heritabilities are on the diagonal, phenotypic correlations are above the diagonal and genetic correlations below the diagonal.

NLB = Number of lambs born.
LW8 = Liveweight at 8 months.
FW12 = Fleece weight at 12 months of a shorn lamb.
NFS = Number of foetuses scanned.
WWT = Weaning Weight.
LW12I = Liveweight at 12 months of individual.

(References, Johnson et al., 1989; Fogarty, 1995).

The blank cells in table 3.2.1. are empty as the correlation figures between those traits are not required in the calculations. The NFS values in table 3.2.1. were estimated based on the equivalent NLB figures. It was assumed that the heritability of NFS would be higher than that of NLB, and the phenotypic standard deviation of NFS would be lower than NLB due to the reduced opportunity for environmental influences. That is, ewes will have been exposed to 2-3 months of pregnancy before NFS is measured while they have had 9 months of pregnancy before NLB is measured.

The simultaneous equations were solved to calculate the index weighting factors, using Microsoft Excel. The normal equations for each of the two options were formatted into a set of simultaneous equations, where: $Pb = G$,

The equation $Pb = G$ was solved to find b by inverting the P matrix, then multiplying it with the G matrix (including relative economic values) to get the b values, *i.e.*, $b = P^{-1}G$. A set of 6 b values for the 6 selection characters in each of the two options were obtained using this method.

3.2.2. Comparison of the two different selection predictors.

The weighting factors and co-variances and variances derived in the previous section were used to compare the two different selection index options by:

- The expected genetic gain in the objective, objective traits and index characters, and
- The correlation of the two estimated selection index values for 50 hogget ewes in a simulated flock.

3.2.2.1. Expected genetic gain in objective, objective traits and index characters.

The expected genetic gain was calculated for annual gain per animal.
The formulas used to calculate the expected genetic gains are:

Breeding Objective

The expected genetic gain in the breeding objective was calculated as cents per animal per generation, using the formulae:

$$\Delta G_T = i\beta_{TI}\sigma_I,$$

where ΔG_T is the genetic change in the breeding objective
i is the selection intensity,
$\beta_{TI} = \frac{Cov(T,I)}{Var(I)}$, (and is assumed to be equal to unity, as the b weighting values have BLP properties), and
σ_I is the standard deviation of the Index.

The standard deviation of the index, $\sigma_I = \sqrt{VarI}$, for the I_{NLB} is:

$$
\begin{aligned}
VarI = {} & b_{NLB}^2 Var(X_{NLB}) + b_{WWT}^2 Var(X_{WWT}) + b_{LW12I}^2 Var(X_{LW12I}) + b_{LW12PHS}^2 Var(X_{LW12PHS}) \\
& + b_{FW12I}^2 Var(X_{FW12I}) + b_{FW12PHS}^2 Var(X_{FW12PHS}) + 2b_{NLB} b_{WWT} Cov(X_{NLB}, X_{WWT}) \\
& + 2b_{NLB} b_{LW12I} Cov(X_{NLB}, X_{LW12I}) + 2b_{NLB} b_{LW12PHS} Cov(X_{NLB}, X_{LW12PHS}) \\
& + b_{NLB} b_{FW12I} Cov(X_{NLB}, X_{FW12I}) + 2b_{NLB} b_{FW12PHS} Cov(X_{NLB}, X_{FW12PHS}) \\
& + 2b_{WWT} b_{LW12I} Cov(X_{WWT}, X_{LW12I}) + 2b_{WWT} b_{LW12PHS} Cov(X_{WWT}, X_{LW12PHS}) \\
& + 2b_{WWT} b_{FW12I} Cov(X_{WWT}, X_{FW12I}) + 2b_{WWT} b_{FW12PHS} Cov(X_{WWT}, X_{FW12PHS}) \\
& + 2b_{LW12I} b_{LW12PHS} Cov(X_{LW12I}, X_{LW12PHS}) + 2b_{LW12I} b_{FW12I} Cov(X_{LW12I}, X_{FW12I}) \\
& + 2b_{LW12I} b_{FW12PHS} Cov(X_{LW12I}, X_{FW12PHS}) + 2b_{FW12I} b_{FW12PHS} Cov(X_{FW12I}, X_{FW12PHS})
\end{aligned}
$$

The variance formulae for the I_{NFS} option was the same, except for the replacement of the NLB variances and covariances with the other selection characters being replaced by NFS variances and covariances, and the I_{NFS} weighting factors being used.

The variance of the selection index was calculated by using a matrix algebra method to check previous calculations by :

- ($b'P\,b$ matrix transposed) x P matrix to get the standard deviation for the Selection Index.

There are 3 different selection intensity figures based upon the different flock age structures, labeled as options 1, 2, and 3. Option 2 is used to calculate the genetic changes for the breeding objective, and objective traits and selection characters.

To calculate the genetic gain per animal per year, the figures were divided by the average of the ram and ewe generation intervals, as stated in the flock details.

Breeding objective traits and selection characters.

The formulae used to calculate the genetic gains in the breeding objective traits and selection characters are the same for the I_{NLB} and I_{NFS} indexes, except for the respective σ_I values.

The formulae are:

Number of lambs born:

$$\Delta G_{NLB} = \frac{iCov(G_{NLB}, I)}{\sigma_I}$$, where

ΔG_{NLB} is the expected genetic change in units for the trait number of lambs born per animal per generation,

i is the selection intensity,

$Cov(G_{NLB}, I)$ is the co-variance between the genotypic value for number of lambs born and the selection index, and

σ_I is the standard deviation for the selection index.

$$\begin{aligned}
Cov(G_{NLB}, I) &= Cov(G_{NLB}, b_{NLB}X_{NLB} + b_{WWT}X_{WWT} + b_{LW12I}X_{LW12I} + b_{LW12PHS}X_{LW12PHS} \\
&\quad + b_{FW12I}X_{FW12I} + b_{FW12PHS}X_{FW12PHS}) \\
&= b_{NLB}Var(G_{NLB}) + b_{WWT}Cov(G_{NLB}, G_{WWT}) + b_{LW12I}Cov(G_{NLB}, G_{LW12I}) \\
&\quad + b_{FW12I}Cov(G_{NLB}, G_{FW12I}) + b_{FW12PHS}Cov(G_{NLB}, G_{FW12PHS})
\end{aligned}$$

The units for the genetic gain in the trait are number of lambs per animal per generation. The genetic gain was divided by the generation interval to give the genetic gain per animal per year. The same format was used for the other objective traits and selection characters:

Liveweight at 8 months (kg per animal per generation):

$$\Delta G_{LW8} = \frac{iCov(G_{LW8}, I)}{\sigma_I}$$

Fleece weight at 12 months (kg per animal per generation):

$$\Delta G_{FW12} = \frac{iCov(G_{FW12}, I)}{\sigma_I}$$

Number of foetuses scanned (lambs per animal per generation):

$$\Delta G_{NFS} = \frac{iCov(G_{NFS}, I)}{\sigma_I}$$

Weaning Weight (kg per animal per generation):

$$\Delta G_{WWT} = \frac{iCov(G_{WWT}, I)}{\sigma_I}$$

Individual liveweight at 12 months (kg per animal per generation):

$$\Delta G_{LW12I} = \frac{iCov(G_{LW12I}, I)}{\sigma_I}$$

3.2.2.2. Calculating estimated selection index values.

The selection indexes for the hogget ewes were calculated for both of the two each selection indexes.

The NLB index formula was:

$$EBV = b_{NLB}(X_{NLB} - X'_{NLB}) + b_{WWT}(X_{WWT} - X'_{WWT}) + b_{LW12I}(X_{LW12I} - X'_{LW12I}) +$$
$$b_{LW12PHS}(X_{LW12PHS} - X'_{LW12PHS}) + b_{FW12I}(X_{FW12I} - X'_{FW12I}) + b_{FW12PHS}(X_{FW12PHS} - X'_{FW12PHS})$$

where b_{NLB}, b_{WWT}, b_{LW12I}, $b_{LW12PHS}$, b_{FW12I}, and $b_{FW12PHS}$ are the weighting factors for the selection phenotypic deviations, $(X_{NLB} - X'_{NLB})$, $(X_{WWT} - X'_{WWT})$, $(X_{LW12I} - X'_{LW12I})$, $(X_{LW12PHS} - X'_{LW12PHS})$, $(X_{LW12PHS} - X'_{LW12PHS})$, and $(X_{FW12PHS} - X'_{FW12PHS})$ are the phenotypic deviations of each of the hogget from the flock mean for each of the selection characters; number of lambs born of their dams, weaning weight, individual liveweight at 12 months, paternal half-sib liveweight at 12 months, individual fleece weight at 12 months, and paternal half-sib fleece weight at 12 months respectively.

The NFS index formula was the same as the NLB formulae except for the replacement of $b_{NLB}(X_{NLB} - X'_{NLB})$ for $b_{NFS}(X_{NFS} - X'_{NFS})$, and the NFS b weighting factors used.

3.2.2.3. Flock details.

The simulated flock details used in the study were:

1) Flock means for phenotypic performances.

The flock means for the selection characters are in table 3.2.2.3.1.

Table 3.2.2.3.1. The flock means for the selection characters.

Trait - Selection Character	Measurement
Number of lambs born	1
Number of foetuses scanned	1
Weaning Weight (kg)	25
Individual liveweight at 12 months (kg)	40
Paternal half-sib liveweight at 12 months (kg)	40
Individual fleece weight at 12 months (kg)	2.8
Paternal half-sib fleece weight at 12 months (kg)	2.8

2) Selection differentials.

Tables 3.2.2.3.2., and 3.2.2.3.3. show the selection differentials used in the calculations. The ram : ewe ratio is 1 : 100, so with a 100% average of lambs weaned per ewe joined to a ram, and assuming a 50 % male : female ratio of hoggets, the proportions of ram hoggets selected each year (used for 2 years) is 0.01(1%).

The calculations of the figures in tables 3.2.2.3.2., and 3.2.2.3.3. are in appendix III.

Table 3.2.2.3.2. Selection differentials for ewes.

Option	Percent of breeding flock (%)	Proportion selected	Selection differential
1	22	0.44	0.895
2	25	0.5	0.798
3	30	0.6	0.644

Table 3.2.2.3.3. Selection differentials for rams.

Flock size	Selection differential.
1000 ewes	2.61
2000 ewes	2.64
5000 ewes	2.65

4) Generation Intervals.

The ewes are mated to lamb at 2, 3, 4, 5, and 6 years of age. The generation intervals for each of the selection options are calculated in table 3.2.2.3.4.

Table 3.2.2.3.4. Generation intervals of ewes.

Age of ewe at lambing	OPTION 1 Proportion of breeding flock (%)	OPTION 2 Proportion of breeding flock (%)	OPTION 3 Proportion of breeding flock (%)
2 years	22	25	30
3 years	21	24	25
4 years	20	20	20
5 years	19	16	15
6 years	18	15	10
Generation Interval	3.9	3.8	3.5

The rams are mated for their lambs to be born when the rams are 2 and 3 years, so their generation interval is (2 + 3)/2 = 2.5 years.

Chapter Four.

RESULTS.

4.1. Finn and East Friesian Results.

4.1.1. Predictions of phenotypic measurements for the 4 crosses of each of the 23 ram types.

The phenotypic figures for each of the 10 traits of the 23 ram types are in appendix IV. The ram type, (numbered 1 to 23), and resulting progeny type are shown for each of the 4 crosses (Cross 1: Ram type x Straightbred Romney ewe (D1) = P1; Cross 2: Ram type x P1 ewe = P2.....). The predicted additive genetic and non-additive genetic interaction (heterosis) figures and phenotypic measurement expressed by the progeny based upon it's sire, dam and individual genotypes are in the corresponding columns.

The heterosis figures for each ram cross are made up of the percentage of the original individual, maternal, and paternal heterosis for each trait depending upon the breed compositions of the sire, dam and individual involved in each cross. The methods used to calculate these figures are explained in Section 3.1.1.4.: Calculations of expected phenotypic performances, (Chapter 3 Materials and Methods in the paragraph labeled table 4).

The highest and lowest phenotypic values after the 4th cross of the ram types (composed of all 3 breeds) are shown in tables 4.1.1.1. and 4.1.1.2. and indicate the range of predicted phenotypic performances for the 10 traits. The highest value for the prolifacy traits - NLB, and HNLB is for the ram type with highest amount of Finn genes, and least amount of Romney genes, and is produced by a 3 breed fixed crossbreeding system. The lowest value for the prolifiacy traits is from the ram types with the most amount of Romney genes. The traits - B.WT, H.WT, and E.WT are highest for the ram types with the most East Friesian genes (produced by rotational crossbreeding systems), and the lowest values for the ram types with the most Romney genes (and least heterosis). The fleeceweight traits are highest for the ram types of either the ram types with the most Finn or East Friesian genes. They are lowest for the ram types with the most Romney and Finn (produced by rotational crossbred system) genes. The fibre diameter values are highest for the Ram types with the most Finn (rotational cross) or East Friesian genes, and lowest for the ram type with the most amount of Finn genes (fixed cross).

The level of heterosis varied for the different ram types due to the breed composition i.e., percentage of breed of each ram type and the crossbreeding system used to produce it. The highest heterosis value was expressed in the phenotypes of the progeny from Ram type 7 (1/4R1/2F1/4EF). The progeny of Ram type 1 (R) expressed no heterosis at all, due to only one breed being involved in the crosses.

The additive values for number of lambs born increased with each cross for all of the ram types, and the survival to weaning decreased as the proportion of Finn increased in the crosses. The level of heterosis for some ram types increased with each cross, peaked and then either decreased for some ram types, or stabilised for others.

The ram with the highest weaning percentage was Ram type 9 (1/2F1/2EF) - 208%, (Cross 4), where there was a big increase in the phenotypic value from Cross 1 (104%) to Cross 2 (173%). Most of the ram types had this large increase from Cross 1 to Cross 2, compared to the changes between the other crosses. Ram type 9 did not have any Romney genes and had a 4% higher predicted weaning percentage than the highest ram type composed of all 3 breeds - Ram type 7 (1/4R1/2F1/4EF).

The ram with the lowest weaning percentage was the straightbred Romney ram, ram type 1. The predicted weaning performance of the Romney ram type did improve with each cross, due to the genetic additive difference of the stud Romney with the original Romney ewes, however not as much as the other ram types.

Table 4.1.1.1. Highest phenotypic values for the 10 traits (for ram types with all three breeds in their composition).

Trait	Phenotypic value	Ram type number and composition
NLW	202%	Ram 7 - 1/4R1/2F1/4EF
H.NLB	174%	Ram 7 - 1/4R1/2F1/4EF
B.WT	4.9 kg	Ram 18 - 2/7R1/7F4/7EF
W.WT	36.8 kg	Ram 7 - 1/4R1/2F1/4EF
S.WT	42.4 kg	Ram 7 - 1/4R1/2F1/4EF
H.WT	64.7 kg	Ram 18 - 2/7R1/7F4/7EF Ram 20 - 1/7R2/7F4/7EF
E.WT	80.7 kg	Ram 18 - 2/7R1/7F4/7EF
H.FW	4.2 kg	Ram 7 - 1/4R1/2F1/4EF
E.FW	4.8 kg	Ram 7 - 1/4R1/2F1/4EF Ram 18 - 2/7R1/7F4/7EF
FD	39 microns	Ram 7 - 1/4R1/2F1/4EF Ram 18 - 2/7R1/7F4/7EF

Table 4.1.1.2. Lowest phenotypic values for the 10 traits (for ram types with all three of the breeds in their composition).

Trait	Phenotypic value	Ram type number and composition
NLW	144%	Ram 21- 3/4R1/8F1/8EF
H.NLB	124%	Ram 21- 3/4R1/8F1/8EF
B.WT	4 kg	Ram 17 - 2/7R4/7F1/7EF
W.WT	29.2 kg	Ram 21- 3/4R1/8F1/8EF
S.WT	33.7 kg	Ram 21- 3/4R1/8F1/8EF
H.WT	52.6 kg	Ram 21- 3/4R1/8F1/8EF
E.WT	66.4 kg	Ram 21- 3/4R1/8F1/8EF
H.FW	3.6 kg	Ram 10- 1/2R3/8F1/8EF
E.FW	4.3 kg	Ram 10- 1/2R3/8F1/8EF Ram 17- 2/7R4/7F1/7EF Ram 21- 3/4R1/8F1/8EF
FD	35.6microns	Ram 10- 1/2R3/8F1/8EF

4.1.2. Effect on performance of 8 selected ram types in a breeding flock over a 5 year period.

The effect of the 8 selected ram types on the average flock performance of a Romney ewe flock has been summarised into 16 Summary tables labelled from 4.1.2.1 to 4.1.2.16. They show the predicted phenotypic 'flock averages' (for the 10 traits) for the base year 0 (original flock performances) and 5 consecutive years - year 1 to year 5 (year 1 being the year ram type is first crossed to the flock). The summary tables are in the order of decreasing proportions of the Romney breed in the ram type.

The effect of the different selection options, a and b can be seen for each ram type, where options a and b are two different flock age structures (refer tables 3.1.2.2.1. and 3.1.2.2.2). The difference between the two options is larger for the higher performing ram types, e.g., 166% and 176% for the weaning percentage in year 5 of ram type 7, compared to 108% and 109% for ram type 1.

Table 4.1.2.1. Summary Table of Yearly Performance for

Option 6a - Ram 1: R

	NLW	B.WT	W.WT	S.WT	H.WT	E.WT	H.FW	E.FW	FD
Year	(lambs)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	96%	4.0	22	28	40	55	3.0	3.4	35.0
2	98%	4.0	23	28	43	55	3.2	3.4	34.9
3	102%	4.0	23	28	45	55	3.3	3.5	34.7
4	105%	4.0	24	29	45	56	3.4	3.6	34.6
5	108%	4.0	24	29	46	57	3.4	3.7	34.4

Table 4.1.2.2. Summary Table of Yearly Performance for

Option 6b - Ram 1:R

	NLW	B.WT	W.WT	S.WT	H.WT	E.WT	H.FW	E.FW	FD
Year	(lambs)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	96%	4.0	23	28	40	55	3.0	3.4	35.0
2	98%	4.0	23	28	43	55	3.2	3.4	34.9
3	102%	4.0	23	28	45	56	3.3	3.5	34.7
4	106%	4.0	24	29	45	56	3.4	3.6	34.5
5	109%	4.0	24	29	46	57	3.4	3.8	34.3

Table 4.1.2.3. Summary Table of Yearly Performance for Option 7a - Ram 11: 2/3R1/3F

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	96%	4.0	24	31	40	55	3.0	3.4	35.0
2	103%	4.0	25	32	46	55	3.3	3.4	35.2
3	113%	4.0	26	32	49	57	3.5	3.5	35.3
4	124%	4.0	27	33	50	59	3.6	3.7	35.5
5	133%	4.0	27	33	51	61	3.6	3.9	35.6

Table 4.1.2.4. Summary Table of Yearly Performance for Option 7b - Ram 11: 2/3R1/3F

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	96%	4.0	24	31	40	55	3.0	3.4	35.0
2	104%	4.0	25	32	46	55	3.3	3.4	35.2
3	116%	4.0	26	33	49	57	3.5	3.6	35.4
4	128%	4.0	27	33	50	60	3.6	3.8	35.6
5	138%	4.0	28	34	51	62	3.6	4.0	35.6

Table 4.1.2.5. Summary Table of Yearly Performance for Option 1a - Ram 6: 1/2R1/4F1/4EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	98%	4.3	26	33	40	55	3.0	3.4	35.0
2	106%	4.3	27	34	50	55	3.5	3.4	35.5
3	118%	4.3	28	35	55	56	3.8	3.6	36.1
4	131%	4.4	29	35	56	58	3.8	3.8	36.6
5	142%	4.4	30	36	57	60	3.9	4.1	37.0

Table 4.1.2.6. Summary Table of Yearly Performance for Option 1b - Ram 6: 1/2R1/4F1/4EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	98%	4.3	26	33	40	55	3.0	3.4	35.0
2	108%	4.3	27	34	50	55	3.5	3.4	35.7
3	122%	4.3	29	35	55	57	3.8	3.6	36.5
4	137%	4.4	30	35	56	59	3.8	3.9	37.0
5	148%	4.4	31	36	57	60	3.9	4.2	37.3

Table 4.1.2.7. Summary Table of Yearly Performance for

Option 5a -Ram 3: 1/2R1/2F

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	97%	4.0	25	33	40	55	3.0	3.4	35.0
2	105%	4.0	26	33	48	55	3.4	3.4	35.3
3	118%	4.0	27	34	51	57	3.6	3.5	35.5
4	132%	4.0	28	34	52	60	3.6	3.7	35.6
5	144%	3.9	28	35	52	62	3.6	3.9	35.6

Table 4.1.2.8. Summary Table of Yearly Performance for

Option 5b - Ram 3: 1/2R1/2F

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	97%	4.0	25	33	40	55	3.0	3.4	35.0
2	107%	4.0	26	34	48	55	3.4	3.4	35.4
3	123%	4.0	27	34	51	58	3.6	3.6	35.7
4	139%	3.9	28	35	52	61	3.6	3.8	35.7
5	151%	3.9	29	35	52	63	3.6	4.0	35.7

Table 4.1.2.9. Summary Table of Yearly Performance for

Option 2a - Ram 7: 1/4R1/F1/4EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	100%	4.3	28	38	40	55	3.0	3.4	35.0
2	112%	4.4	30	38	55	55	3.7	3.4	36.0
3	129%	4.4	31	39	61	59	4.1	3.7	37.1
4	149%	4.4	33	40	62	65	4.2	4.0	38.0
5	166%	4.4	34	41	63	70	4.2	4.3	38.6

Table 4.1.2.10. Summary Table of Yearly Performance for

Option 2b- Ram 7: 1/4R1/2F1/4EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	100%	4.3	28	38	40	55	3.0	3.4	35.0
2	114%	4.4	30	39	55	55	3.7	3.4	36.3
3	137%	4.4	32	40	61	61	4.1	3.7	37.7
4	158%	4.4	34	41	63	68	4.2	4.1	38.6
5	176%	4.4	36	42	63	74	4.2	4.5	39.2

Table 4.1.2.11. Summary Table of Yearly Performance for
Option 3a - Ram 8: 1/4R1/4F1/2EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	98%	4.4	28	34	40	55	3.0	3.4	35.0
2	108%	4.5	29	35	53	55	3.6	3.4	35.6
3	123%	4.5	30	36	59	59	3.9	3.6	36.3
4	140%	4.5	32	36	61	64	3.9	3.9	36.9
5	154%	4.6	33	37	62	69	3.9	4.1	37.3

Table 4.1.2.12. Summary Table of Yearly Performance for
Option 3b - Ram 8: 1/4R1/4F1/2EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	98%	4.4	28	34	40	55	3.0	3.4	35.0
2	110%	4.5	29	35	53	55	3.6	3.4	35.8
3	128%	4.5	31	36	59	60	3.9	3.7	36.7
4	147%	4.6	32	37	61	66	3.9	4.0	37.3
5	162%	4.6	34	38	62	71	3.9	4.3	37.7

Table 4.1.2.13. Summary Table of Yearly Performance for
Option 8a - Ram 17: 2/7R4/7F1/7EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	97%	4.1	27	35	40	55	3.0	3.4	35.0
2	108%	4.1	28	36	51	55	3.5	3.4	35.5
3	124%	4.1	29	36	55	58	3.7	3.6	35.9
4	142%	4.1	30	36	55	62	3.7	3.8	36.1
5	157%	4.1	31	37	56	65	3.7	4.0	36.2

Table 4.1.2.14. Summary Table of Yearly Performance for
Option 8b - Ram 17: 2/7R4/7F1/7EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	97%	4.1	27	35	40	55	3.0	3.4	35.0
2	111%	4.1	28	36	51	55	3.5	3.4	35.7
3	131%	4.1	29	36	55	59	3.7	3.6	36.2
4	150%	4.1	30	37	55	64	3.7	3.9	36.3
5	165%	4.0	31	37	56	68	3.7	4.1	36.3

Table 4.1.2.15. Summary Table of Yearly Performance for Option 4a - Ram 19: 1/7R4/7F2/7EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	98%	4.3	28	37	40	55	3.0	3.4	35.0
2	111%	4.3	29	37	54	55	3.6	3.4	35.7
3	129%	4.3	30	38	58	59	3.9	3.6	36.3
4	148%	4.2	31	38	59	64	3.8	3.9	36.7
5	165%	4.2	32	38	59	68	3.8	4.1	36.7

Table 4.1.2.16. Summary Table of Yearly Performance for Option 4b - Ram 19: 1/7R4/7F2/7EF

Year	NLW (lambs)	B.WT (kg)	W.WT (kg)	S.WT (kg)	H.WT (kg)	E.WT (kg)	H.FW (kg)	E.FW (kg)	FD (u)
0	96%	4.0	20	27	40	55	3.0	3.4	35.0
1	98%	4.3	28	37	40	55	3.0	3.4	35.0
2	114%	4.3	29	38	54	55	3.6	3.4	36.0
3	136%	4.3	31	38	58	60	3.9	3.7	36.7
4	157%	4.2	32	38	59	66	3.8	4.0	36.9
5	174%	4.2	33	39	59	71	3.8	4.3	36.9

4.1.3. Expected changes in average flock performances and efficiency of lamb and wool production for corresponding ewe liveweight.

4.1.3.1. Expected changes in flock performance.

The predicted expected changes in average flock performances from the base year 0 for 5 traits are in Appendix V.

The traits are: - Total weight of lamb weaned per ewe

- Average ewe hogget liveweight
- Average MA ewe liveweight
- Average ewe hogget fleeceweight
- Average MA ewe fleece weight

The changes have been calculated to raise the management and planning issues of the analysis. For example the total weaning weight of lambs per ewe is predicted to increase by 43 kg for Option 2b - Ram type 7 (1/4R1/2F1/4EF). This increase in output per ewe suggests a change in required input such as kg of Dry Matter for feeding. The results from this section may enable a feasibility analysis of the predictions in terms of available resources and types of management changes needed.

Annual changes in lamb production and ewe liveweight.

Year 1

The average weight of the ewes does not change in the first year, as the ewes are all D1s, however their lamb production increases from 2.5 kg for Ram type 1 (R) to 9 kg for Ram type 7 (1/4R1/2F1/4EF). As the ewes are all of the same genotype, they all have the same average expected level of production, therefore all of the ewe progeny (within each ram type option) can be assessed for potential second generation dams (to produce the P2)s. As the ewes are all of the same genotypes for all of the ram options, i.e., 55 kg ewes, the ewes with the higher producing lambs may already need a change in their management.

There are no differences between the selection options (a and b), as the selection rates are the same in year 1.

Year 2.

There is still no change in the weight of the mixed age ewes in year 2, as they are all D1s, and the P1s/D2s are at the hogget age. Year 2 is the first year the change in selection policies becomes an option, and there is an increase in the total weight of lambs weaned from the original selection rate. The larger the change in the lamb weight increase, the greater the effect of the selection rate change (in kg). The lowest increase is with Ram type 1 - (R), 3.5 kg for both options, and the greatest is Ram type 7 - (1/4R1/2F1/4EF), with 14 kg and 15.5 kg for options a and b accordingly.

Year 3.

Year 3 is the first year there is a change in ewe weight, with one generation of P1s - the 2 year old ewes. The increase in liveweight is greatest for Ram type 7 - (1/4R1/4F1/4EF), 4.5, and 6 kg for each selection option a and b, and lowest for Ram type 1 - (R), 0.5 kg for both selection options, a and b. The increase in total weight of lamb weaned per ewe is greatest for Ram type 7 - (1/4R1/2F1/4EF), 22 kg and 25kg for the selection options a and b. The lowest increase is for Ram type 1 (R), 4.5 kg for both selection options, a and b.

Year 4.

The average increase in ewe liveweight is again greatest for Ram type 7, 10 kg and 13 kg and lowest for Ram type 1, 1kg for both options. The weight of weaned lamb is again greatest for type Ram 7 - 30 kg and 35 kg, and lowest for Ram type 1 (R), 6 kg for both selection options, a and b.

Year 5.

In year 5, the MA ewes are a mixture of P0s, P1s, P2s, and P3s. The average liveweight is greatest for Ram type 7, 25 and 19 kg heavier than in the base year 0, and lowest for Ram type 1, at 1kg heavier than the base year. The range in actual ewe liveweights for Ram type 7 is 55 kg (P0s) to 79 kg (P3s), and for Ram type 1 the range is 55 kg (P0s) to 58 kg (P3s). The greatest increase in weight of lambs weaned per ewe greatest for Ram type 7, at 37 kg and 43 kg and lowest for Ram type 1, at 6.5 kg for both selection options. The ewe genotypes, including the hogget ewes range from P0s to P4s. The range in total weight of lambs weaned per ewe for Ram type 7 is 29 kg (P1s) to 64kg (P4s), and for Ram type 1 the range is from 24 kg to 30 kg.

4.1.3.2. Efficiency of lamb production and ewe fleeceweight.

The efficiency of lamb and fleeceweight production relative to ewe liveweight has been calculated and graphed to show the 'efficiency rates' between the ram types, and for decreasing amounts of Romney genes. Actual figures for the analysis are in Appendix VI. The graphs are in two sections : Lamb production (weight of lambs weaned per ewe liveweight), and wool production (fleeceweight produced per ewe liveweight).

The legend is the same for all of the graphs:

Ram type 1 - R
Ram type 11 - 2/3R1/3F
Ram type 6 - 1/2R1/4F1/4EF
Ram type 3 - 1/2R1/2F
Ram type 7 - 1/4R1/2F1/4EF
Ram type 8 - 1/4R1/4F1/2EF
Ram type 17 - 2/7R4/7F1/7EF
Ram type 19 - 1/7R4/7F2/7EF

Weight of lambs weaned per ewe liveweight.

In the base year 0 the ratio of lamb weight weaned or produced per kg of ewe liveweight is 0.35 kg of lamb weaned per kg of ewe liveweight for all of the ram type options. The production rate increases each year for all of the 8 ram types and for the change in selection options from a to b, except for option 6 - Ram type 1 (R). The general pattern of the graphs indicates an increase in lamb production efficiency as the percentage of Romney genes in the ram types decreases. For all of the years (Year 1 to Year 5), the ewes from option 2 - Ram type 7 (1/4R1/2F1/4EF) have the highest efficiency of lamb production and the ewes from option 6 - the purebred ram, Ram type 1 (R) have the lowest efficiency of lamb production. The ratios for each ram type and selection option (a or b) have been graphed for the base year 0 and the 5 following years - figures 4.1.3.1 to 4.1.3.6.

Figure 4.1.3.2.1:

Ratio of weight of lambs weaned per ewe liveweight in the base Year 0.

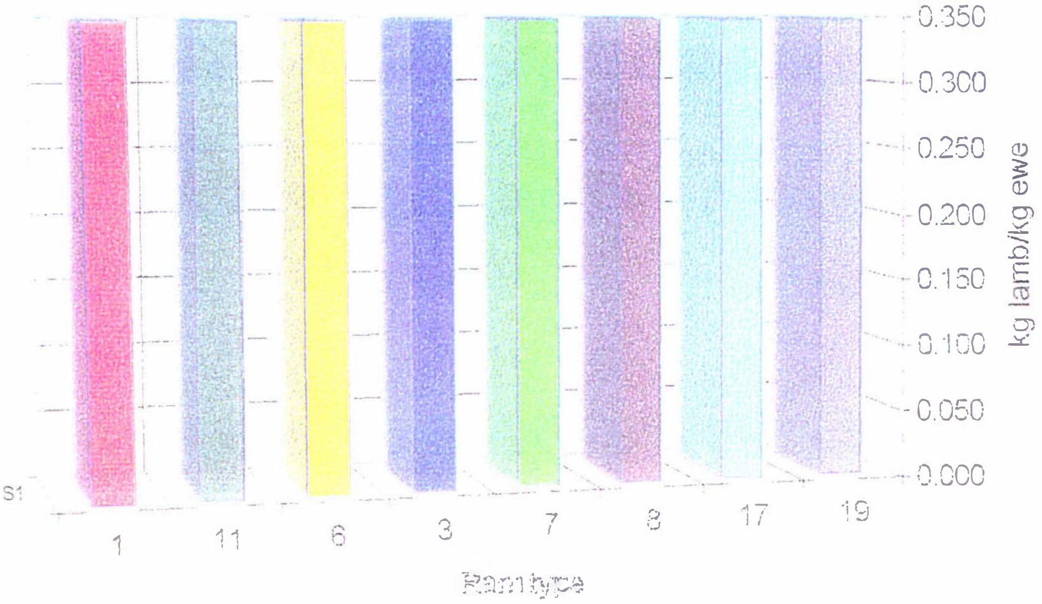


Figure 4.1.3.2.2:

Ratio of weight of lambs weaned per ewe liveweight in Year 1.

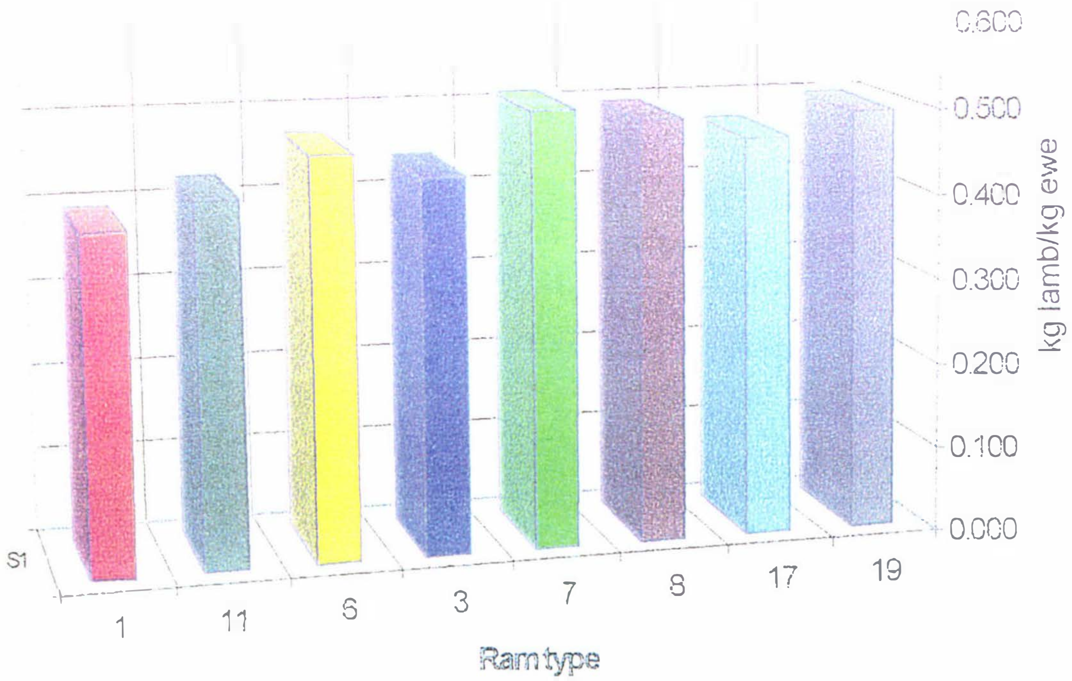


Figure 4.1.3.2.3:

Ratio of weight of lamb weaned per ewe liveweight in Year 2.

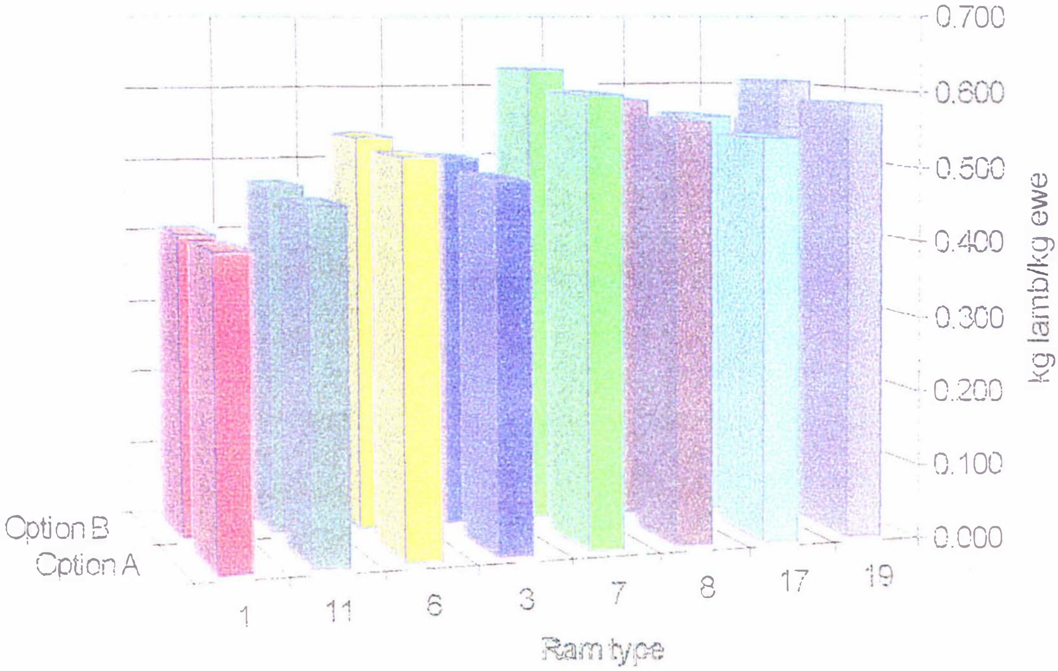


Figure 4.1.3.2.4:

Ratio of weight of lamb weaned per ewe liveweight in Year 3.

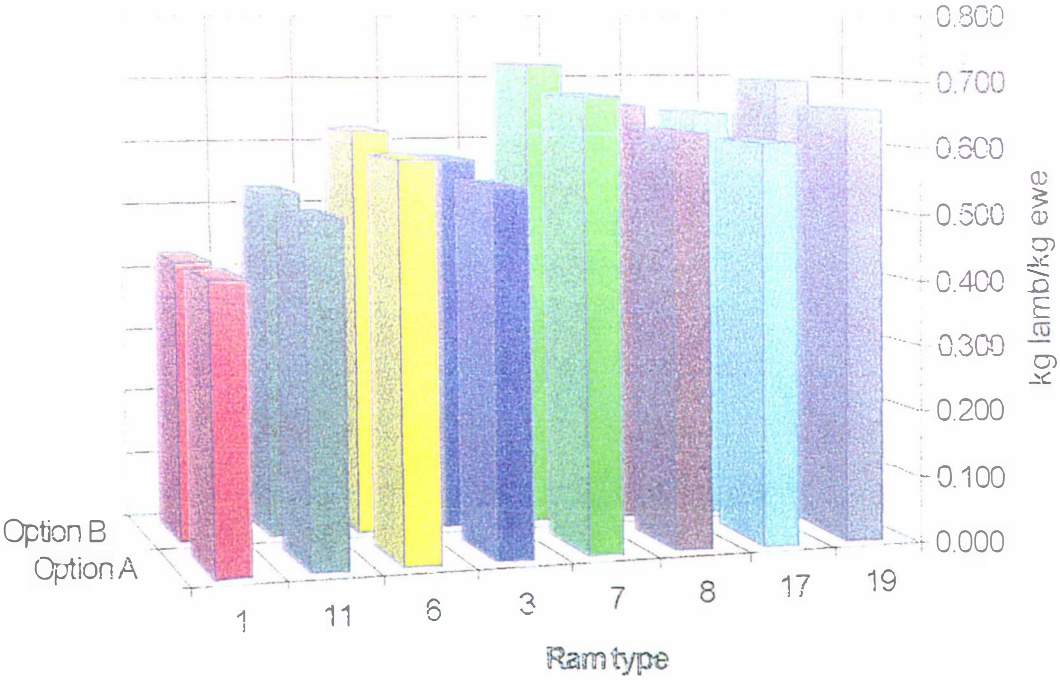


Figure 4.1.3.2.5:

Ratio of weight of lamb weaned per ewe liveweight in Year 4.

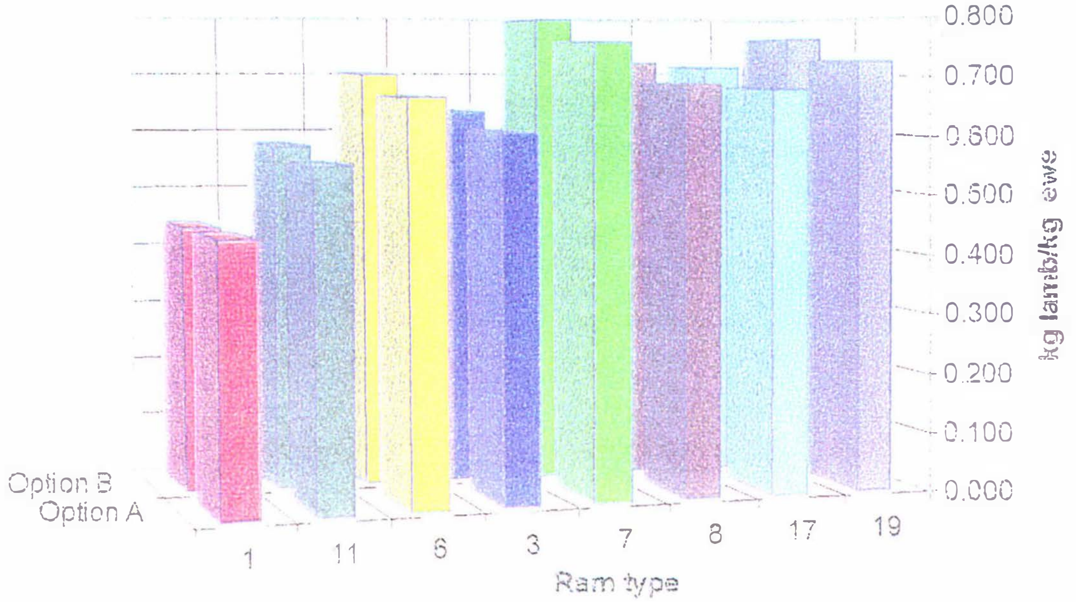
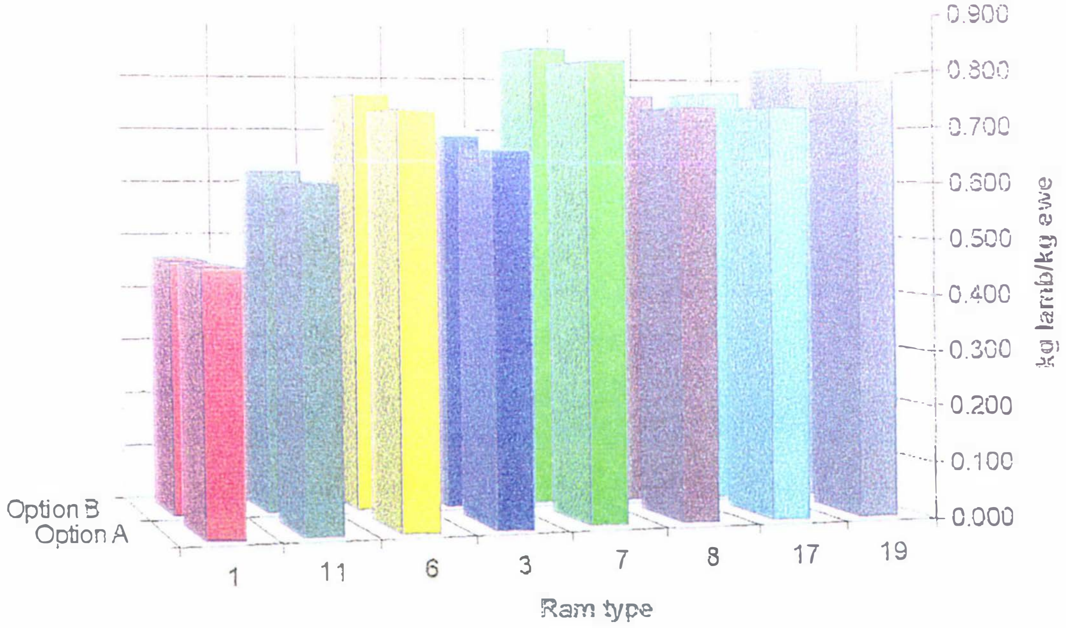


Figure 4.1.3.2.6:

Ratio of weight of lamb weaned per ewe liveweight in Year 5.



Fleeceweight production per ewe liveweight.

The grams of wool produced per kg of ewe liveweight for the base year - Year 0 is 62g/kg of ewe liveweight. The wool production efficiency is the same for Years 1 and 2 as the base year, because the ewes in the flock are still all Romney ewes. The first generation of 'crossbred' progeny (P1s) are not classed as mature age ewes until year 3.

The wool production efficiency general pattern is opposite to the efficiency of lamb production with the wool production efficiency decreasing with decreasing percentages of Romney genes with the exception of Ram type 6 (1/2R1/4F1/4EF). The pattern from year to year is also different to that of the efficiency of lamb production, with a mixture of increases, decreases, and no changes between increasing years. Ram types 6, 1, and 11 cause an increase in the wool production efficiency from the base year 0, 4 of the ram options cause a slight decrease in the wool production efficiency - Ram types 7, 8, 19, and 17, and Ram type 17 has no change in the wool production efficiency ratio with ewe liveweight,

The highest wool production efficiency ratio is from Ram type 6 (1/2R1/4F1/4EF), at 68g/kg and 70g/kg in Year 5. The lowest wool production is from option 3 - Ram type 8 (1/4R1/4F1/2EF), at 60g/kg for both selection options in year 5. The annual performances have been graphed in figures 4.1.3.7 to 4.1.3.10.

Figure 4.1.3.2.7:

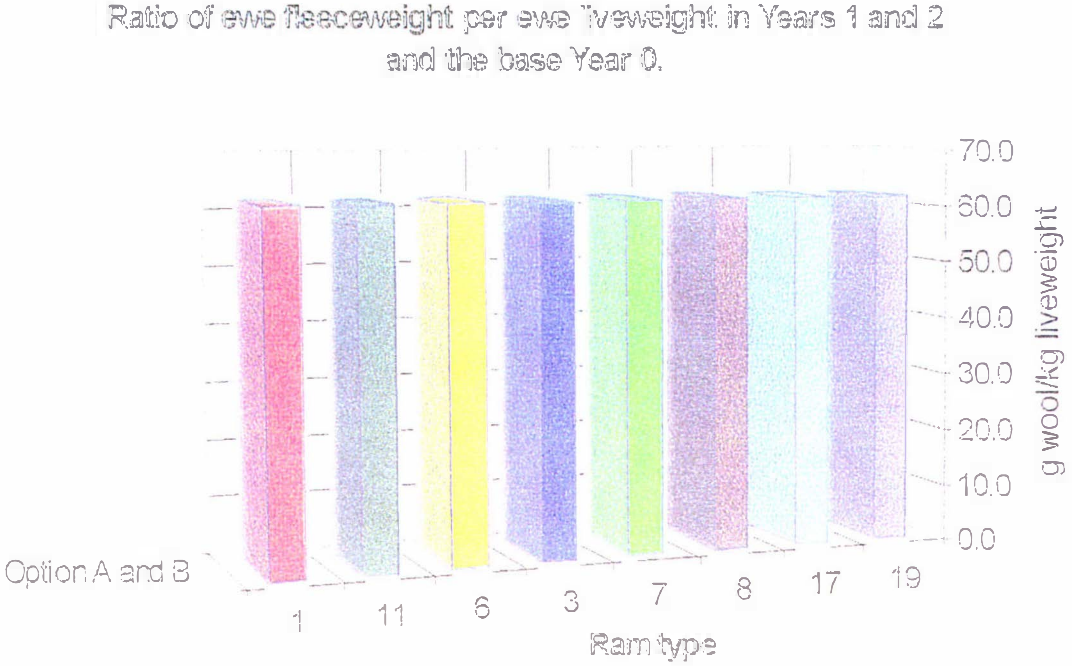


Figure 4.1.3.2.8:

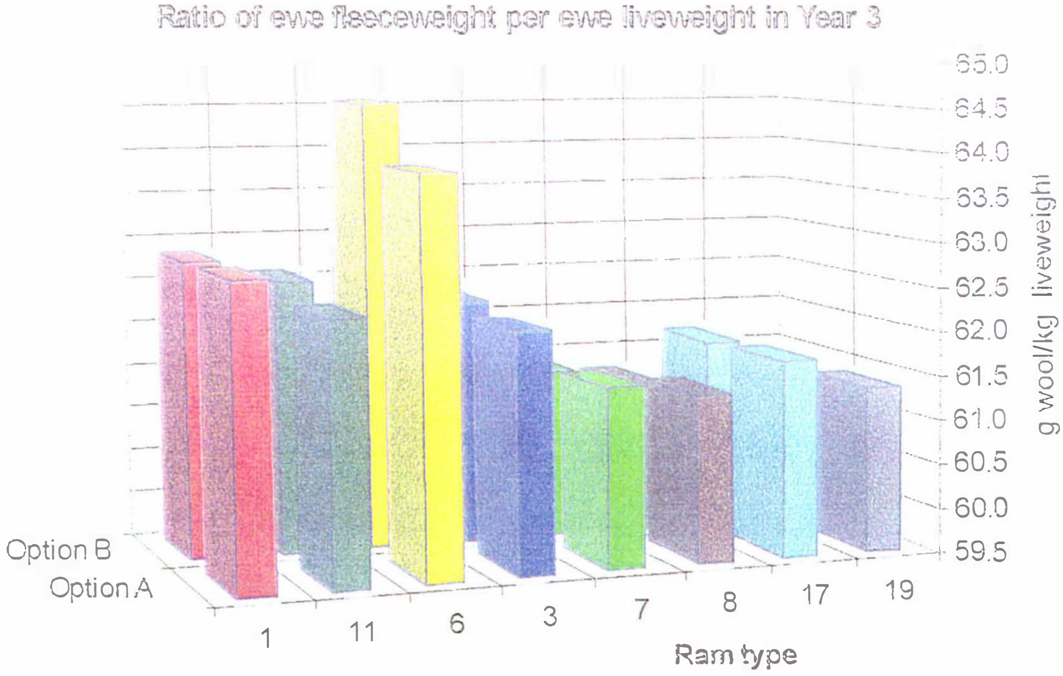


Figure 4.1.3.2.9:

Ratio of ewe fleeceweight per ewe liveweight in Year 4

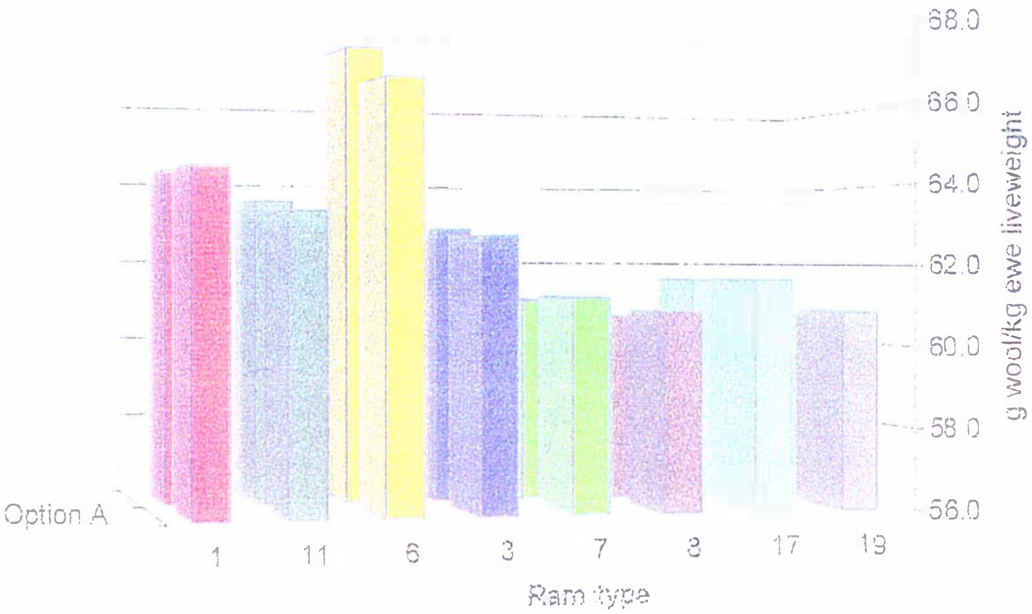
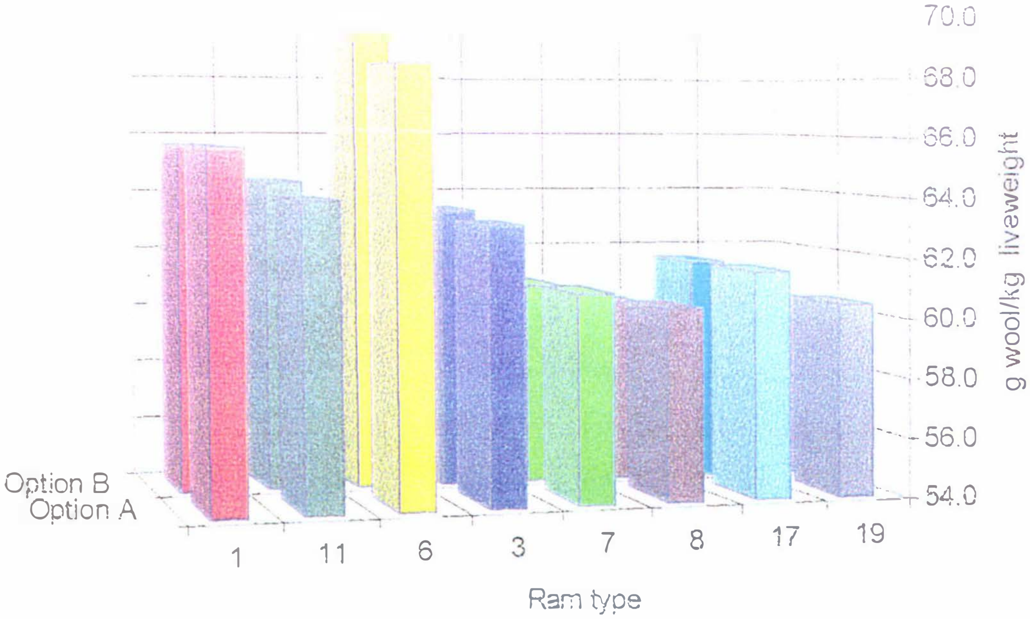


Figure 4.1.3.2.10:

Ratio of ewe fleeceweight per ewe liveweight in Year 5



4.2. Number of Foetuses Scanned as a Selection Predictor.

4.2.1. Weighting factors.

The weighting factors calculated for the two selection indexes, in table 4.2.1.1. show the difference between the two different predictors - NLB and NFS. The negative values are likely to be a reflection of the negative phenotypic correlation of individual 12 month fleeceweight with the reproductive traits - NLB and NFS.

Table 4.2.1.1. Weighting factors for two selection indexes - I_{NLB} and I_{NFS}.

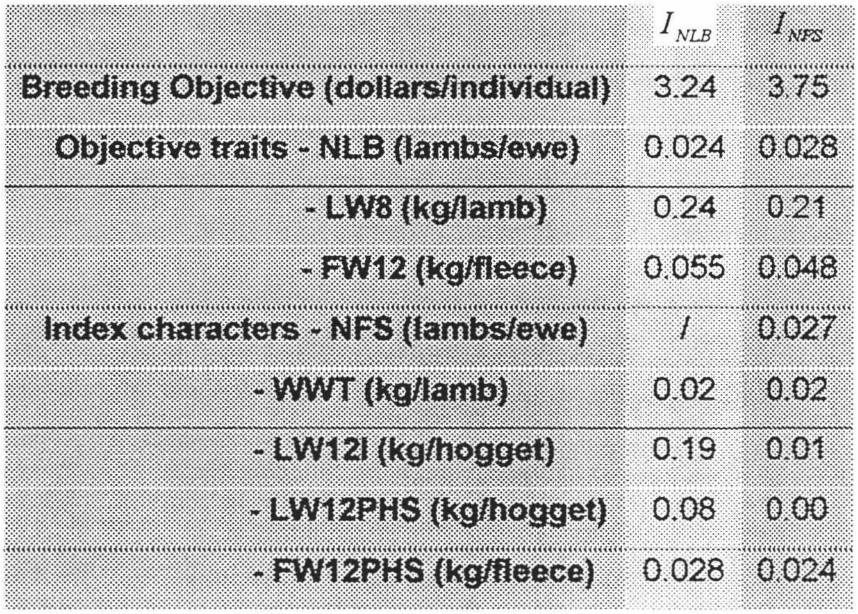
	I_{NLB}	I_{NFS}
NLB/NFS	4.88	6.53
WWT	-0.80	-0.83
LW12I	0.30	0.30
LW12PHS	-0.09	0.09
FW12I	4.76	4.89
FW12PHS	-0.16	-0.18

4.2.2. Genetic response in the breeding objective, traits and characters.

While there are negative weighting values in both selection options the breeding objective and all of the traits and characters show positive genetic responses for both selection indexes. Table 4.2.2.1. shows the predicted annual genetic responses for the selection indexes.

The genetic gain for the breeding objective is higher for the NFS index due to the faster genetic gain in the NLB trait than is achieved by the NLB index. This greater rate of gain in NLB outweighs the slower rates of gain in LW8 and FW12 in the NFS index.

Table 4.2.2.1. Predicted annual genetic response/ewe for the two selection indexes - I_{NLB} and I_{NFS}.



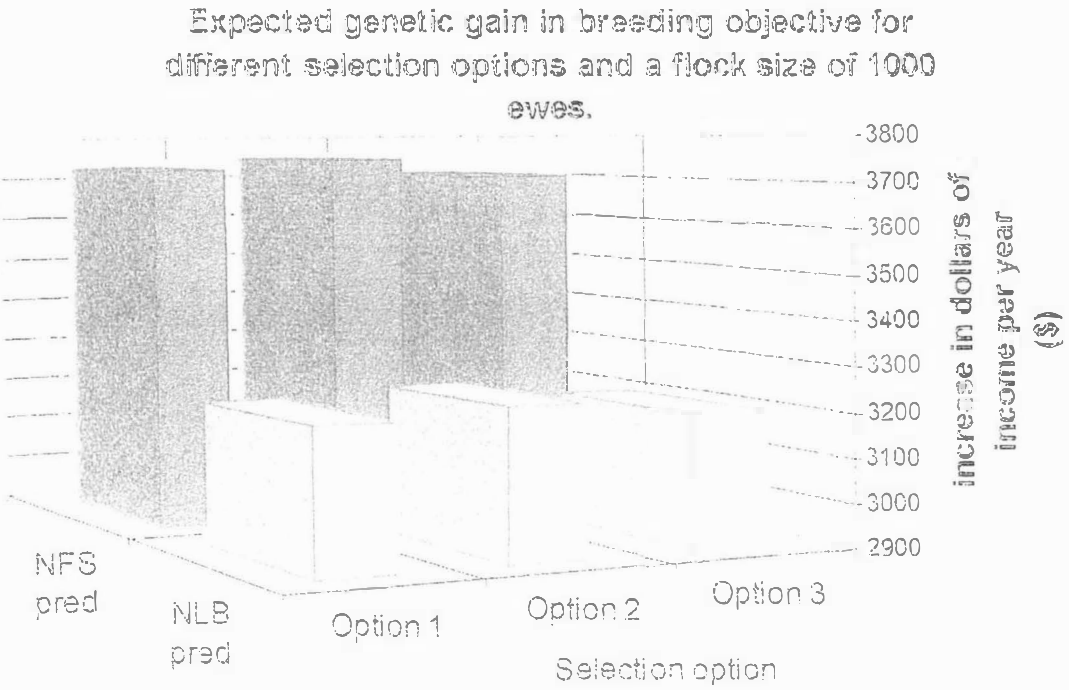
	I_{NLB}	I_{NFS}
Breeding Objective (dollars/individual)	3.24	3.75
Objective traits - NLB (lambs/ewe)	0.024	0.028
- LW8 (kg/lamb)	0.24	0.21
- FW12 (kg/fleece)	0.055	0.048
Index characters - NFS (lambs/ewe)	/	0.027
- WWT (kg/lamb)	0.02	0.02
- LW12I (kg/hogget)	0.19	0.01
- LW12PHS (kg/hogget)	0.08	0.00
- FW12PHS (kg/fleece)	0.028	0.024

The annual genetic response per ewe has been multiplied by 1000 to give the estimated increase of income for a flock of 1000 ewes in dollars per year, and graphed, see figure 4.2.3.1. Three different selection options have also been included (different flock age structures), but the difference between them appears negligible. The difference in the expected increase in income between the two selection indexes is approximately \$500 (50 cents/ewe/year: 16% increase).

4.2.3. Ewe Hogget Indexes.

The 50 ewe hoggets were ranked for both of the selection indexes, from 1 to 50, with 1 being the lowest value and 50 the highest for each respective selection index. The top and bottom 10 (top and bottom 20%) ewes for each selection index were selected to compare the respective rank numbers of the two indexes for selection. A Spearman's rank correlation coefficient for the two ranking systems was calculated at 0.64. The null hypothesis that there was no correlation at the 0.01 level of significance was tested and rejected, concluding a relationship between the two selection index rankings.

Figure 4.2.2.1:



Expected genetic gain in breeding objective for different selection options and a flock size of 1000 ewes.

Chapter Five.

DISCUSSION.

5.1. Finnish Landrace and East Friesian.

The introduction of the Finnish Landrace and East Friesian sheep genes into New Zealand has provided an opportunity to change the current gene pool and hence the phenotypic performance of sheep in New Zealand, especially the reproductive traits. By crossbreeding them with the current New Zealand breeds there is flexibility available in utilising these new genes (Clarke, 1982b).

An important question for sheep breeders in New Zealand, such as DIBO Genetics, is what proportions of genes from these new breeds are best for New Zealand management and resource conditions. Recognition of how these genes are best introduced into commercial breeders flocks, also requires consideration.

One way to look at the composition aspect is to set objectives such as those of the studmasters' of DIBO Genetics. Their aim is for their clients' ewes to wean two 30kg lambs per year (60kg) from the hogget age. The average New Zealand ewe currently weans one 24kg lamb per year (Walpole, 1995). Thus the DIBO objective requires an increase in production by 150% relative to the New Zealand average. This can not occur in one year from just one cross, and to get the whole flock producing at this level will take even longer. Therefore ram breeders, must find a ram type that can be introduced to their clients' flocks to increase their production to the performance levels they advertise without excessive costs in management and resources. Furthermore, the change needs to be as risk free as possible, and enable the farmer to stabilise some sort of breeding system within their flock. Ram breeders' must also consider how economical and feasible it is to produce the ram type by taking advantage of the heterosis effects and assessing the potential for genetic improvement of the ram type at the stud level. It is important to analyse all aspects of production costs and returns, due to the changes in breed rankings for different traits (Clarke and Meyer, 1982). In an attempt to account for performance in a variety of traits, 10 different traits were analysed in this study.

5.1.2. Ram composite production.

DIBO Genetics wanted a ram type made up of the three breeds – Romney, Finn and East Friesian, so 23 ram types were simulated to cover as many options as possible. The three purebred rams of each breed type were included to act as a comparison to the crossbreeding– Ram types 1, 2, and 4. Of the 20 crossbred ram types 11 were composed of all three breeds and 9 were composed of 2 breeds. Of the 9 two breed types all of them except for 1 had the Romney breed in them. The majority of the two breed type rams were a variation of the Romney and Finn breeds, due to the DIBO studmasters stating a preference for those two breeds over East Friesian. The 20 crossbred ram types were simulated by different rotational and fixed breed crosses that were considered the quickest and easiest ways to produce them.

The ram types can then be developed into either a composite breed or be continually generated from the purebred parents breeds. If the breed is developed into a composite breed, a number of issues are raised - are the numbers involved large enough to allow for continual genetic improvement or will inbreeding effects occur, and the effects of the increased variation in the crosses beyond the first cross. The composite breed will also lose 1/3 of the original heterosis (if 3 breeds are equally involved) for each of the traits. Therefore any genetic improvement must be made either by selection within the new composite breed, or by continuing to generate the composite type from the purebred breeds and introducing the new genes into the flock (through rams or ewes).

If the desired ram type is not developed into a composite breed but is continually produced by the crossbreeding methods, then the number of crosses, generations, and surplus composite types must be considered. The genetic improvement would then depend upon the genetic improvement made within the purebred parent breeds, and the selection methods for crossbreeding. These two factors may also be influenced by the numbers of animals involved, especially in the case of the Finn and East Friesian breeds. The rams produced by fixed breed crossing can be formed after less crosses and generations than the ram types formed by rotational crossing (see Chapter 3. Materials and Methods, table 3.1). Therefore if the ram chosen is produced by a rotational system then a number of sheep of the less desired genotypes are produced before the desired composition is reached. In addition it takes two further cycles each time to breed more rams and to upgrade the ram types, if a composite is not formed. Ram 7 type (1/4R1/2F1/4EF) can be produced by a fixed crossbreeding system with just two different crosses, and two generations, whereas Ram type 17 (2/7R4/7F1/7EF) is produced by a rotational crossbreeding system, taking more than 4 generations and 4 crosses to produce from the purebred parental breeds. Of the ram types that have all three breeds in them, Ram types 6, 7, and 8 are the 3 ram types that can be produced most quickly, and the rotationally bred rams the longest. The continual production of the desired ram type will require access to a continual supply of the purebred parent breeds, and there will be a lot of stock produced of different genotypes.

5.1.3. Ram type analysis.

Due to the relatively recent introduction of the Finn and East Friesian breeds into New Zealand, there was very little data available to calculate the additive and non-additive figures used for the analysis. The majority of the additive figures and all of the non-additive figures had to be guesstimated based on literature published overseas and from some performance figures from DIBO Genetics. The non-additive figures were assumed to be the same between all of the breeds for all of the 10 traits. These basic genetic parameters are very important in making decisions on the ways in which breed resources may be utilised efficiently in alternative crossbreeding strategies (Clarke, 1982b). Therefore the performances of the crossbreds and purebreds in New Zealand at present are very important for determining the ideal ram type compositions.

All of the 23 ram types in this study had an overall positive effect on the simulated flock, increasing the phenotypic measurements of all 10 of the traits. The lowest increase in performance (from the original Flock Romney figures) was from the straightbred Romney ram. Although some of the additive effects from the Romney ram - ram type 1 were the same as for some of the other ram types, there were no heterosis effects (as the only breed involved was Romney, and no heterosis was predicted between the Stud Romney and Flock Romney lines), thus making the overall phenotypic performance lower than those rams types. Ram type 7 (1/4R1/2F1/4EF), had the highest heterosis effect of all of the ram types: 16% for lambing percentage at lambing, 34% for lamb weaning weight, 26% for ewe liveweight, and 25% for ewe fleece weight.

The predicted phenotypic performances in this study were all higher than the figures recorded for the Crater Research Station trials in the early 1970's in Meyer *et al.,* (1977). The lines of the breeds used in the research are different to the lines in use in New Zealand at present, and the additive figures used in this study were different to the purebred measurements in the trials. For example the additive figures for number of lambs born used in the study are different to that of the recorded figures in the Crater Research figures: 2.7 and 2.5 for the Finn and East Friesian on Somes Island and 2.2, and 2.1 on Mana Islands compared to the figures, 2.75 and 2.3 as used in this study.

From the results of part one of the study – the 4 crosses of each ram type, and the objectives of DIBO Genetics, 8 ram types were selected for further analysis. DIBO Genetics wished to evaluate having a majority of Finn breed in the ram type, with less Romney and a small East Friesian contribution. Consequently variations on this theme were chosen, as well as the Romney ram to compare the straightbred Romney option with crossbreeding. Further analysis of all 23 ram types may have provided different end results to those presented here.

5.1.4. Introduction of genes to commercial flocks.

Planning the introduction of a ram composite into a flock is very important, as the three breeds involved in the ram types create a range of different genotypes, and potential phenotypes. These changes in the individual crossbred progeny suggest different requirements for management practices. For example, if the ewes are going to be larger in liveweight and produce more lambs, they are going to require more feed. It is also important to enable full utilisation of the breed and crossbreeding effects.

In this study the objective of using the ram type across a flock for 5 years was to simulate the result of a farmer buying a certain ram type and using it for 4 years. The resulting mixture of genotypes were used to calculate the average phenotypic performance of the flock for each year.

The results calculated in year 5 are not the final phenotypic performances to be expected from the ram type, as there is a large range of genotypes involved in the ‘average’ figures reported, e.g., P1s, P2s, P3s and P4s (refer tables 3.1.2.2.2. and 3.1.2.2.3., page 44). The figures calculated in part 1 of the study - the 4 crosses of each ram type would be more of an indication of what the flock performance would end up at, as they are the actual cross performance.

The introduction of the genes can be planned for individual situations based upon a farmer’s personal preferences, management skills, and available resources. The client has to decide at what rate they want to introduce the new genes into their flock. Some may wish to introduce the genes and upgrade their ewes to get a uniform flock as quickly as possible, and others may want to introduce them at a slower rate, to enable their management skills to evolve more slowly.

In this study the method of introduction was in year 2 to select replacement ewes (for the breeding flock) from the first cross progeny (P1), in year 3 to select ewe replacements from the second cross progeny (P2) and so on.

The other progeny were not considered as replacements and the ewes not breeding replacements were still crossed to the composite ram. An alternative to this system would be to cross the ewes not breeding replacements to some other breed such as a terminal sire (which would result in even more heterosis). Two flock structure options (a and b) were taken within the study of each of the 8 selected ram types, to study the effect of different selection rates of replacements into the flock, and to lower the generation interval. The difference between the two selection options of each ram type was greatest for the higher producing rams, for example the average weaning percentage of the flock crossed to the highest performing ram type - Ram type 7 in Year 5 was estimated to be 166% for option a and 176% for option b, and was 108% and 109% for the selection options of the lowest producing ram type - Ram type 1 (R). Therefore by increasing the replacement rate the flock can be upgraded to the desired performance levels at a faster rate, the performance while upgrading is higher, and while more replacements are chosen (thereby lowering the selection differential) there are more progeny of that particular cross produced, and increased numbers to select for producing the next generation. Initially some ram buyers may not wish to cross the ram composite to their whole flock, and may just use it across the older sheep to get an idea of the production and management changes required (if any). Another possible alternative is to adapt a 2- breed fixed system for crossing the ram composite to the straightbred ewes and sell of the first cross (P1) ewes to other farmers for them to either upgrade their ewes of for them to use them as replacements into their flock of P1/D2 ewes. The farmer breeding the P1/D2s would also need to allow for replacement of the straightbred ewes. The buyer of the first cross ewes could then breed second cross (P2) progeny that could be passed on to other farmers. These types of systems are not used in New Zealand though, being more common in Australia and the U.K.

There is no obvious way of avoiding the mixture of genotypes in a flock, if the breeder wishes to reach a desired composite as quickly as possible. However, with some careful planning the full benefits of the new breeds should outweigh the costs of this problem.

A good 5 year plan of what is going to happen in the flock is important not only to manage the matings of the different genotypes, and to allocate the appropriate resources, but to also provide a checking system, where phenotypic performances can be regulated against their genotypic potential, and acted upon accordingly.

5.1.5. Profit Analysis.

When considering a change in any operation, all traits that contribute to the overall system must be studied. In a sheep breeding operation this can be undertaken by using a profit analysis which incorporates all such contributing factors whereby the predicted income and costs are studied. This was not carried out in this study, but is considered to be the next step in the analysis.

Some examples of the changes in income could include direct income and indirect benefits such as:

- Higher weaning percentage, therefore more lambs to send for slaughter, and higher numbers of ewes to select from for replacement into the breeding flock.
- Faster growing lambs, resulting in shorter finishing times giving management flexibility for a staggered system of weaning and slaughter times.
- Higher wool weights.
- Increased hogget fertility and fecundity, therefore more profitable hogget stock units.
- Larger lambs to send to works,

and costs:

- Larger ewes, therefore increased DM requirements.
- Increased average fibre diameter of wool.
- Change in management to manage higher producing ewes, i.e., more

lambs.

- Short-term management costs from the mixture of genotypes, e.g., mob separations.
- Cost of purchasing new rams.

5.1.6. Appearance of new breeds.

There is also another issue that comes with the Finn and East Friesian sheep breeds. They do not look like the traditional New Zealand sheep in terms of their pink noses and ears. It has been observed that the crossbred offspring of the Finn and East Friesian with some New Zealand breeds are a combination of black and pink facial features. Some personal opinions of this subjective trait may play a part in the initial acceptance of these breeds. Whether these features have a significant effect on production in New Zealand or not i.e., does it make them more susceptible to skin cancer etc., will become apparent and appropriate selection and management techniques developed in time.

5.1.7. How study results can be used.

As has been previously mentioned, it is important to have some idea of expected flock performance and requirements, and to plan management strategies. However as there is little known about the new breeds' phenotypic performances in New Zealand, and their heterosis effects when crossed with current New Zealand breeds (and each other) the predictions in this study can at the most can only serve as ballpark guidelines. However, the calculations used for the predictions have been designed to facilitate the re-calculation of the predictions (and results tables) for different additive and/or non-additive interaction figures by changing the data in tables 1 and 2 of the trait computer worksheets.

The results in part 1, the expected phenotypic measurements are given based upon the genotypes of the individuals, dams, and sires, allow an assessment of the expected additive values, heterosis effects and phenotypic performances of different combinations of the three breeds - for first, second, third, and fourth crosses. The results in part 2 are an example of the effect of 8 ram types on an entire breeding flock. The results in part 3 show the increase in production each year from the base year for the system chosen in this study. This may give some guidelines for the commercial farmer to consider and plan for, for example Ram 7 (1/4R1/2F1/4EF) increases the average liveweight of the mixed age ewes by 15kg in year 5 (from 55kg to 70kg) for option a and by 19kg (from 55kg to 74kg) for option b, and the average weight of lambs weaned per ewe by 37kg in year 5 (from 19kg to 56 kg) for option a and from by 44kg (from 19kg to 63kg) for option b. This may mean changes in numbers of ewes in the breeding flock to cater for increased DM requirements.

The production efficiencies of lamb and wool production are important as a large ewe who has a high liveweight but only produces the same amount of weaned lamb as a ewe of a much lower liveweight is going to lower the efficiency of the production system.

The traits - weight of lamb weaned per ewe, ewe liveweight and ewe fleeceweight were analysed in more depth than the other traits, as they were considered to be the main parameters of the profit analysis. However the other traits such as hogget liveweights, wool weights and slaughter weights are also important in the overall analysis, and must also be considered.

As the ram breeder has already experienced first hand the new breeds and the management of the different composites, then they can play an important part in offering advice to their clients and prospective clients, while remembering that all of the clients will have their own individual situation to cater for.

5.1.8. Ram type choice.

Without considering the costs of the breed effects, e.g., increased ewe liveweights, Ram type 7 (1/4R1/2F1/4EF) is the most efficient producer of the 8 analysed ram types for total lamb weight at weaning per ewe liveweight - 0.80 and 0.85kg lamb/kg ewe live weight for the two selection options in year 5. Its fleece production ranking is lower - only being the 5th highest at 61g wool/kg ewe liveweight for both selection options in year 5. It has the most heterosis of all the 23 ram types for the first, second, third and fourth crosses, and relatively high additive values compared to the other ram types. If the breed type was stabilised, 1/3 of the heterosis would be lost, but 2/3s of the original heterosis expressed as individual, maternal and paternal heterosis would be retained.

The ewe body weight of the Finn is not as big as the East Friesian (58 kg and 80 kg respectively), so 1/2 Finn and 1/4R (58 kg liveweight) will minimise the ewe size increase, with the 1/4 East Friesian enabling some body size for lambing bigger lambs at birth. The milking ability of the East Friesian was not studied, but by including some East Friesian genes, it is assumed it will be beneficial to lamb growth. The average fibre diameter of the Finn breed is lower than the other breeds. During the establishment of the breed composition of the flock the 1/2 F should enable some selection for fibre diameter to be carried out. The input of 1/4 East Friesian, heterosis and selection should increase average wool weights.

The production ratios of the lamb weight weaned per ewe liveweight and fleeceweight per ewe liveweight provided mixed results for all of the ram types. Ram type 7 had the highest lamb production efficiency, but one of the lower wool production efficiencies, compared to the 7 other ram types. As the liveweight established itself, the wool production may increase, especially after adjusted management practices, as more information is received on the breeds.

The production of the ram type 7 by a three breed fixed breeding system is more efficient for ram production than some of the other systems, as there is only one cross of progeny (1/2R1/2EF) produced to get the 1/4R1/2F1/4EF.

5.2. Ultrasound Pregnancy Scanning.

This study looked at the possibility of using the results from ultrasound pregnancy scanning – number of foetuses scanned to assist with selection decisions. As scanning is already in used as a management tool, and the recording of data is carried out by the paddock separations, (as mentioned in Chapter 1 - The Introduction) the use of NFS as a selection predictor was studied.

Two models were simulated: A model considered to be an example of the current models used today – The NLB model, and the NFS model, where the NFS selection predictor replaced the NLB selection predictor.

All of the figures for the parameters were obtained from published literature, except for those involving NFS. As there was no available data they all had to be estimated based on the corresponding NLB figures while assuming that there would be less environmental influence on the phenotypic values.

The rates of expected genetic change for the objective traits of both selection indexes were found to be similar to that of Callow *et al.,* (1986). The NLB index was more similar than the NFS index, especially for the trait - number of lambs born, where the published figure of Callow *et al.*, (1986) and the NLB index were both 0.024 lambs/ewe, and the NFS index was 0.028 lambs/ewe. The hogget fleeceweight genetic change figures were lower for the figures in this study than the published figure of Callow *et al.*, (1986). The overall objective genetic gain was found to be higher for the NFS index than the NLB index, thereby indicating the value of using the NFS data. The NLB trait was also higher for the NFS index, but the two other objective traits, and the selection characters were higher for the NLB index.

The rates of genetic change compared to the NLB results showed a larger overall objective gain and NLB gain than the NLB selection index. The other objective traits and predictor characters were lower for the NFS index than the NLB index.

The higher expected breeding objective gain adds to the already beneficial practice of ultrasound pregnancy scanning – the management benefit, differential treatment being able to be applied to dry, single and multiple bearing ewes. Dry ewes can be re-mated or managed separately from the pregnant ewes e.g., by being sold. The pregnant ewes can be managed accordingly to the number of lambs they are carrying, hence multiple bearing ewes are not underfed meaning wool growth and their own liveweight and lamb rearing ability do not suffer, and single bearing ewes are not overfed, causing dystocia problems and over fat ewes.

Ultrasound pregnancy may also be easier to record than NLB, where the number of lambs born to each ewe have to counted and recorded in some way under paddock conditions. If due to some environmental cause e.g., snow at lambing many ewes loose their lambs, it may be impossible to recognise what has happened, or a number of ewes have lost their lambs for other reasons e.g., nutritional or disease during gestation. At lambing time these ewes will have reduced numbers of lambs and will be recorded as having the same fertility and fecundity as ewes that were never in lamb or had concieved a lower number of foetuses. The preferential treatment may also enable the genotypic potential to be utilised more, thus some of the traits that were predicted to have lower rates of genetic increase may be higher phenotypically.

Chapter Six.

CONCLUSION.

The two methods, the simulation of crossbreeding newly imported genes with current genes in New Zealand and number of foetuses scanned as a selection predictor have both been found to have positive effects on the prolificacy, and other traits of the sheep in this study.

The 2 imported breeds - Finnish Landrace and East Friesian were crossbred with the New Zealand Romney to generate 23 different ram types for use by commercial farmers. The rams were produced by different crossbreeding systems, therefore some were generated from the straightbreds faster than others. They also offered different additive genetic values and breed interaction values to the ewe flocks. The 23 different ram types - a variation of the different breed compositions all gave increases in performances relative to the Romney base for the ten traits studied.

The ram type chosen as being potentially the best composite of the new genes (Finn and East Friesian) in this study for increasing weaning percentage was Ram type 7 - 1/4R1/2F1/4EF. Ram type 7 can be produced relatively simply by a three breed fixed cross system, involving 2 different crosses and 2 generations: 1) R x EF

2) 1/2R1/2EF x F.

Ram type 7 had the highest weight of lamb weaned per ewe liveweight of the 8 analysed ram types - 0.8 and 0.85kg lamb/kg ewe liveweight for the two selection selection options, and the fifth highest fleeceweight production per ewe liveweight of 61g wool/kg ewe liveweight for both options at year 5. The straightbred Romney ram produced 0.5 kg lamb per kg ewe liveweight and 66 g wool per kg of ewe liveweight for both options in year 5.

There were a mixture of different genotypes in the commercial flocks from the crossbred rams, highligting a need for management planning to be taken for all of the 20 crossbred ram types, and 2 purebred ram types.

The production rate from the ewes of each ram type and the consequences of the generation and continual production of the ram types are the important issues to consider in the decision of finding the desired breed composition. The scarcity of data available to estimate the breed additive and breed interaction figures has limited the validity of the results, providing only a guideline until more data is obtained. More data is very important from throughout New Zealand on the breed performances in the New Zealand environments and their crossbreeding performances to enable more accurate prediction of phenotypic performances. The cost- benefit analysis of the study as mentioned in the discussion would be a further step to this study and the continuation of all 23 ram types analysed further, not just the 8 ram types in this study. Some carcass evaluation would also provide valuable information.

The potential of using ultrasound pregnancy scanning results as a selection predictor has shown that the genetic gains are greater than the use of lambing results. The scarcity of the foetal number parameters resulted in a number of assumptions and guesstimates that may have biased the results.

The introduction of the new genes - Finnish Landrace and East Friesian and the use of scanning results as a selection predictor have both been found in this study to increase the phenotypic performances of sheep in New Zealand.

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Appendix I.

An example of the procedure for calculating the expected performance of a ram type with the average Romney ewe.

Ram type used: Ram 6, 1/2R 1/4F 1/4EF.

PART 1: 4 Crosses of Ram type.

Table 1. Non-additive figures for breed interaction effects.

	Type of heterosis		**Heterosis %**
C R	A	B	C
3	MATERNAL NLB	1	0.05
4	PATERNAL NLB	1	0.01
5	INDIVIDUAL STW	1	0.055
6	MATERNAL STW	1	0.04

Table 2. Additive breed effects for number of lambs born and survival to weaning.

		OR	**SR**	**F**	**EF**
C R	A	B	C	D	E
9	NLB	1.18	1.4	2.75	2.3
10	STW	0.85	0.85	0.75	0.85

Table 3. Total heterosis and heterosis for each component.

	Ram Type	Cross No.	Maternal NLB HV	Paternal NLB HV	Individua l STW HV	Maternal STW HV	Total Heterosis
C R	A	B	C	D	E	F	H
38	6	1	=$B$3 + ($C$3 * H$121)	=$B$4 + ($C$4 * $O121)	=$B$5 + ($C$5 * B$126)	=$B$6 + ($C$6 * H121)	= $C38 * $D38 * $E38 *$F38
39	6	2	=$B$3 + ($C$3 * I$121)	=$B$4 + ($C$4 * $O121)	=$B$5 + ($C$5 * C$126)	=$B$6 + ($C$6 *I$121)	= $C39 * $D39 * $E39 *$F39
40	6	3	=$B$3+ ($C$3 * $J121)	=$B$4 + ($C$4 * $O121)	=$B$5 + ($C$5 * D$126)	=$B$6 + ($C$6 *J$121)	= $C40 * $D40 * $E40 *$F40
41	6	4	= $B$3 + ($C$3 * K121)	=$B$4 + ($C$4 * $O121)	=$B$5 + ($C$5 * E$126)	=$B$6 + ($C$6 *K121)	= $C41 * $D41 * $E41 *$F41

Table 4. Percent of Heterosis Expressed.

Table 4a. Individual Heterosis

		Progeny 1	**Progeny 2**	**Progeny 3**	**Progeny 4**
C R	A	B	C	D	E
126	6	= (B176 *(H176 + I176) + C176 * (E176 + I176) + D176 *(E176 + H176)) / (C177 * E177)	= (B176 *(M176 + N176) + C176 *(J176 + N176) + D176 *(J176 + M176)) / (C177 * J177)	= (B176 *(R176 + S176) + C176 * (O176 + S176) + D176 *(O176 +R176)) / (C177 * O177)	= (B176 *(W176 + X176) + C176 * (T176 + X176) + D176* (T176 + W176)) / (C177 * T177)

Table 4b. Maternal Heterosis.

	Ram Type	**Dam 1**	**Dam 2**	**Dam 3**	**Dam 4**
C R	G	H	I	J	K
121	6	0	=B126	=C126	=D126

Table 4c Paternal heterosis.

	Ram Type	**% heterosis expressed**	**Fraction of heterosis expressed**
CR	**M**	N	O
121	6	100	1

Table 5 Breed Composition Breakdown.

	Ram Type	**R6 SR**	**F**	**EF**	**D1 TR**	**OR**	**SR**	**F**	**EF**	**P1/D2 TR**	**OR**	**SR**	**F**	**EF**	**P2/D3 TR**	**OR**	**SR**	**F**	**EF**
CR	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
176	6	1	1	1	1	1	0	0	0	6	1	=$J176/$J177 - $K176/$K177	1	1	10	1	=$O176/$O177 - $P176/$P177	3	3
177		2	4	4	1	1	0	0	0	8	2	0	8	8	16	4	0	16	16

table 5 continued ....

	P3/D4 TR	**OR**	**SR**	**F**	**EF**	**P4 TR**	**OR**	**SR**	**F**	**EF**
CR	T	U	V	W	X	Y	Z	AA	AB	AC
176	18	1	=$T176/$T177 - $U176/$U177	7	7	17	1	=$Y176/$Y177 - $Z176/$Z177	15	15
177	32	8	0	32	32	32	16	0	64	64

Table 6. Lambing percentage at Weaning.

	Ram Type	**Dam**	**Progeny**	**Heterosis**	**NLB (additive)**	**STW (additive)**	**Lambing % at Weaning**
C R	A	B	C	D	E	F	H
237	6 - 1/2R 1/4F 1/4EF	R	3/4R 1/8F 1/8EF	= H38	= $B$11* ($F176/$F177)	= $C$12 * ($J176/$J177) + $D$12 * ($M176/M177) + $E$12 * ($N176/$N177)	= $D237 * $E237 * $F237
238		3/4R 1/8F 1/8EF	5/8R 3/16F 3/16EF	= H39	= $B$11 * ($K176/$K177) + $C$11 * ($L176) + $D$11 * ($M176/$M177) + $E$11 * ($N176/$N177)	= $C$12 * ($O176/$O177) + $D$12 * ($R176/$R177) + $E$12 * ($S176/$S177)	= $D238 * $E238 * $F238
239		5/8R 3/16F 3/16EF	9/16R 7/32F 7/32EF	= H40	= $B$11 * ($P176/$P177) + $C$11 * ($Q176) + $D$11 * ($R176/$R177) + $E$11 * ($S176/$S177)	=$C$12 * ($T176/$T177) + $D$12 * ($W176/$W177) + $E$12 * ($X176/$X177)	= $D239 * $E239 * $F239
240		9/16R 7/32F 7/32EF	17/32R 15/64F 15/64EF	= H41	= $B$11 * ($U176/$U177) + $C$11 * ($V176) + $D$11 * ($W176/$W177) + $E$11 * ($X176/$X177)	=$C$12 * ($Y176/$Y177) + $D$12 * ($AB176/$AB177) + $E$12 * ($AC176/$AC177)	= $D240 * $E240 * $F240

Part 2 : Effect of ram type on a breeding flock for 4 crosses.

Table 1. Performance of Ram 6 with Romney ewe for base year and 4 subsequent crosses.

	Option 1							
C R	A	C	E	I	J	K	L	**M**
4	Ram	Ewe	Progeny	NLW	HNLW	B.WT	W.WT	S.WT
5	R	R	R	=NLW! $B$11* NLW! $B$12	=HNLW! $B$11* HNLW! $B$12	=B.WT! $B$10	=W.WT! $B$10	=S.WT! $B$10
6	=E.WT! A234	=E.WT! B234	=E.WT! C234	=NLW! $H$237	=HNLW! $H$237	=B.WT! $F$234	=W.WT! $F$234	=S.WT! $F$234
7		=E.WT! B235	=E.WT! C235	=NLW! $H$238	=HNLW! $H$238	=B.WT! $F$235	=W.WT! $F$235	=S.WT! $F$235
8		=E.WT! B236	=E.WT! C236	=NLW! $H$239	=HNLW! $H$239	=B.WT! $F$236	=W.WT! $F$236	=S.WT! $F$236
9		=E.WT! B237	=E.WT! C237	=NLW! $H$240	=HNLW! $H$240	=B.WT! $F$237	=W.WT! $F$237	=S.WT! $F$237

table 1 continued ....

C R	N	O	P	Q	R
4	H.WT	E.WT	H.FW	E.FWw	FD
5	=H.WT! $B$10	=E.WT! $B$10	=H.FW! $B$10	=E.FW! $B$10	=FD! $B$10
6	=H.WT! $F$234	=E.WT! $E$234	=H.FW! $F$234	=E.FW! $F$234	=FD! $F$234

7	=H.WT!$F$235	=E.WT!$E$235	=H.FW!$F$235	=E.FW!$F$235	=FD!$F$235
8	=H.WT!$F$236	=E.WT!$E$236	=H.FW!$F$236	=E.FW!$F$236	=FD!$F$236
9	=H.WT!$F$237	=E.WT!$E$237	=H.FW!$F$237	=E.FW!$F$237	=FD!$F$237

Table 2. Predicted flock performance for 5 year period.

	Age Structure Option 1a			**Option 1b**	
C R	A	B	C	D	E
13	Age	% Flock	% B.Flock	% Flock	%B.Flock
14	Hoggets	1	0.22	1	0.3
15	2T	=100*C15/(100-100*C$14)	0.21	=100*E15/(100-100*E$14)	0.25
16	3 yrs	=100*C16/(100-100*C$14)	0.2	=100*E16/(100-100*E$14)	0.2
17	4 yrs	=100*C17/(100-100*C$14)	0.15	=100*E17/(100-100*E$14)	0.15
18	5 yrs	=100*C18/(100-100*C$14)	0.11	=100*E18/(100-100*E$14)	0.1
19	6 yrs	=100*C19/(100-100*C$14)	0.11	=100*E19/(100-100*E$14)	0
20					Total 1a
21					Total 1b

table 2 continued ..... Weaning Performance

	NLW Performance					
C R	F	G	H	I	J	K
12	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
13						
14	=J5	=J6	=J7	=J8	=$J$9	=$J$9
15	=I$5	=I6	=I6	=$I$7	=$I$8	=$I$9
16	=I5	=I6	=I6	=$I$6	=$I$7	=I8
17	=I5	=I6	=I6	=$I$6	=$I$6	=I7
18	=I5	=I6	=I6	=$I$6	=$I$6	=$I$6
19	=I5	=I6	=I6	=$I$6	=$I$6	=$I$6
20	=F14*C14+F15*C15+F16*C16+F17*C17+F18*C18+F19*C19	=G14*C14+G15*C15+G16*C16+G17*C17+G18*C18+G19*C19	=H14*C14+H15*C15+H16*C16+H17*C17+H18*C18+H19*C19	=I14*$C$14+I15*$C$15+I16*$C$16+I17*$C$17+I18*$C$18+I19*$C$19	=J14*$C$14+J15*$C$15+J16*$C$16+J17*$C$17+J18*$C$18+J19*$C$19	=K14*$C$14+K15*$C$15+K16*$C$16+K17*$C$17+K18*$C$18+K19*$C$19
21	=F14*C14+F15*C15+F16*C16+F17*C17+F18*C18+F19*C19	=G14*C14+G15*C15+G16*C16+G17*C17+G18*C18+G19*C19	=H14*E14+H15*E15+H16*E16+H17*E17+H18*E18+H19*E19	=I14*$E$14+I15*$E$15+I16*$E$16+I17*$E$17+I18*$E$18+I19*$E$19	=J14*$E$14+J15*$E$15+J16*$E$16+J17*$E$17+J18*$E$18+J19*$E$19	=K14*$E$14+K15*$E$15+K16*$E$16+K17*$E$17+K18*$E$18+K19*$E$19

table 2 continued ....Birth Weight

	Birth Weight					
C R	L	M	N	O	P	Q
12	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
13						
14	=$K$5	=$K6	=$K7	=$K8	=$K9	=$K9
15	=$K$5	=$K$6	=$K$6	=$K$7	=$K$8	=$K$9

16	=$K$5	=$K$6	=$K$6	=$K$6	=$K$7	=$K$8
17	=$K$5	=$K$6	=$K$6	=$K$6	=$K$6	=$K$7
18	=$K$5	=$K$6	=$K$6	=$K$6	=$K$6	=$K$6
19	=$K$5	=$K$6	=$K$6	=$K$6	=$K$6	=$K$6
20	=L14*$C$14+L15*$C$15+L16*$C$16+L17*$C$17+L18*$C$18+L19*$C$19	=M14*$C$14+M15*$C$15+M16*$C$16+M17*$C$17+M18*$C$18+M19*$C$19	=N14*$C$14+N15*$C$15+N16*$C$16+N17*$C$17+N18*$C$18+N19*$C$19	=O14*$C$14+O15*$C$15+O16*$C$16+O17*$C$17+O18*$C$18+O19*$C$19	=P14*$C$14+P15*$C$15+P16*$C$16+P17*$C$17+P18*$C$18+P19*$C$19	=Q14*$C$14+Q15*$C$15+Q16*$C$16+Q17*$C$17+Q18*$C$18+Q19*$C$19
21	=L14*$C$14+L15*$C$15+L16*$C$16+L17*$C$17+L18*$C$18+L19*$C$19	=M14*$C$14+M15*$C$15+M16*$C$16+M17*$C$17+M18*$C$18+M19*$C$19	=N14*$E$14+N15*$E$15+N16*$E$16+N17*$E$17+N18*$E$18+N19*$E$19	=O14*$E$14+O15*$E$15+O16*$E$16+O17*$E$17+O18*$E$18+O19*$E$19	=P14*$E$14+P15*$E$15+P16*$E$16+P17*$E$17+P18*$E$18+P19*$E$19	=Q14*$E$14+Q15*$E$15+Q16*$E$16+Q17*$E$17+Q18*$E$18+Q19*$E$19

table 2 continued .... Weaning Weight

	Weaning Weight					
C R	R	S	T	U	V	W
12	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
13						
14	=L5	=$L6	=$L7	=$L8	=$L9	=$L9
15	=$L$5	=$L$6	=$L$6	=$L$7	=$L$8	=$L$9
16	=$L$5	=$L$6	=$L$6	=$L$6	=$L$7	=$L$8
17	=$L$5	=$L$6	=$L$6	=$L$6	=$L$6	=$L$7
18	=$L$5	=$L$6	=$L$6	=$L$6	=$L$6	=$L$6
19	=$L$5	=$L$6	=$L$6	=$L$6	=$L$6	=$L$6
20	=R14*$C$14+R15*$C$15+R16*$C$16+R17*$C$17+R18*$C$18+R19*$C$19	=S14*$C$14+S15*$C$15+S16*$C$16+S17*$C$17+S18*$C$18+S19*$C$19	=T14*$C$14+T15*$C$15+T16*$C$16+T17*$C$17+T18*$C$18+T19*$C$19	=U14*$C$14+U15*$C$15+U16*$C$16+U17*$C$17+U18*$C$18+U19*$C$19	=V14*$C$14+V15*$C$15+V16*$C$16+V17*$C$17+V18*$C$18+V19*$C$19	=W14*$C$14+W15*$C$15+W16*$C$16+W17*$C$17+W18*$C$18+W19*$C$19

21	=R14*$C$14+R15*$C$15+R16*$C$16+R17*$C$17+R18*$C$18+R19*$C$19	=S14*$C$14+S15*$C$15+S16*$C$16+S17*$C$17+S18*$C$18+S19*$C$19	=T14*$E$14+T15*$E$15+T16*$E$16+T17*$E$17+T18*$E$18+T19*$E$19	=U14*$E$14+U15*$E$15+U16*$E$16+U17*$E$17+U18*$E$18+U19*$E$19	=V14*$E$14+V15*$E$15+V16*$E$16+V17*$E$17+V18*$E$18+V19*$E$19	=W14*$E$14+W15*$E$15+W16*$E$16+W17*$E$17+W18*$E$18+W19*$E$19

table 2 continued .... Slaughter Weight

	Slaughter Weight					
C R	X	Y	Z	AA	AB	AC
12	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
13						
14	=M5	=$M6	=$M7	=$M8	=$M9	=$M9
15	=$M$5	=$M$6	=$M$6	=$M$7	=$M$8	=$M$9
16	=$M$5	=$M$6	=$M$6	=$M$6	=$M$7	=$M$8
17	=$M$5	=$M$6	=$M$6	=$M$6	=$M$6	=$M$7
18	=$M$5	=$M$6	=$M$6	=$M$6	=$M$6	=$M$6
19	=$M$5	=$M$6	=$M$6	=$M$6	=$M$6	=$M$6
20	=X14*$C$14+X15*$C$15+X16*$C$16+X17*$C$17+X18*$C$18+X19*$C$19	=Y14*$C$14+Y15*$C$15+Y16*$C$16+Y17*$C$17+Y18*$C$18+Y19*$C$19	=Z14*$C$14+Z15*$C$15+Z16*$C$16+Z17*$C$17+Z18*$C$18+Z19*$C$19	=AA14*$C$14+AA15*$C$15+AA16*$C$16+AA17*$C$17+AA18*$C$18+AA19*$C$19	=AB14*$C$14+AB15*$C$15+AB16*$C$16+AB17*$C$17+AB18*$C$18+AB19*$C$19	=AC14*$C$14+AC15*$C$15+AC16*$C$16+AC17*$C$17+AC18*$C$18+AC19*$C$19
21	=X14*$C$14+X15*$C$15+X16*$C$16+X17*$C$17+X18*$C$18+X19*$C$19	=Y14*$C$14+Y15*$C$15+Y16*$C$16+Y17*$C$17+Y18*$C$18+Y19*$C$19	=Z14*$E$14+Z15*$E$15+Z16*$E$16+Z17*$E$17+Z18*$E$18+Z19*$E$19	=AA14*$E$14+AA15*$E$15+AA16*$E$16+AA17*$E$17+AA18*$E$18+AA19*$E$19	=AB14*$E$14+AB15*$E$15+AB16*$E$16+AB17*$E$17+AB18*$E$18+AB19*$E$19	=AC14*$E$14+AC15*$E$15+AC16*$E$16+AC17*$E$17+AC18*$E$18+AC19*$E$19

table 2 continued ......Hogget and Mixed Age Ewe Liveweights

	Hogget and MA ewe weight					
C R	AD	AE	AF	AG	AH	AI
12	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
13						
14	=N5	=N5	=N6	=N7	=N8	=N9
15	=$O$5	=$O$5	=$O$5	=$O6	=$O7	=$O8
16	=$O$5	=$O$5	=$O$5	=$O$5	=$O$6	=$O$7
17	=$O$5	=$O$5	=$O$5	=$O$5	=$O$5	=$O$6
18	=$O$5	=$O$5	=$O$5	=$O$5	=$O$5	=$O$5
19	=$O$5	=$O$5	=$O$5	=$O$5	=$O$5	=$O$5
20	=AD15*$B$15+AD16*$B$16+AD17*$B$17+AD18*$B$18+AD19*$B$19	=AE15*$B$15+AE16*$B$16+AE17*$B$17+AE18*$B$18+AE19*$B$19	=AF15*$B$15+AF16*$B$16+AF17*$B$17+AF18*$B$18+AF19*$B$19	=AG15*$B$15+AG16*$B$16+AG17*$B$17+AG18*$B$18+AG19*$B$19	=AH15*$B$15+AH16*$B$16+AH17*$B$17+AH18*$B$18+AH19*$B$19	=AI15*$B$15+AI16*$B$16+AI17*$B$17+AI18*$B$18+AI19*$B$19
21	=AD14*$C$14+AD15*$C$15+AD16*$C$16+AD17*$C$17+AD18*$C$18+AD19*$C$19	=AE14*$C$14+AE15*$C$15+AE16*$C$16+AE17*$C$17+AE18*$C$18+AE19*$C$19	=AF14*$E$14+AF15*$E$15+AF16*$E$16+AF17*$E$17+AF18*$E$18+AF19*$E$19	=AG14*$E$14+AG15*$E$15+AG16*$E$16+AG17*$E$17+AG18*$E$18+AG19*$E$19	=AH14*$E$14+AH15*$E$15+AH16*$E$16+AH17*$E$17+AH18*$E$18+AH19*$E$19	=AI14*$E$14+AI15*$E$15+AI16*$E$16+AI17*$E$17+AI18*$E$18+AI19*$E$19

table 2 continued .... Hogget and Mixed Age Ewe Fleece Weight

	Hogget and MA ewe fleece weight					
C R	AJ	AK	AL	AM	AM	AN
12	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
13						
14	=P5	=P5	=P6	=P7	=P8	=P9

15	=$Q$5	=$Q$5	=$Q$5	=$Q$6	=$Q$7	=$Q$8
16	=$Q$5	=$Q$5	=$Q$5	=$Q$5	=$Q$6	=$Q$7
17	=$Q$5	=$Q$5	=$Q$5	=$Q$5	=$Q$5	=$Q$6
18	=$Q$5	=$Q$5	=$Q$5	=$Q$5	=$Q$5	=$Q$5
19	=$Q$5	=$Q$5	=$Q$5	=$Q$5	=$Q$5	=$Q$5
20	=AJ15*$B$15+AJ16*$B$16+AJ17*$B$17+AJ18*$B$18+AJ19*$B$19	=AK15*$B$15+AK16*$B$16+AK17*$B$17+AK18*$B$18+AK19*$B$19	=AL15*$B$15+AL16*$B$16+AL17*$B$17+AL18*$B$18+AL19*$B$19	=AM15*$B$15+AM16*$B$16+AM17*$B$17+AM18*$B$18+AM19*$B$19	=AN15*$B$15+AN16*$B$16+AN17*$B$17+AN18*$B$18+AN19*$B$19	=AO15*$B$15+AO16*$B$16+AO17*$B$17+AO18*$B$18+AO19*$B$19
21	=AJ14*$C$14+AJ15*$C$15+AJ16*$C$16+AJ17*$C$17+AJ18*$C$18+AJ19*$C$19	=AK14*$C$14+AK15*$C$15+AK16*$C$16+AK17*$C$17+AK18*$C$18+AK19*$C$19	=AL14*$E$14+AL15*$E$15+AL16*$E$16+AL17*$E$17+AL18*$E$18+AL19*$E$19	=AM14*$E$14+AM15*$E$15+AM16*$E$16+AM17*$E$17+AM18*$E$18+AM19*$E$19	=AN14*$E$14+AN15*$E$15+AN16*$E$16+AN17*$E$17+AN18*$E$18+AN19*$E$19	=AO14*$E$14+AO15*$E$15+AO16*$E$16+AO17*$E$17+AO18*$E$18+AO19*$E$19

table 2 continued .... Average fibre diameter

	Average Fibre Diameter					
C R	AP	AQ	AR	AS	AT	AU
12	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
13						
14	=$R$5	=$R$5	=$R$6	=$R$7	=$R$8	=$R$9
15	=$R$5	=$R$5	=$R$5	=$R$6	=$R$7	=$R$8
16	=$R$5	=$R$5	=$R$5	=$R$5	=$R$6	=$R$7
17	=$R$5	=$R$5	=$R$5	=$R$5	=$R$5	=$R$6
18	=$R$5	=$R$5	=$R$5	=$R$5	=$R$5	=$R$5

19	=$R$5	=$R$5	=$R$5	=$R$5	=$R$5	=$R$5
20	=AP14*$C$14+AP15*$C$15+AP16*$C$16+AP17*$C$17+AP18*$C$18+AP19*$C$19	=AQ14*$C$14+AQ15*$C$15+AQ16*$C$16+AQ17*$C$17+AQ18*$C$18+AQ19*$C$19	=AR14*$C$14+AR15*$C$15+AR16*$C$16+AR17*$C$17+AR18*$C$18+AR19*$C$19	=AS14*$C$14+AS15*$C$15+AS16*$C$16+AS17*$C$17+AS18*$C$18+AS19*$C$19	=AT14*$C$14+AT15*$C$15+AT16*$C$16+AT17*$C$17+AT18*$C$18+AT19*$C$19	=AU14*$C$14+AU15*$C$15+AU16*$C$16+AU17*$C$17+AU18*$C$18+AU19*$C$19
21	=AP14*$C$14+AP15*$C$15+AP16*$C$16+AP17*$C$17+AP18*$C$18+AP19*$C$19	=AQ14*$C$14+AQ15*$C$15+AQ16*$C$16+AQ17*$C$17+AQ18*$C$18+AQ19*$C$19	=AR14*$E$14+AR15*$E$15+AR16*$E$16+AR17*$E$17+AR18*$E$18+AR19*$E$19	=AS14*$E$14+AS15*$E$15+AS16*$E$16+AS17*$E$17+AS18*$E$18+AS19*$E$19	=AT14*$E$14+AT15*$E$15+AT16*$E$16+AT17*$E$17+AT18*$E$18+AT19*$E$19	=AU14*$E$14+AU15*$E$15+AU16*$E$16+AU17*$E$17+AU18*$E$18+AU19*$E$19

Table 3. Summary table for Yearly performance for Option 1a

	Year	NLW	B.WT	W.WT	S.WT	H.WT	E.WT	H.FW	E.FW	FD
C R	A	B	C	D	E	F	G	H	I	J
27	0	=F20	=L20	=R20	=X20	=$AD$14	=AD20	=$AJ$14	=AJ20	=AP20
28	1	=G20	=M20	=S20	=Y20	=$AE$14	=AE20	=$AK$14	=AK20	=AQ20
29	2	=H20	=N20	=T20	=Z20	=$AF$14	=AF20	=$AL$14	=AL20	=AR20
30	3	=I20	=O20	=U20	=AA20	=$AG$14	=AG20	=$AM$14	=AM20	=AS20
31	4	=J20	=P20	=V20	=AB20	=$AH$14	=AH20	=$AN$14	=AN20	=AT20
32	5	=K20	=Q20	=W20	=AC20	=$AI$14	=AI20	=$AO$14	=AO20	=AU20

Table 4. Summary table for yearly performance of option 1b

	Year	NLW	B.WT	W.WT	S.WT	H.WT	E.WT	H.FW	E.FW	FD
C R	A	B	C	D	E	F	G	H	I	J
37	0	=F21	=L21	=R21	=X21	=$AD$14	=AD21	=$AJ$14	=AJ21	=AP21
38	1	=G21	=M21	=S21	=Y21	=$AE$14	=AE21	=$AK$14	=AK21	=AQ21

39	2	=H21	=N21	=T21	=Z21	=$AF$14	=AF21	=$AL$14	=AL21	=AR21
40	3	=I21	=O21	=U21	=AA21	=$AG$14	=AG21	=$AM$14	=AM21	=AS21
41	4	=J21	=P21	=V21	=AB21	=$AH$14	=AH21	=$AN$14	=AN21	=AT21
42	5	=K21	=Q21	=W21	=AC21	=$AI$14	=AI21	=$AO$14	=AO21	=AU21

PART 3: Changes in average phenotypic measurements in breeding flock.

Table 1. Total weight of lambs weaned per ewe and change in total weaning weight per ewe from base year 0.

	Option 1a	**Total Weaning Weight**		**Change in Total Weaning Weight**
C R	A	B	C	D
12	=A6	Average per ewe		
13	Year 0	=Options!B26*Options!D26		=Options!$B26*Options!$D26 - Options!$B$26*Options!$D$26
14	Year 1	=Options!B27*Options!D27		=Options!$B27*Options!$D27 - Options!$B$26*Options!$D$26
15	Year 2	=Options!B28*Options!D28		=Options!$B28*Options!$D28 - Options!$B$26*Options!$D$26
16	Year 3	=Options!B29*Options!D29		=Options!$B29*Options!$D29 - Options!$B$26*Options!$D$26
17	Year 4	=Options!B30*Options!D30		=Options!$B30*Options!$D30 - Options!$B$26*Options!$D$26
18	Year 5	=Options!B31*Options!D31		=Options!$B31*Options!$D31 - Options!$B$26*Options!$D$26

table 1 continued......... Average hogget and ewe weights

	Option 1a	**Average Hogget liveweight**		**Change in average hogget liveweight**		**Average ewe liveweight**		**Change in average ewe liveweight**
C R	F	G	H	I	J	K	L	M
13	Year 0	=Options!F26		=Options!F26 - Options!$F$26		=Options!G26		=Options!G26 - Options!$G$26

14	Year 1	=Options!F27		=Options!F27 - Options!$F$26		=Options!G27		=Options!G27 - Options!$G$26
15	Year 2	=Options!F28		=Options!F28 - Options!$F$26		=Options!G28		=Options!G28 - Options!$G$26
16	Year 3	=Options!F29		=Options!F29 - Options!$F$26		=Options!G29		=Options!G29 - Options!$G$26
17	Year 4	=Options!F30		=Options!F30 - Options!$F$26		=Options!G30		=Options!G30 - Options!$G$26
18	Year 5	=Options!F31		=Options!F31 - Options!$F$26		=Options!G31		=Options!G31 - Options!$G$26

Table 2. Average hogget and MA ewe fleece weights.

	Option 1a	**Average Hogget fleece weight (kg)**		**Change in average hogget fleece weight (kg)**		**Average MA ewe fleece weight (kg)**		**Change in average MA ewe fleece weight (kg)**
C R	F	G	H	I	J	K	L	M
13	Year 0	=Options!H26		=Options!H26 - Options!$H$26		=Options!I26		=Options!I26 - Options!$I$26
14	Year 1	=Options!H27		=Options!H27 - Options!$H$26		=Options!I27		=Options!I27 - Options!$I$26
15	Year 2	=Options!H28		=Options!H28 - Options!$H$26		=Options!I28		=Options!I28 - Options!$I$26
16	Year 3	=Options!H29		=Options!H29 - Options!$H$26		=Options!I29		=Options!I29 - Options!$I$26
17	Year 4	=Options!H30		=Options!H30 - Options!$H$26		=Options!I30		=Options!I30 - Options!$I$26
18	Year 5	=Options!H31		=Options!H31 - Options!$H$26		=Options!I31		=Options!I31 - Options!$I$26

APPENDIX II.

The Fraction Method for calculating the percentage of original heterosis (of breeds) expressed in a cross.

Heterosis Calculations

The amount of heterosis expected in the progeny of two parents is usually calculated by using a method involving matrices (Lopez-Villalobos and Garrick, 1996). The percentage or fraction of the original heterosis (from a first generation cross involving the breeds/lines involved) can be calculated for any specified cross involving those breeds/lines.

Another method for calculating the percentage of original heterosis for the breeds or lines involved is the 'Fraction Method'. Like the method involving matrices, the Fraction method can be used for any crosses between crossbred and/or purebred dams and sires, including sires and dams of the same breed combination.

The Fraction method involves fractions and simple multiplication and addition. The general method can be adapted to personal preferences, once the general principle has been understood.

The method is explained in a 5 step process with the aid of algebraic notation and is followed by 3 worked examples.

The Fraction Method.

Step 1: Write the breed composition of both the dam and sire in fractional form.
(It is important to describe the breeds in the same order throughout the whole method).

e.g., Dam: M/k breed A, L/z breed B, F/n breed C
Sire: e/h breed A, f/i breed B, g/j breed C

Note: 1) $M/k + L/z + F/n = e/h + f/i + g/j = 1.0$

2) The letters used in this step represent the different numbers used to describe the fractions of the breeds in the dam and ram respectively, they do not represent anything else. The dams numerator letters are capitals, and the sires are in the lower case, due to the pattern established in step 4 where the emphasis is on not multiplying the same letters together, and that there should only be lower case letters in the brackets.

Step 2: Calculate the lowest common denominator of the fractions and convert all of the fractions to this common denominator.

e.g., Lowest common denominator = T, therefore the new fractions are:

Dam: $\frac{A}{T}$ *breed A* $\frac{B}{T}$ breed B $\frac{C}{T}$ breed C

Sire: $\frac{a}{T}$ breed A $\frac{b}{T}$ breed B $\frac{c}{T}$ breed C

Step 3: Square the common denominator. This is the denominator for the final fraction.

e.g., $T^2 = L$

Step 4: Multiply the numerator of the first breed of the dam with each of the other breeds of the sire and add together. Carry out this procedure with all of the breeds in the dam, multiplying them with the other breeds in the sire.

Do not multiply any numbers together that are numerators for the same breed. Add all of the new numerators together. This is the numerator for the final fraction.

e.g., $A(b+c)+B(a+c)+C(a+b)=R$

Step 5: Form a fraction with the denominator and numerator from Steps 3 and 4.

This is the fraction of the original heterosis that will be expressed in the progeny of the dam and sire. The fraction can be left in this form or converted into a percentage.

e.g., Fraction of original heterosis expressed in the progeny, $P = \frac{R}{L}$

Three worked examples.

Example 1.

The dam is three quarters Romney, 1/8th Finn, and 1/8th East Friesian, and the sire is half Romney, a quarter Finn and a quarter East Friesian.

Step 1: Dam: 3/4 R, 1/8 F, 1/8 EF

Sire: 1/2R, 1/4 F, 1/4 EF,

Step 2: Lowest common denominator = 8

$\therefore$ Dam: $\frac{6}{8}$R, $\frac{1}{8}$F, $\frac{1}{8}$ EF

Sire: $\frac{4}{8}$ R, $\frac{2}{8}$F, $\frac{2}{8}$ EF,

Step 3: $8^2 = 64$,

Step 4: $6(2+2)+1(4+2)+1(4+2)=36$

Step 5: $\frac{36}{64} = 56\ \%$

Therefore, the progeny from this cross will express on average 56% of the full heterosis expressed from a F1 cross of the 3 breeds involved in the cross.

Example 2.

The dam is one half Romney, one half Finn, and the sire is pure East Friesian.

Step 1: Dam: $1/2$ R, $1/2$ F

Sire: $1/1$ EF

Step 2: Lowest common denominator: 2

$\therefore$ Dam: $\frac{1}{2}$ R, $\frac{1}{2}$ F

Sire: $\frac{2}{2}$ EF

Step 3: $2^2 = 4$

Step 4: $1(2) + 1(2) = 2 + 2 = 4$

Step 5: $\frac{4}{4} = 100\%$

Therefore, the progeny from this cross will express on average 100% of the full heterosis expressed from a F1 cross of the 3 breeds involved in the cross.

Example 3.

The dam is pure Romney, and the sire one half Romney, three eighth Finn, and one eighth East Friesian.

Step 1: Dam: $1/1$ R

Sire: $1/2$ R, $3/8$ F, $1/8$ EF

Step 2: Lowest common denominator: 8

$\therefore$ Dam: $\frac{8}{8}$R

Sire: $\frac{4}{8}$R, $\frac{3}{8}$F, $\frac{1}{8}$EF

Step 3: $8^2 = 64$

Step 4: $8(3 + 1) = 32$

Step 5: $\frac{32}{64} = 50\%$

Therefore, the progeny from this cross will express on average 50% of the full heterosis expressed from a F1 cross of the 3 breeds involved in the cross.

Appendix III.

3.1. The normal equations used for the calculation of the b weighting factors.

Normal equations for: Number of lambs born as a selection predictor.

1) Number of lambs born equation.

$$b_{NLB}Var(X_{NLB}) + b_{WWT}Cov(X_{NLB}, X_{WWT}) + b_{LW12I}Cov(X_{NLB}, X_{LW12I})$$
$$+b_{LW12PHS}Cov(X_{NLB}, X_{LW12PHS}) + b_{FW12I}Cov(X_{NLB}, X_{FW12I}) + b_{FW12PHS}Cov(X_{NLB}, X_{FW12PHS})$$
$$= 10.5Cov(G_{NLB}, G_{NLB}) + 0.55Cov(G_{NLB}, G_{LW8}) + 3.0Cov(G_{NLB}, G_{FW12})$$

2) Weaning weight equation.

$$b_{NLB}Cov(X_{NLB}, X_{WWT}) + b_{WWT}Var(X_{WWT}) + b_{LW12I}Cov(X_{WWT}, X_{LW12I})$$
$$+b_{LW12PHS}Cov(X_{WWT}, X_{LW12PHS}) + b_{FW12I}Cov(X_{WWT}, X_{FW12I}) + b_{FW12PHS}Cov(X_{WWT}, X_{FW12PHS})$$
$$= 10.5Cov(G_{WWT}, G_{NLB}) + 0.55Cov(G_{WWT}, G_{LW8}) + 3.0Cov(G_{WWT}, G_{FW12})$$

3) Individual liveweight at 12 months equation.

$$b_{NLB}Cov(X_{NLB}, X_{LW12I}) + b_{WWT}Cov(X_{WWT}, X_{LW12I}) + b_{LW12I}Var(X_{LW12I})$$
$$+b_{LW12PHS}Cov(X_{LW12I}, X_{LW12PHS}) + b_{FW12I}Cov(X_{LW12I}, X_{FW12I}) + b_{FW12PHS}Cov(X_{LW12I}, X_{FW12PHS})$$
$$= 10.5Cov(G_{LW12I}, G_{NLB}) + 0.55Cov(G_{LW12I}, G_{LW8}) + 3.0Cov(G_{LW12I}, G_{FW12})$$

4) Paternal half sib liveweight at 12 months equation.

$$b_{NLB}Cov(X_{NLB}, X_{LW12PHS}) + b_{WWT}Cov(X_{WWT}, X_{LW12PHS}) + b_{LW12I}Cov(X_{LW12I}, X_{LW12PHS})$$
$$+b_{LW12PHS}Var(X_{LW12PHS}) + b_{FW12I}Cov(X_{LW12PHS}, X_{FW12I}) + b_{FW12PHS}Cov(X_{LW12PHS}, X_{FW12PHS})$$
$$= 10.5Cov(G_{LW12PHS}, G_{NLB}) + 0.55Cov(G_{LW12PHS}, G_{LW8}) + 3.0Cov(G_{LW12PHS}, G_{FW12})$$

5) Individual fleece weight at 12 months equation.

$$b_{NLB}Cov(X_{NLB}, X_{FW12I}) + b_{WWT}Cov(X_{WWT}, X_{FW12I}) + b_{LW12I}Cov(X_{LW12I}, X_{FW12I})$$
$$+b_{LW12PHS}Cov(X_{LW12PHS}, X_{FW12I}) + b_{FW12I}Var(X_{FW12I}) + b_{FW12PHS}Cov(X_{FW12I}, X_{FW12PHS})$$
$$= 10.5Cov(G_{FW12I}, G_{NLB}) + 0.55Cov(G_{FW12I}, G_{LW8}) + 3.0Cov(G_{FW12I}, G_{FW12})$$

6) Paternal half sib fleece weight at 12 months equation.

$$b_{NLB}Cov(X_{NLB}, X_{FW12PHS}) + b_{WWT}Cov(X_{WWT}, X_{FW12PHS}) + b_{LW12I}Cov(X_{LW12I}, X_{FW12PHS})$$
$$+b_{LW12PHS}Cov(X_{LW12PHS}, X_{FW12PHS}) + b_{FW12I}Cov(X_{FW12I}, X_{FW12PHS}) + b_{FW12PHS}Var(X_{FW12PHS})$$
$$= 10.5Cov(G_{FW12PHS}, G_{NLB}) + 0.55Cov(G_{FW12PHS}, G_{LW8}) + 3.0Cov(G_{FW12PHS}, G_{FW12})$$

Number of foetuses scanned as a selection predictor.

1) Number of foetuses scanned equation.

$$
\begin{aligned}
&b_{NFS}Var(X_{NFS}) + b_{WWT}Cov(X_{NFS}, X_{WWT}) + b_{LW12I}Cov(X_{NFS}, X_{LW12I}) \\
&+b_{LW12PHS}Cov(X_{NFS}, X_{LW12PHS}) + b_{FW12I}Cov(X_{NFS}, X_{FW12I}) + b_{FW12PHS}Cov(X_{NFS}, X_{FW12PHS}) \\
&= 10.5Cov(G_{NFS}, G_{NLB}) + 0.55Cov(G_{NFS}, G_{LW8}) + 3.0Cov(G_{NFS}, G_{FW12})
\end{aligned}
$$

2) Weaning weight equation.

$$
\begin{aligned}
&b_{NFS}Cov(X_{NFS}, X_{WWT}) + b_{WWT}Var(X_{WWT}) + b_{LW12I}Cov(X_{WWT}, X_{LW12I}) \\
&+b_{LW12PHS}Cov(X_{WWT}, X_{LW12PHS}) + b_{FW12I}Cov(X_{WWT}, X_{FW12I}) + b_{FW12PHS}Cov(X_{WWT}, X_{FW12PHS}) \\
&= 10.5Cov(G_{WWT}, G_{NLB}) + 0.55Cov(G_{WWT}, G_{LW8}) + 3.0Cov(G_{WWT}, G_{FW12})
\end{aligned}
$$

3) Individual liveweight at 12 months equation.

$$
\begin{aligned}
&b_{NFS}Cov(X_{NFS}, X_{LW12I}) + b_{WWT}Cov(X_{WWT}, X_{LW12I}) + b_{LW12I}Var(X_{LW12I}) \\
&+b_{LW12PHS}Cov(X_{LW12I}, X_{LW12PHS}) + b_{FW12I}Cov(X_{LW12I}, X_{FW12I}) + b_{FW12PHS}Cov(X_{LW12I}, X_{FW12PHS}) \\
&= 10.5Cov(G_{LW12I}, G_{NLB}) + 0.55Cov(G_{LW12I}, G_{LW8}) + 3.0Cov(G_{LW12I}, G_{FW12})
\end{aligned}
$$

4) Paternal half sib liveweight at 12 months equation.

$$
\begin{aligned}
&b_{NFS}Cov(X_{NFS}, X_{LW12PHS}) + b_{WWT}Cov(X_{WWT}, X_{LW12PHS}) + b_{LW12I}Cov(X_{LW12I}, X_{LW12PHS}) \\
&+b_{LW12PHS}Var(X_{LW12PHS}) + b_{FW12I}Cov(X_{LW12PHS}, X_{FW12I}) + b_{FW12PHS}Cov(X_{LW12PHS}, X_{FW12PHS}) \\
&= 10.5Cov(G_{LW12PHS}, G_{NLB}) + 0.55Cov(G_{LW12PHS}, G_{LW8}) + 3.0Cov(G_{LW12PHS}, G_{FW12})
\end{aligned}
$$

5) Individual fleece weight at 12 months equation.

$$
\begin{aligned}
&b_{NFS}Cov(X_{NFS}, X_{FW12I}) + b_{WWT}Cov(X_{WWT}, X_{FW12I}) + b_{LW12I}Cov(X_{LW12I}, X_{FW12I}) \\
&+b_{LW12PHS}Cov(X_{LW12PHS}, X_{FW12I}) + b_{FW12I}Var(X_{FW12I}) + b_{FW12PHS}Cov(X_{FW12I}, X_{FW12PHS}) \\
&= 10.5Cov(G_{FW12I}, G_{NLB}) + 0.55Cov(G_{FW12I}, G_{LW8}) + 3.0Cov(G_{FW12I}, G_{FW12})
\end{aligned}
$$

6) Paternal half sib fleece weight at 12 months equation.

$$
\begin{aligned}
&b_{NFS}Cov(X_{NFS}, X_{FW12PHS}) + b_{WWT}Cov(X_{WWT}, X_{FW12PHS}) + b_{LW12I}Cov(X_{LW12I}, X_{FW12PHS}) \\
&+b_{LW12PHS}Cov(X_{LW12PHS}, X_{FW12PHS}) + b_{FW12I}Cov(X_{FW12I}, X_{FW12PHS}) + b_{FW12PHS}Var(X_{FW12PHS}) \\
&= 10.5Cov(G_{FW12PHS}, G_{NLB}) + 0.55Cov(G_{FW12PHS}, G_{LW8}) + 3.0Cov(G_{FW12PHS}, G_{FW12})
\end{aligned}
$$

3.2. Selection differential calculations.

Table 1. Selection differential calculations for a flock size of 1000 ewes

Percent of breeding flock	Number of hogget ewes needed	Number of hoggets available	Proportion selected	Selection differential
22	220	500	0.44	0.896 = (0.25/220) = 0.895
25	250	500	0.5	0.798 - (0.25/250) = 0.797
30	300	500	0.6	0.644 - (0.25/300) = 0.643

Table 2. Selection differential calculations for a flock size of 2000 ewes

Percent of breeding flock	Number of hogget ewes needed	Number of hoggets available	Proportion selected	Selection differential
22	440	1000	0.44	0.896 = (0.25/440) = 0.895
25	500	1000	0.5	0.798 - (0.25/500) = 0.798
30	600	1000	0.6	0.644

Table 3. Selection differential calculation for a flock size of 5000 ewes

Percent of breeding flock	Number of hogget ewes needed	Number of hoggets available	Proportion selected	Selection differential
22	1100	500	0.44	0.896
25	1250	500	0.5	0.798
30	1500	500	0.6	0.644

Table 4. Selection differentials for rams.

Flock size (number of ewes)	Number of ram hoggets	Number of rams selected per year	Proportion of ram hoggets selected per year	Selection differential
1000	500	5	0.01	2.660 - (0.25/5) = 2.61
2000	1000	10	0.01	2.660 - (0.25/10) = 2.64
5000	2500	25	0.01	2.660 - (0.25/25) = 2.65

Appendix IV.

Results tables of the phenotypic measurements for the 4 crosses of the 23 ram types and 10 traits: Weaning Percentage - NLW

Hogget Weaning Percentage - HNLW
Birth Weight - B.WT
Weaning Weight - W.WT
Slaughter Weight - S.WT
Hogget Weight - H.WT
Ewe Weight - E.WT
Hogget Fleece Weight - H.FW
Ewe Fleece Weight - E.FW
Average Fibre Diameter - FD

LAMBING PERCENTAGE AT WEANING					
SIRE	**PROGENY**	**HETEROSIS**	**NLB**	**STW (%)**	**Weaning %**
1 - R	R	0%	1.18	0.85	**100%**
	R	0%	1.29	0.85	**110%**
	R	0%	1.35	0.85	**114%**
	R	0%	1.37	0.85	**117%**
2 - F	1/2R 1/2F	5%	1.18	0.80	**100%**
	1/4R 3/4F	12%	1.97	0.78	**171%**
	1/8R 7/8F	6%	2.36	0.76	**191%**
	1/16R 15/16F	3%	2.55	0.76	**199%**
3 - 1/2R 1/2F	3/4R 1/4F	4%	1.18	0.83	**101%**
	5/8R 3/8F	8%	1.63	0.81	**143%**
	9/16R 7/16F	8%	1.85	0.81	**162%**
	17/32R 15/32F	8%	1.96	0.80	**171%**
4 - EF	1/2R 1/2EF	5%	1.18	0.85	**106%**
	1/4R 3/4EF	12%	1.74	0.85	**166%**
	1/8R 7/8EF	6%	2.02	0.85	**182%**
	1/16R 15/16EF	3%	2.16	0.85	**189%**
5 - 1/2R 1/2EF	3/4R 1/4EF	4%	1.18	0.85	**104%**
	5/8R 3/8EF	8%	1.52	0.85	**140%**
	9/16R 7/16EF	8%	1.68	0.85	**155%**
	17/32R 15/32EF	8%	1.77	0.85	**163%**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	4%	1.18	0.84	**103%**
	5/8R 3/16F 3/16EF	8%	1.57	0.83	**142%**
	9/16R 7/32F 7/32EF	8%	1.77	0.83	**159%**
	17/32R 15/64F 15/64EF	8%	1.86	0.83	**167%**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	7%	1.18	0.83	**104%**
	7/16R 3/8F 3/16EF	16%	1.74	0.81	**165%**
	11/32R 7/16F 7/32EF	16%	2.02	0.81	**190%**
	19/64R 15/32F 15/64EF	16%	2.16	0.80	**202%**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	4%	1.18	0.84	**103%**
	7/16R 3/16F 3/8EF	8%	1.68	0.83	**152%**
	11/32R 7/32F 7/16EF	7%	1.94	0.83	**172%**
	19/64R 15/64F 15/32EF	8%	2.06	0.83	**185%**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	7%	1.18	0.83	**104%**
	1/4R 3/8F 3/8EF	15%	1.85	0.81	**173%**
	1/8R 7/16F 7/16EF	12%	2.19	0.81	**197%**
	1/16R 15/32F 15/32EF	10%	2.36	0.80	**208%**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	4%	1.18	0.83	**102%**
	5/8R 9/32F 3/32EF	8%	1.60	0.82	**142%**
	9/16R 21/64F 7/64EF	7%	1.81	0.82	**159%**
	17/32R 45/128F 15/128EF	7%	1.91	0.81	**167%**
11 - 2/3R 1/3F	5/6R 1/6F	3%	1.18	0.83	**101%**
	3/4R 1/4F	6%	1.52	0.83	**132%**
	17/24R 7/24F	7%	1.68	0.82	**147%**
	11/16R 5/16F	7%	1.77	0.82	**155%**
12 - 2/3R 1/3EF	5/6R 1/6EF	3%	1.18	0.85	**103%**
	3/4R 1/4EF	6%	1.44	0.85	**130%**
	17/24R 7/24EF	7%	1.57	0.85	**142%**
	11/16R 5/16EF	7%	1.64	0.85	**149%**
13 - 1/3R 2/3F	2/3R 1/3F	4%	1.18	0.82	**101%**
	1/2R 1/2F	10%	1.74	0.80	**153%**
	5/12R 7/12F	9%	2.02	0.79	**174%**
	3/8R 5/8F	8%	2.16	0.79	**184%**

14 - 1/3R 2/3EF	2/3R 1/3EF	4%	1.18	0.85	**105%**
	1/2R 1/2EF	10%	1.59	0.85	**149%**
	5/12R 7/12EF	9%	1.80	0.85	**166%**
	3/8R 5/8EF	8%	1.90	0.85	**174%**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	3%	1.18	0.84	**102%**
	19/28R 3/14F 3/28EF	8%	1.55	0.83	**138%**
	35/56R 1/4F 7/56EF	9%	1.73	0.83	**155%**
	67/112R 15/56F 15/112EF	9%	1.82	0.82	**164%**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	3%	1.18	0.84	**103%**
	19/28R 3/28F 3/14EF	8%	1.52	0.84	**137%**
	35/36R 7/56 1/4EF	9%	1.68	0.84	**153%**
	67/112R 15/112F 15/56EF	9%	1.77	0.84	**161%**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	5%	1.18	0.82	**102%**
	13/28R 3/7F 3/28EF	11%	1.74	0.81	**156%**
	21/56R 1/2F 7/56EF	10%	2.02	0.80	**178%**
	37/112R 15/28F 15/112EF	10%	2.16	0.80	**189%**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	5%	1.18	0.84	**104%**
	13/28R 3/28F 3/7EF	11%	1.64	0.84	**153%**
	21/56R 7/56F 1/2EF	10%	1.88	0.84	**173%**
	37/112R 15/112F 15/28EF	10%	1.99	0.84	**183%**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	6%	1.18	0.82	**102%**
	5/14R 3/7F 3/14EF	13%	1.80	0.81	**165%**
	1/4R 1/2F 1/4EF	11%	2.12	0.80	**188%**
	11/56R 15/28F 15/56EF	10%	2.27	0.80	**200%**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	6%	1.18	0.84	**104%**
	5/14R 3/14F 3/7EF	13%	1.74	0.83	**163%**
	1/4R 1/4F 1/2EF	11%	2.02	0.83	**185%**
	11/56R 15/56F 15/28EF	9%	2.16	0.82	**194%**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	2%	1.18	0.84	**101%**
	13/16R 3/32F 3/32EF	5%	1.43	0.84	**126%**
	25/32R 7/64F 7/64EF	6%	1.56	0.84	**138%**
	49/64R 15/128F 15/128EF	6%	1.62	0.84	**144%**
22 - 3/4R 1/4F	7/8R 1/8F	2%	1.18	0.84	**101%**
	13/16R 3/16F	5%	1.46	0.83	**127%**
	25/32R 7/32F	5%	1.60	0.83	**139%**
	49/64R 15/64F	6%	1.67	0.83	**146%**
23 - 3/4R 1/4EF	7/8R 1/8EF	2%	1.18	0.85	**102%**
	13/16R 3/16EF	5%	1.40	0.85	**125%**
	25/32R 7/32EF	5%	1.51	0.85	**135%**
	49/64R 15/64EF	6%	1.57	0.85	**141%**

HOGGET LAMBING PERCENTAGE AT WEANING.					
SIRE	**PROGENY**	**HETEROSIS**	**NLB**	**STW (%)**	**Weaning %**
1 - R	R	0%	1.00	0.800	**80%**
	R	0%	1.15	0.800	**92%**
	R	0%	1.23	0.800	**98%**
	R	0%	1.26	0.800	**101%**
2 - F	1/2R 1/2F	5%	1.00	0.775	**82%**
	1/4R 3/4F	12%	1.70	0.763	**145%**
	1/8R 7/8F	6%	2.05	0.756	**164%**
	1/16R 15/16F	3%	2.23	0.753	**173%**
3 - 1/2R 1/2F	3/4R 1/4F	4%	1.00	0.788	**82%**
	5/8R 3/8F	8%	1.43	0.781	**121%**
	9/16R 7/16F	8%	1.64	0.778	**138%**
	17/32R 15/32F	8%	1.74	0.777	**147%**
4 - EF	1/2R 1/2EF	5%	1.00	0.825	**87%**
	1/4R 3/4EF	12%	1.50	0.838	**141%**
	1/8R 7/8EF	6%	1.75	0.844	**156%**
	1/16R 15/16EF	3%	1.88	0.847	**163%**
5 - 1/2R 1/2EF	3/4R 1/4EF	4%	1.00	0.813	**84%**
	5/8R 3/8EF	8%	1.33	0.819	**118%**
	9/16R 7/16EF	8%	1.49	0.822	**133%**
	17/32R 15/32EF	8%	1.57	0.823	**140%**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	4%	1.00	0.800	**83%**
	5/8R 3/16F 3/16EF	8%	1.38	0.800	**119%**
	9/16R 7/32F 7/32EF	8%	1.56	0.800	**136%**
	17/32R 15/64F 15/64EF	8%	1.66	0.800	**144%**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	7%	1.00	0.794	**85%**
	7/16R 3/8F 3/16EF	16%	1.51	0.791	**139%**
	11/32R 7/16F 7/32EF	16%	1.77	0.789	**162%**
	19/64R 15/32F 15/64EF	16%	1.90	0.788	**174%**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	4%	1.00	0.806	**84%**
	7/16R 3/16F 3/8EF	8%	1.46	0.809	**128%**
	11/32R 7/32F 7/16EF	7%	1.69	0.811	**148%**
	19/64R 15/64F 15/32EF	8%	1.81	0.812	**159%**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	7%	1.00	0.800	**85%**
	1/4R 3/8F 3/8EF	15%	1.60	0.800	**147%**
	1/8R 7/16F 7/16EF	12%	1.90	0.800	**170%**
	1/16R 15/32F 15/32EF	10%	2.05	0.800	**181%**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	4%	1.00	0.794	**82%**
	5/8R 9/32F 3/32EF	8%	1.40	0.791	**120%**
	9/16R 21/64F 7/64EF	7%	1.60	0.789	**136%**
	17/32R 45/128F 15/128EF	7%	1.70	0.788	**144%**
11 - 2/3R 1/3F	5/6R 1/6F	3%	1.00	0.792	**81%**
	3/4R 1/4F	6%	1.33	0.788	**111%**
	17/24R 7/24F	7%	1.50	0.785	**126%**
	11/16R 5/16F	7%	1.58	0.784	**133%**
12 - 2/3R 1/3EF	5/6R 1/6EF	3%	1.00	0.808	**83%**
	3/4R 1/4EF	6%	1.27	0.813	**109%**
	17/24R 7/24EF	7%	1.40	0.815	**122%**
	11/16R 5/16EF	7%	1.47	0.816	**128%**
13 - 1/3R 2/3F	2/3R 1/3F	4%	1.00	0.783	**82%**
	1/2R 1/2F	10%	1.52	0.775	**129%**
	5/12R 7/12F	9%	1.78	0.771	**149%**
	3/8R 5/8F	8%	1.90	0.769	**158%**

14 - 1/3R 2/3EF	2/3R 1/3EF	4%	1.00	0.817	**85%**
	1/2R 1/2EF	10%	1.38	0.825	**126%**
	5/12R 7/12EF	9%	1.58	0.829	**142%**
	3/8R 5/8EF	8%	1.67	0.831	**150%**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	3%	1.00	0.796	**82%**
	19/28R 3/14F 3/28EF	8%	1.36	0.795	**116%**
	35/56R 1/4F 7/56EF	9%	1.54	0.794	**132%**
	67/112R 15/56F 15/112EF	9%	1.63	0.793	**141%**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	3%	1.00	0.804	**83%**
	19/28R 3/28F 3/14EF	8%	1.33	0.805	**115%**
	35/36R 7/56 1/4EF	9%	1.49	0.806	**131%**
	67/112R 15/112F 15/56EF	9%	1.58	0.807	**138%**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	5%	1.00	0.789	**83%**
	13/28R 3/7F 3/28EF	11%	1.51	0.784	**132%**
	21/56R 1/2F 7/56EF	10%	1.77	0.781	**153%**
	37/112R 15/28F 15/112EF	10%	1.90	0.780	**163%**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	5%	1.00	0.811	**85%**
	13/28R 3/28F 3/7EF	11%	1.43	0.816	**130%**
	21/56R 7/56F 1/2EF	10%	1.64	0.819	**148%**
	37/112R 15/112F 15/28EF	10%	1.75	0.820	**158%**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	6%	1.00	0.793	**84%**
	5/14R 3/7F 3/14EF	13%	1.56	0.789	**140%**
	1/4R 1/2F 1/4EF	11%	1.85	0.788	**162%**
	11/56R 15/28F 15/56EF	10%	1.99	0.787	**173%**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	6%	1.00	0.807	**85%**
	5/14R 3/14F 3/7EF	13%	1.51	0.811	**138%**
	1/4R 1/4F 1/2EF	11%	1.76	0.813	**159%**
	11/56R 15/56F 15/28EF	9%	1.89	0.813	**168%**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	2%	1.00	0.800	**81%**
	13/16R 3/32F 3/32EF	5%	1.26	0.800	**106%**
	25/32R 7/64F 7/64EF	6%	1.39	0.800	**118%**
	49/64R 15/128F 15/128EF	6%	1.46	0.800	**124%**
22 - 3/4R 1/4F	7/8R 1/8F	2%	1.00	0.794	**81%**
	13/16R 3/16F	5%	1.29	0.791	**106%**
	25/32R 7/32F	5%	1.43	0.789	**119%**
	49/64R 15/64F	6%	1.50	0.788	**125%**
23 - 3/4R 1/4EF	7/8R 1/8EF	2%	1.00	0.806	**82%**
	13/16R 3/16EF	5%	1.24	0.809	**105%**
	25/32R 7/32EF	5%	1.36	0.811	**116%**
	49/64R 15/64EF	6%	1.42	0.812	**121%**

BIRTH WEIGHT				
SIRE	**PROGENY**	**HETEROSIS**	**Additive B.WT**	**B.WT (kg)**
1 - R	R	0%	4.00	**4.0**
	R	0%	4.00	**4.0**
	R	0%	4.00	**4.0**
	R	0%	4.00	**4.0**
2 - F	1/2R 1/2F	10%	3.50	**3.9**
	1/4R 3/4F	10%	3.25	**3.6**
	1/8R 7/8F	5%	3.13	**3.3**
	1/16R 15/16F	3%	3.06	**3.1**
3 - 1/2R 1/2F	3/4R 1/4F	7%	3.75	**4.0**
	5/8R 3/8F	10%	3.63	**4.0**
	9/16R 7/16F	10%	3.56	**3.9**
	17/32R 15/32F	10%	3.53	**3.9**
4 - EF	1/2R 1/2EF	10%	4.50	**5.0**
	1/4R 3/4EF	10%	4.75	**5.2**
	1/8R 7/8EF	5%	4.88	**5.1**
	1/16R 15/16EF	3%	4.94	**5.1**
5 - 1/2R 1/2EF	3/4R 1/4EF	7%	4.25	**4.6**
	5/8R 3/8EF	10%	4.38	**4.8**
	9/16R 7/16EF	10%	4.44	**4.9**
	17/32R 15/32EF	10%	4.47	**4.9**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	7%	4.00	**4.3**
	5/8R 3/16F 3/16EF	10%	4.00	**4.4**
	9/16R 7/32F 7/32EF	10%	4.00	**4.4**
	17/32R 15/64F 15/64EF	10%	4.00	**4.4**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	12%	3.88	**4.3**
	7/16R 3/8F 3/16EF	18%	3.81	**4.5**
	11/32R 7/16F 7/32EF	18%	3.78	**4.5**
	19/64R 15/32F 15/64EF	18%	3.77	**4.4**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	7%	4.13	**4.4**
	7/16R 3/16F 3/8EF	10%	4.19	**4.6**
	11/32R 7/32F 7/16EF	10%	4.22	**4.6**
	19/64R 15/64F 15/32EF	10%	4.23	**4.6**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	12%	4.00	**4.5**
	1/4R 3/8F 3/8EF	15%	4.00	**4.6**
	1/8R 7/16F 7/16EF	12%	4.00	**4.5**
	1/16R 15/32F 15/32EF	11%	4.00	**4.4**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	7%	3.88	**4.1**
	5/8R 9/32F 3/32EF	9%	3.81	**4.2**
	9/16R 21/64F 7/64EF	8%	3.78	**4.1**
	17/32R 45/128F 15/128EF	8%	3.77	**4.1**
11 - 2/3R 1/3F	5/6R 1/6F	5%	3.83	**4.0**
	3/4R 1/4F	7%	3.75	**4.0**
	17/24R 7/24F	8%	3.71	**4.0**
	11/16R 5/16F	8%	3.69	**4.0**
12 - 2/3R 1/3EF	5/6R 1/6EF	5%	4.17	**4.4**
	3/4R 1/4EF	7%	4.25	**4.5**
	17/24R 7/24EF	8%	4.29	**4.6**
	11/16R 5/16EF	8%	4.31	**4.7**
13 - 1/3R 2/3F	2/3R 1/3F	8%	3.67	**4.0**
	1/2R 1/2F	11%	3.50	**3.9**
	5/12R 7/12F	9%	3.42	**3.7**
	3/8R 5/8F	9%	3.38	**3.7**

14 - 1/3R 2/3EF	2/3R 1/3EF	8%	4.33	**4.7**
	1/2R 1/2EF	11%	4.50	**5.0**
	5/12R 7/12EF	9%	4.58	**5.0**
	3/8R 5/8EF	9%	4.63	**5.0**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	6%	3.93	**4.2**
	19/28R 3/14F 3/28EF	9%	3.89	**4.2**
	35/56R 1/4F 7/56EF	10%	3.88	**4.3**
	67/112R 15/56F 15/112EF	10%	3.87	**4.3**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	6%	4.07	**4.3**
	19/28R 3/28F 3/14EF	9%	4.11	**4.5**
	35/36R 7/56 1/4EF	10%	4.13	**4.5**
	67/112R 15/112F 15/56EF	10%	4.13	**4.6**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	9%	3.79	**4.1**
	13/28R 3/7F 3/28EF	12%	3.68	**4.1**
	21/56R 1/2F 7/56EF	11%	3.63	**4.0**
	37/112R 15/28F 15/112EF	11%	3.60	**4.0**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	9%	4.21	**4.6**
	13/28R 3/28F 3/7EF	12%	4.32	**4.8**
	21/56R 7/56F 1/2EF	11%	4.38	**4.9**
	37/112R 15/112F 15/28EF	11%	4.40	**4.9**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	10%	3.86	**4.3**
	5/14R 3/7F 3/14EF	14%	3.79	**4.3**
	1/4R 1/2F 1/4EF	12%	3.75	**4.2**
	11/56R 15/28F 15/56EF	11%	3.73	**4.2**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	10%	4.14	**4.6**
	5/14R 3/14F 3/7EF	14%	4.21	**4.8**
	1/4R 1/4F 1/2EF	12%	4.25	**4.8**
	11/56R 15/56F 15/28EF	11%	4.27	**4.7**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	3%	4.00	**4.1**
	13/16R 3/32F 3/32EF	5%	4.00	**4.2**
	25/32R 7/64F 7/64EF	6%	4.00	**4.3**
	49/64R 15/128F 15/128EF	7%	4.00	**4.3**
22 - 3/4R 1/4F	7/8R 1/8F	4%	3.88	**4.0**
	13/16R 3/16F	5%	3.81	**4.0**
	25/32R 7/32F	6%	3.78	**4.0**
	49/64R 15/64F	6%	3.77	**4.0**
23 - 3/4R 1/4EF	7/8R 1/8EF	4%	4.13	**4.3**
	13/16R 3/16EF	5%	4.19	**4.4**
	25/32R 7/32EF	6%	4.22	**4.5**
	49/64R 15/64EF	6%	4.23	**4.5**

WEANING WEIGHT				
SIRE	**PROGENY**	**HETEROSIS**	**Additive W.WT**	**W.WT (kg)**
1 - R	R	0%	22.50	**22.5**
	R	0%	23.75	**23.8**
	R	0%	24.38	**24.4**
	R	0%	24.69	**24.7**
2 - F	1/2R 1/2F	15%	23.00	**26.5**
	1/4R 3/4F	23%	24.50	**30.0**
	1/8R 7/8F	11%	25.25	**28.0**
	1/16R 15/16F	5%	25.63	**27.0**
3 - 1/2R 1/2F	3/4R 1/4F	10%	22.75	**24.9**
	5/8R 3/8F	17%	24.13	**28.3**
	9/16R 7/16F	17%	24.81	**29.1**
	17/32R 15/32F	17%	25.16	**29.5**
4 - EF	1/2R 1/2EF	15%	27.50	**31.6**
	1/4R 3/4EF	23%	31.25	**38.3**
	1/8R 7/8EF	11%	33.13	**36.8**
	1/16R 15/16EF	5%	34.06	**35.9**
5 - 1/2R 1/2EF	3/4R 1/4EF	10%	25.00	**27.4**
	5/8R 3/8EF	17%	27.50	**32.3**
	9/16R 7/16EF	17%	28.75	**33.7**
	17/32R 15/32EF	17%	29.38	**34.5**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	10%	23.88	**26.2**
	5/8R 3/16F 3/16EF	17%	25.81	**30.3**
	9/16R 7/32F 7/32EF	17%	26.78	**31.4**
	17/32R 15/64F 15/64EF	17%	27.27	**32.0**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	17%	24.00	**28.2**
	7/16R 3/8F 3/16EF	34%	26.00	**34.8**
	11/32R 7/16F 7/32EF	34%	27.00	**36.1**
	19/64R 15/32F 15/64EF	34%	27.50	**36.8**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	10%	25.13	**27.5**
	7/16R 3/16F 3/8EF	17%	27.69	**32.5**
	11/32R 7/32F 7/16EF	17%	28.97	**34.0**
	19/64R 15/64F 15/32EF	17%	29.61	**34.7**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	17%	25.25	**29.6**
	1/4R 3/8F 3/8EF	29%	27.88	**36.1**
	1/8R 7/16F 7/16EF	23%	29.19	**36.0**
	1/16R 15/32F 15/32EF	20%	29.84	**35.9**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	9%	23.31	**25.5**
	5/8R 9/32F 3/32EF	16%	24.97	**29.0**
	9/16R 21/64F 7/64EF	15%	25.80	**29.7**
	17/32R 45/128F 15/128EF	14%	26.21	**30.0**
11 - 2/3R 1/3F	5/6R 1/6F	6%	22.67	**24.1**
	3/4R 1/4F	12%	24.00	**26.9**
	17/24R 7/24F	14%	24.67	**28.0**
	11/16R 5/16F	14%	25.00	**28.5**
12 - 2/3R 1/3EF	5/6R 1/6EF	6%	24.17	**25.7**
	3/4R 1/4EF	12%	26.25	**29.5**
	17/24R 7/24EF	14%	27.29	**31.0**
	11/16R 5/16EF	14%	27.81	**31.8**
13 - 1/3R 2/3F	2/3R 1/3F	11%	22.83	**25.5**
	1/2R 1/2F	20%	24.25	**29.1**
	5/12R 7/12F	17%	24.96	**29.3**
	3/8R 5/8F	16%	25.31	**29.4**

14 - 1/3R 2/3EF	2/3R 1/3EF	11%	25.83	**28.8**
	1/2R 1/2EF	20%	28.75	**34.5**
	5/12R 7/12EF	17%	30.21	**35.5**
	3/8R 5/8EF	16%	30.94	**35.9**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	8%	23.36	**25.3**
	19/28R 3/14F 3/28EF	16%	25.04	**29.0**
	35/56R 1/4F 7/56EF	18%	25.88	**30.4**
	67/112R 15/56F 15/112EF	18%	26.29	**31.1**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	8%	24.00	**26.0**
	19/28R 3/28F 3/14EF	16%	26.00	**30.1**
	35/36R 7/56 1/4EF	18%	27.00	**31.7**
	67/112R 15/112F 15/56EF	18%	27.50	**32.6**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	13%	23.50	**26.5**
	13/28R 3/7F 3/28EF	23%	25.25	**31.0**
	21/56R 1/2F 7/56EF	21%	26.13	**31.6**
	37/112R 15/28F 15/112EF	20%	26.56	**31.9**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	13%	25.43	**28.6**
	13/28R 3/28F 3/7EF	23%	28.14	**34.5**
	21/56R 7/56F 1/2EF	21%	29.50	**35.7**
	37/112R 15/112F 15/28EF	20%	30.18	**36.3**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	15%	24.21	**27.8**
	5/14R 3/7F 3/14EF	26%	26.32	**33.2**
	1/4R 1/2F 1/4EF	23%	27.38	**33.6**
	11/56R 15/28F 15/56EF	21%	27.90	**33.8**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	15%	25.50	**29.3**
	5/14R 3/14F 3/7EF	26%	28.25	**35.6**
	1/4R 1/4F 1/2EF	23%	29.63	**36.3**
	11/56R 15/56F 15/28EF	19%	30.31	**36.2**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	5%	23.19	**24.3**
	13/16R 3/32F 3/32EF	10%	24.78	**27.1**
	25/32R 7/64F 7/64EF	11%	25.58	**28.5**
	49/64R 15/128F 15/128EF	12%	25.98	**29.2**
22 - 3/4R 1/4F	7/8R 1/8F	5%	22.63	**23.7**
	13/16R 3/16F	9%	23.94	**26.2**
	25/32R 7/32F	11%	24.59	**27.3**
	49/64R 15/64F	12%	24.92	**27.8**
23 - 3/4R 1/4EF	7/8R 1/8EF	5%	23.75	**24.9**
	13/16R 3/16EF	9%	25.63	**28.0**
	25/32R 7/32EF	11%	26.56	**29.4**
	49/64R 15/64EF	12%	27.03	**30.2**

SLAUGHTER WEIGHT.

SIRE	PROGENY	HETEROSIS	Additive S.WT	S.WT (kg)
1 - R	R	0%	28.0	**28.0**
	R	0%	28.5	**28.5**
	R	0%	28.8	**28.8**
	R	0%	28.9	**28.9**
2 - F	1/2R 1/2F	25%	29.5	**36.9**
	1/4R 3/4F	18%	30.8	**36.3**
	1/8R 7/8F	9%	31.4	**34.2**
	1/16R 15/16F	4%	31.7	**33.1**
3 - 1/2R 1/2F	3/4R 1/4F	15%	28.8	**33.0**
	5/8R 3/8F	18%	29.6	**34.8**
	9/16R 7/16F	18%	30.1	**35.4**
	17/32R 15/32F	18%	30.3	**35.6**
4 - EF	1/2R 1/2EF	25%	31.0	**38.8**
	1/4R 3/4EF	18%	33.0	**39.0**
	1/8R 7/8EF	9%	34.0	**37.0**
	1/16R 15/16EF	4%	34.5	**36.0**
5 - 1/2R 1/2EF	3/4R 1/4EF	15%	29.5	**33.9**
	5/8R 3/8EF	18%	30.8	**36.2**
	9/16R 7/16EF	18%	31.4	**36.9**
	17/32R 15/32EF	18%	31.7	**37.3**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	15%	29.1	**33.4**
	5/8R 3/16F 3/16EF	18%	30.2	**35.5**
	9/16R 7/32F 7/32EF	18%	30.7	**36.1**
	17/32R 15/64F 15/64EF	18%	31.0	**36.4**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	28%	29.5	**37.6**
	7/16R 3/8F 3/16EF	34%	30.8	**41.2**
	11/32R 7/16F 7/32EF	34%	31.4	**42.0**
	19/64R 15/32F 15/64EF	34%	31.7	**42.4**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	15%	29.9	**34.3**
	7/16R 3/16F 3/8EF	18%	31.3	**36.8**
	11/32R 7/32F 7/16EF	18%	32.0	**37.7**
	19/64R 15/64F 15/32EF	18%	32.4	**38.1**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	28%	30.3	**38.6**
	1/4R 3/8F 3/8EF	27%	31.9	**40.5**
	1/8R 7/16F 7/16EF	22%	32.7	**40.0**
	1/16R 15/32F 15/32EF	20%	33.1	**39.7**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	14%	28.9	**33.1**
	5/8R 9/32F 3/32EF	16%	29.9	**34.7**
	9/16R 21/64F 7/64EF	15%	30.4	**35.0**
	17/32R 45/128F 15/128EF	15%	30.6	**35.1**
11 - 2/3R 1/3F	5/6R 1/6F	10%	28.5	**31.3**
	3/4R 1/4F	13%	29.3	**33.1**
	17/24R 7/24F	14%	29.6	**33.8**
	11/16R 5/16F	15%	29.8	**34.2**
12 - 2/3R 1/3EF	5/6R 1/6EF	10%	29.0	**31.8**
	3/4R 1/4EF	13%	30.0	**33.9**
	17/24R 7/24EF	14%	30.5	**34.8**
	11/16R 5/16EF	15%	30.8	**35.2**
13 - 1/3R 2/3F	2/3R 1/3F	18%	29.0	**34.3**
	1/2R 1/2F	19%	30.0	**35.8**
	5/12R 7/12F	17%	30.5	**35.7**
	3/8R 5/8F	16%	30.8	**35.7**

14 - 1/3R 2/3EF	2/3R 1/3EF	18%	30.0	**35.5**
	1/2R 1/2EF	19%	31.5	**37.6**
	5/12R 7/12EF	17%	32.3	**37.8**
	3/8R 5/8EF	16%	32.6	**37.9**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	13%	28.9	**32.5**
	19/28R 3/14F 3/28EF	17%	29.8	**34.8**
	35/56R 1/4F 7/56EF	18%	30.3	**35.8**
	67/112R 15/56F 15/112EF	19%	30.5	**36.2**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	13%	29.1	**32.7**
	19/28R 3/28F 3/14EF	17%	30.1	**35.2**
	35/36R 7/56 1/4EF	18%	30.6	**36.2**
	67/112R 15/112F 15/56EF	19%	30.9	**36.7**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	20%	29.3	**35.1**
	13/28R 3/7F 3/28EF	22%	30.4	**37.2**
	21/56R 1/2F 7/56EF	21%	31.0	**37.5**
	37/112R 15/28F 15/112EF	20%	31.3	**37.6**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	20%	29.9	**35.9**
	13/28R 3/28F 3/7EF	22%	31.4	**38.4**
	21/56R 7/56F 1/2EF	21%	32.1	**38.8**
	37/112R 15/112F 15/28EF	20%	32.5	**39.1**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	24%	29.7	**36.7**
	5/14R 3/7F 3/14EF	25%	31.1	**38.8**
	1/4R 1/2F 1/4EF	22%	31.8	**38.8**
	11/56R 15/28F 15/56EF	21%	32.1	**38.8**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	24%	30.1	**37.2**
	5/14R 3/14F 3/7EF	25%	31.7	**39.6**
	1/4R 1/4F 1/2EF	22%	32.5	**39.7**
	11/56R 15/56F 15/28EF	20%	32.9	**39.6**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	7%	28.6	**30.6**
	13/16R 3/32F 3/32EF	11%	29.3	**32.4**
	25/32R 7/64F 7/64EF	12%	29.7	**33.3**
	49/64R 15/128F 15/128EF	13%	29.9	**33.7**
22 - 3/4R 1/4F	7/8R 1/8F	7%	28.4	**30.4**
	13/16R 3/16F	10%	29.1	**32.0**
	25/32R 7/32F	11%	29.4	**32.8**
	49/64R 15/64F	12%	29.6	**33.1**
23 - 3/4R 1/4EF	7/8R 1/8EF	7%	28.8	**30.9**
	13/16R 3/16EF	10%	29.6	**32.7**
	25/32R 7/32EF	11%	30.1	**33.5**
	49/64R 15/64EF	12%	30.3	**33.9**

HOGGET LIVEWEIGHT.				
SIRE	PROGENY	HETEROSIS	Additive H.WT	H.WT (kg)
1 - R	R	0%	43.0	**43.0**
	R	0%	44.5	**44.5**
	R	0%	45.3	**45.3**
	R	0%	45.6	**45.6**
2 - F	1/2R 1/2F	18%	43.0	**50.7**
	1/4R 3/4F	14%	44.5	**50.9**
	1/8R 7/8F	7%	45.3	**48.5**
	1/16R 15/16F	4%	45.6	**47.2**
3 - 1/2R 1/2F	3/4R 1/4F	11%	43.0	**47.8**
	5/8R 3/8F	14%	44.5	**50.7**
	9/16R 7/16F	14%	45.3	**51.6**
	17/32R 15/32F	14%	45.6	**52.0**
4 - EF	1/2R 1/2EF	18%	52.5	**62.0**
	1/4R 3/4EF	14%	58.8	**67.2**
	1/8R 7/8EF	7%	61.9	**66.3**
	1/16R 15/16EF	4%	63.4	**65.7**
5 - 1/2R 1/2EF	3/4R 1/4EF	11%	47.8	**53.1**
	5/8R 3/8EF	14%	51.6	**58.8**
	9/16R 7/16EF	14%	53.6	**61.0**
	17/32R 15/32EF	14%	54.5	**62.1**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	11%	45.4	**50.4**
	5/8R 3/16F 3/16EF	14%	48.1	**54.8**
	9/16R 7/32F 7/32EF	14%	49.4	**56.3**
	17/32R 15/64F 15/64EF	14%	50.1	**57.1**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	20%	45.4	**54.6**
	7/16R 3/8F 3/16EF	26%	48.1	**60.7**
	11/32R 7/16F 7/32EF	26%	49.4	**62.4**
	19/64R 15/32F 15/64EF	26%	50.1	**63.3**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	11%	47.8	**53.1**
	7/16R 3/16F 3/8EF	14%	51.6	**58.8**
	11/32R 7/32F 7/16EF	14%	53.6	**61.0**
	19/64R 15/64F 15/32EF	14%	54.5	**62.1**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	20%	47.8	**57.5**
	1/4R 3/8F 3/8EF	22%	51.6	**62.8**
	1/8R 7/16F 7/16EF	18%	53.6	**63.1**
	1/16R 15/32F 15/32EF	16%	54.5	**63.2**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	11%	44.2	**48.9**
	5/8R 9/32F 3/32EF	13%	46.3	**52.1**
	9/16R 21/64F 7/64EF	12%	47.3	**53.0**
	17/32R 45/128F 15/128EF	12%	47.9	**53.4**
11 - 2/3R 1/3F	5/6R 1/6F	7%	43.0	**46.2**
	3/4R 1/4F	10%	44.5	**49.1**
	17/24R 7/24F	11%	45.3	**50.3**
	11/16R 5/16F	11%	45.6	**50.9**
12 - 2/3R 1/3EF	5/6R 1/6EF	7%	46.2	**49.6**
	3/4R 1/4EF	10%	49.3	**54.3**
	17/24R 7/24EF	11%	50.8	**56.4**
	11/16R 5/16EF	11%	51.6	**57.5**
13 - 1/3R 2/3F	2/3R 1/3F	14%	43.0	**48.8**
	1/2R 1/2F	15%	44.5	**51.3**
	5/12R 7/12F	14%	45.3	**51.4**
	3/8R 5/8F	13%	45.6	**51.4**

14 - 1/3R 2/3EF	2/3R 1/3EF	14%	49.3	**56.0**
	1/2R 1/2EF	15%	54.0	**62.2**
	5/12R 7/12EF	14%	56.3	**64.0**
	3/8R 5/8EF	13%	57.5	**64.8**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	10%	44.4	**48.6**
	19/28R 3/14F 3/28EF	13%	46.5	**52.7**
	35/56R 1/4F 7/56EF	14%	47.6	**54.4**
	67/112R 15/56F 15/112EF	15%	48.2	**55.3**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	10%	45.7	**50.1**
	19/28R 3/28F 3/14EF	13%	48.6	**55.0**
	35/36R 7/56 1/4EF	14%	50.0	**57.2**
	67/112R 15/112F 15/56EF	15%	50.7	**58.2**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	15%	44.4	**50.9**
	13/28R 3/7F 3/28EF	18%	46.5	**54.7**
	21/56R 1/2F 7/56EF	16%	47.6	**55.5**
	37/112R 15/28F 15/112EF	16%	48.2	**55.8**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	15%	48.4	**55.6**
	13/28R 3/28F 3/7EF	18%	52.6	**61.9**
	21/56R 7/56F 1/2EF	16%	54.8	**63.8**
	37/112R 15/112F 15/28EF	16%	55.8	**64.7**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	17%	45.7	**53.7**
	5/14R 3/7F 3/14EF	20%	48.6	**58.1**
	1/4R 1/2F 1/4EF	18%	50.0	**58.8**
	11/56R 15/28F 15/56EF	16%	50.7	**59.1**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	17%	48.4	**56.9**
	5/14R 3/14F 3/7EF	20%	52.6	**63.0**
	1/4R 1/4F 1/2EF	18%	54.8	**64.4**
	11/56R 15/56F 15/28EF	16%	55.8	**64.7**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	5%	44.2	**46.6**
	13/16R 3/32F 3/32EF	8%	46.3	**50.1**
	25/32R 7/64F 7/64EF	9%	47.3	**51.7**
	49/64R 15/128F 15/128EF	10%	47.9	**52.6**
22 - 3/4R 1/4F	7/8R 1/8F	6%	43.0	**45.4**
	13/16R 3/16F	8%	44.5	**48.1**
	25/32R 7/32F	9%	45.3	**49.3**
	49/64R 15/64F	9%	45.6	**49.9**
23 - 3/4R 1/4EF	7/8R 1/8EF	6%	45.4	**47.9**
	13/16R 3/16EF	8%	48.1	**51.9**
	25/32R 7/32EF	9%	49.4	**53.8**
	49/64R 15/64EF	9%	50.1	**54.8**

EWE LIVEWEIGHT				
SIRE	**PROGENY**	**HETEROSIS**	**Additive E.WT**	**E.WT (kg)**
1 - R	R	0%	56.5	**56.5**
	R	0%	57.3	**57.3**
	R	0%	57.6	**57.6**
	R	0%	57.8	**57.8**
2 - F	1/2R 1/2F	18%	56.5	**66.7**
	1/4R 3/4F	14%	57.3	**65.5**
	1/8R 7/8F	7%	57.6	**61.7**
	1/16R 15/16F	4%	57.8	**59.9**
3 - 1/2R 1/2F	3/4R 1/4F	11%	56.5	**62.8**
	5/8R 3/8F	14%	57.3	**65.2**
	9/16R 7/16F	14%	57.6	**65.7**
	17/32R 15/32F	14%	57.8	**65.9**
4 - EF	1/2R 1/2EF	18%	67.5	**79.7**
	1/4R 3/4EF	14%	73.8	**84.4**
	1/8R 7/8EF	7%	76.9	**82.3**
	1/16R 15/16EF	4%	78.4	**81.2**
5 - 1/2R 1/2EF	3/4R 1/4EF	11%	62.0	**68.9**
	5/8R 3/8EF	14%	65.5	**74.6**
	9/16R 7/16EF	14%	67.3	**76.6**
	17/32R 15/32EF	14%	68.1	**77.6**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	11%	59.3	**65.9**
	5/8R 3/16F 3/16EF	14%	61.4	**69.9**
	9/16R 7/32F 7/32EF	14%	62.4	**71.2**
	17/32R 15/64F 15/64EF	14%	63.0	**71.8**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	20%	59.3	**71.3**
	7/16R 3/8F 3/16EF	26%	61.4	**77.6**
	11/32R 7/16F 7/32EF	26%	62.4	**78.9**
	19/64R 15/32F 15/64EF	26%	63.0	**79.6**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	11%	62.0	**68.9**
	7/16R 3/16F 3/8EF	14%	65.5	**74.6**
	11/32R 7/32F 7/16EF	14%	67.3	**76.6**
	19/64R 15/64F 15/32EF	14%	68.1	**77.6**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	20%	62.0	**74.6**
	1/4R 3/8F 3/8EF	22%	65.5	**79.6**
	1/8R 7/16F 7/16EF	18%	67.3	**79.2**
	1/16R 15/32F 15/32EF	16%	68.1	**78.9**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	11%	57.9	**64.1**
	5/8R 9/32F 3/32EF	13%	59.3	**66.8**
	9/16R 21/64F 7/64EF	12%	60.0	**67.2**
	17/32R 45/128F 15/128EF	12%	60.4	**67.4**
11 - 2/3R 1/3F	5/6R 1/6F	7%	56.5	**60.7**
	3/4R 1/4F	10%	57.3	**63.1**
	17/24R 7/24F	11%	57.6	**64.0**
	11/16R 5/16F	11%	57.8	**64.4**
12 - 2/3R 1/3EF	5/6R 1/6EF	7%	60.2	**64.6**
	3/4R 1/4EF	10%	62.8	**69.2**
	17/24R 7/24EF	11%	64.0	**71.1**
	11/16R 5/16EF	11%	64.7	**72.1**
13 - 1/3R 2/3F	2/3R 1/3F	14%	56.5	**64.1**
	1/2R 1/2F	15%	57.3	**65.9**
	5/12R 7/12F	14%	57.6	**65.4**
	3/8R 5/8F	13%	57.8	**65.2**

14 - 1/3R 2/3EF	2/3R 1/3EF	14%	63.8	**72.5**
	1/2R 1/2EF	15%	68.3	**78.6**
	5/12R 7/12EF	14%	70.5	**80.0**
	3/8R 5/8EF	13%	71.6	**80.7**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	10%	58.1	**63.6**
	19/28R 3/14F 3/28EF	13%	59.6	**67.5**
	35/56R 1/4F 7/56EF	14%	60.4	**69.0**
	67/112R 15/56F 15/112EF	15%	60.8	**69.8**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	10%	59.6	**65.3**
	19/28R 3/28F 3/14EF	13%	62.0	**70.2**
	35/36R 7/56 1/4EF	14%	63.1	**72.2**
	67/112R 15/112F 15/56EF	15%	63.7	**73.2**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	15%	58.1	**66.7**
	13/28R 3/7F 3/28EF	18%	59.6	**70.1**
	21/56R 1/2F 7/56EF	16%	60.4	**70.3**
	37/112R 15/28F 15/112EF	16%	60.8	**70.4**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	15%	62.8	**72.1**
	13/28R 3/28F 3/7EF	18%	66.7	**78.4**
	21/56R 7/56F 1/2EF	16%	68.6	**79.9**
	37/112R 15/112F 15/28EF	16%	69.6	**80.7**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	17%	59.6	**70.0**
	5/14R 3/7F 3/14EF	20%	62.0	**74.2**
	1/4R 1/2F 1/4EF	18%	63.1	**74.2**
	11/56R 15/28F 15/56EF	16%	63.7	**74.2**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	17%	62.8	**73.7**
	5/14R 3/14F 3/7EF	20%	66.7	**79.8**
	1/4R 1/4F 1/2EF	18%	68.6	**80.7**
	11/56R 15/56F 15/28EF	16%	69.6	**80.6**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	5%	57.9	**61.0**
	13/16R 3/32F 3/32EF	8%	59.3	**64.2**
	25/32R 7/64F 7/64EF	9%	60.0	**65.6**
	49/64R 15/128F 15/128EF	10%	60.4	**66.4**
22 - 3/4R 1/4F	7/8R 1/8F	6%	56.5	**59.6**
	13/16R 3/16F	8%	57.3	**61.8**
	25/32R 7/32F	9%	57.6	**62.8**
	49/64R 15/64F	9%	57.8	**63.2**
23 - 3/4R 1/4EF	7/8R 1/8EF	6%	59.3	**62.5**
	13/16R 3/16EF	8%	61.4	**66.3**
	25/32R 7/32EF	9%	62.4	**68.0**
	49/64R 15/64EF	9%	63.0	**68.9**

HOGGET FLEECE WEIGHT				
SIRE	**PROGENY**	**HETEROSIS**	**Additive H.FW**	**H.FW (kg)**
1 - R	R	0%	3.20	**3.2**
	R	0%	3.30	**3.3**
	R	0%	3.35	**3.4**
	R	0%	3.38	**3.4**
2 - F	1/2R 1/2F	18%	2.90	**3.4**
	1/4R 3/4F	20%	2.85	**3.4**
	1/8R 7/8F	10%	2.83	**3.1**
	1/16R 15/16F	5%	2.81	**2.9**
3 - 1/2R 1/2F	3/4R 1/4F	11%	3.05	**3.4**
	5/8R 3/8F	17%	3.08	**3.6**
	9/16R 7/16F	17%	3.09	**3.6**
	17/32R 15/32F	17%	3.09	**3.6**
4 - EF	1/2R 1/2EF	18%	3.35	**4.0**
	1/4R 3/4EF	20%	3.53	**4.2**
	1/8R 7/8EF	10%	3.61	**4.0**
	1/16R 15/16EF	5%	3.66	**3.8**
5 - 1/2R 1/2EF	3/4R 1/4EF	11%	3.28	**3.6**
	5/8R 3/8EF	17%	3.41	**4.0**
	9/16R 7/16EF	17%	3.48	**4.1**
	17/32R 15/32EF	17%	3.52	**4.1**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	11%	3.16	**3.5**
	5/8R 3/16F 3/16EF	17%	3.24	**3.8**
	9/16R 7/32F 7/32EF	17%	3.28	**3.8**
	17/32R 15/64F 15/64EF	17%	3.30	**3.9**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	20%	3.09	**3.7**
	7/16R 3/8F 3/16EF	32%	3.13	**4.1**
	11/32R 7/16F 7/32EF	32%	3.15	**4.2**
	19/64R 15/32F 15/64EF	32%	3.16	**4.2**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	11%	3.20	**3.6**
	7/16R 3/16F 3/8EF	17%	3.30	**3.9**
	11/32R 7/32F 7/16EF	17%	3.35	**3.9**
	19/64R 15/64F 15/32EF	17%	3.38	**3.9**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	20%	3.13	**3.8**
	1/4R 3/8F 3/8EF	27%	3.19	**4.1**
	1/8R 7/16F 7/16EF	22%	3.22	**3.9**
	1/16R 15/32F 15/32EF	19%	3.23	**3.9**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	11%	3.11	**3.4**
	5/8R 9/32F 3/32EF	15%	3.16	**3.6**
	9/16R 21/64F 7/64EF	14%	3.19	**3.6**
	17/32R 45/128F 15/128EF	14%	3.20	**3.6**
11 - 2/3R 1/3F	5/6R 1/6F	7%	3.10	**3.3**
	3/4R 1/4F	12%	3.15	**3.5**
	17/24R 7/24F	13%	3.18	**3.6**
	11/16R 5/16F	14%	3.19	**3.6**
12 - 2/3R 1/3EF	5/6R 1/6EF	7%	3.25	**3.5**
	3/4R 1/4EF	12%	3.38	**3.8**
	17/24R 7/24EF	13%	3.44	**3.9**
	11/16R 5/16EF	14%	3.47	**3.9**
13 - 1/3R 2/3F	2/3R 1/3F	14%	3.00	**3.4**
	1/2R 1/2F	19%	3.00	**3.6**
	5/12R 7/12F	17%	3.00	**3.5**
	3/8R 5/8F	15%	3.00	**3.5**

14 - 1/3R 2/3EF	2/3R 1/3EF	14%	3.30	**3.7**
	1/2R 1/2EF	19%	3.45	**4.1**
	5/12R 7/12EF	17%	3.53	**4.1**
	3/8R 5/8EF	15%	3.56	**4.1**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	10%	3.14	**3.4**
	19/28R 3/14F 3/28EF	16%	3.20	**3.7**
	35/56R 1/4F 7/56EF	17%	3.24	**3.8**
	67/112R 15/56F 15/112EF	18%	3.25	**3.8**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	10%	3.20	**3.5**
	19/28R 3/28F 3/14EF	16%	3.30	**3.8**
	35/36R 7/56 1/4EF	17%	3.35	**3.9**
	67/112R 15/112F 15/56EF	18%	3.38	**4.0**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	15%	3.05	**3.5**
	13/28R 3/7F 3/28EF	22%	3.08	**3.7**
	21/56R 1/2F 7/56EF	20%	3.09	**3.7**
	37/112R 15/28F 15/112EF	19%	3.09	**3.7**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	15%	3.24	**3.7**
	13/28R 3/28F 3/7EF	22%	3.36	**4.1**
	21/56R 7/56F 1/2EF	20%	3.43	**4.1**
	37/112R 15/112F 15/28EF	19%	3.46	**4.1**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	17%	3.07	**3.6**
	5/14R 3/7F 3/14EF	25%	3.11	**3.9**
	1/4R 1/2F 1/4EF	22%	3.13	**3.8**
	11/56R 15/28F 15/56EF	20%	3.13	**3.8**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	17%	3.20	**3.8**
	5/14R 3/14F 3/7EF	25%	3.30	**4.1**
	1/4R 1/4F 1/2EF	22%	3.35	**4.1**
	11/56R 15/56F 15/28EF	19%	3.38	**4.0**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	5%	3.18	**3.4**
	13/16R 3/32F 3/32EF	10%	3.27	**3.6**
	25/32R 7/64F 7/64EF	11%	3.32	**3.7**
	49/64R 15/128F 15/128EF	12%	3.34	**3.7**
22 - 3/4R 1/4F	7/8R 1/8F	6%	3.13	**3.3**
	13/16R 3/16F	9%	3.19	**3.5**
	25/32R 7/32F	11%	3.22	**3.6**
	49/64R 15/64F	11%	3.23	**3.6**
23 - 3/4R 1/4EF	7/8R 1/8EF	6%	3.24	**3.4**
	13/16R 3/16EF	9%	3.36	**3.7**
	25/32R 7/32EF	11%	3.42	**3.8**
	49/64R 15/64EF	11%	3.45	**3.8**

MA EWE FLEECE WEIGHT				
SIRE	PROGENY	HETEROSIS	Additive E.FW	E.FW (kg)
1 - R	R	0%	3.70	**3.7**
	R	0%	3.85	**3.9**
	R	0%	3.93	**3.9**
	R	0%	3.96	**4.0**
2 - F	1/2R 1/2F	17%	3.45	**4.0**
	1/4R 3/4F	14%	3.48	**4.0**
	1/8R 7/8F	7%	3.49	**3.7**
	1/16R 15/16F	3%	3.49	**3.6**
3 - 1/2R 1/2F	3/4R 1/4F	11%	3.58	**4.0**
	5/8R 3/8F	13%	3.66	**4.2**
	9/16R 7/16F	13%	3.71	**4.2**
	17/32R 15/32F	13%	3.73	**4.2**
4 - EF	1/2R 1/2EF	17%	3.95	**4.6**
	1/4R 3/4EF	14%	4.23	**4.8**
	1/8R 7/8EF	7%	4.36	**4.7**
	1/16R 15/16EF	3%	4.43	**4.6**
5 - 1/2R 1/2EF	3/4R 1/4EF	11%	3.83	**4.2**
	5/8R 3/8EF	13%	4.04	**4.6**
	9/16R 7/16EF	13%	4.14	**4.7**
	17/32R 15/32EF	13%	4.20	**4.8**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	11%	3.70	**4.1**
	5/8R 3/16F 3/16EF	13%	3.85	**4.4**
	9/16R 7/32F 7/32EF	13%	3.93	**4.5**
	17/32R 15/64F 15/64EF	13%	3.96	**4.5**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	19%	3.64	**4.3**
	7/16R 3/8F 3/16EF	25%	3.76	**4.7**
	11/32R 7/16F 7/32EF	25%	3.82	**4.8**
	19/64R 15/32F 15/64EF	25%	3.85	**4.8**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	11%	3.76	**4.2**
	7/16R 3/16F 3/8EF	13%	3.94	**4.5**
	11/32R 7/32F 7/16EF	13%	4.03	**4.6**
	19/64R 15/64F 15/32EF	13%	4.08	**4.6**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	19%	3.70	**4.4**
	1/4R 3/8F 3/8EF	21%	3.85	**4.6**
	1/8R 7/16F 7/16EF	17%	3.93	**4.6**
	1/16R 15/32F 15/32EF	15%	3.96	**4.6**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	10%	3.64	**4.0**
	5/8R 9/32F 3/32EF	12%	3.76	**4.2**
	9/16R 21/64F 7/64EF	12%	3.82	**4.3**
	17/32R 45/128F 15/128EF	11%	3.85	**4.3**
11 - 2/3R 1/3F	5/6R 1/6F	7%	3.62	**3.9**
	3/4R 1/4F	10%	3.73	**4.1**
	17/24R 7/24F	11%	3.78	**4.2**
	11/16R 5/16F	11%	3.81	**4.2**
12 - 2/3R 1/3EF	5/6R 1/6EF	7%	3.78	**4.1**
	3/4R 1/4EF	10%	3.98	**4.4**
	17/24R 7/24EF	11%	4.07	**4.5**
	11/16R 5/16EF	11%	4.12	**4.6**
13 - 1/3R 2/3F	2/3R 1/3F	13%	3.53	**4.0**
	1/2R 1/2F	15%	3.60	**4.1**
	5/12R 7/12F	13%	3.63	**4.1**
	3/8R 5/8F	12%	3.65	**4.1**

14 - 1/3R 2/3EF	2/3R 1/3EF	13%	3.87	**4.4**
	1/2R 1/2EF	15%	4.10	**4.7**
	5/12R 7/12EF	13%	4.22	**4.8**
	3/8R 5/8EF	12%	4.28	**4.8**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	9%	3.66	**4.0**
	19/28R 3/14F 3/28EF	13%	3.80	**4.3**
	35/56R 1/4F 7/56EF	14%	3.86	**4.4**
	67/112R 15/56F 15/112EF	14%	3.90	**4.5**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	9%	3.74	**4.1**
	19/28R 3/28F 3/14EF	13%	3.90	**4.4**
	35/36R 7/56 1/4EF	14%	3.99	**4.5**
	67/112R 15/112F 15/56EF	14%	4.03	**4.6**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	14%	3.59	**4.1**
	13/28R 3/7F 3/28EF	17%	3.69	**4.3**
	21/56R 1/2F 7/56EF	16%	3.74	**4.3**
	37/112R 15/28F 15/112EF	15%	3.76	**4.3**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	14%	3.81	**4.3**
	13/28R 3/28F 3/7EF	17%	4.01	**4.7**
	21/56R 7/56F 1/2EF	16%	4.11	**4.8**
	37/112R 15/112F 15/28EF	15%	4.16	**4.8**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	17%	3.63	**4.2**
	5/14R 3/7F 3/14EF	19%	3.74	**4.5**
	1/4R 1/2F 1/4EF	17%	3.80	**4.4**
	11/56R 15/28F 15/56EF	16%	3.83	**4.4**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	17%	3.77	**4.4**
	5/14R 3/14F 3/7EF	19%	3.96	**4.7**
	1/4R 1/4F 1/2EF	17%	4.05	**4.7**
	11/56R 15/56F 15/28EF	15%	4.10	**4.7**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	5%	3.70	**3.9**
	13/16R 3/32F 3/32EF	8%	3.85	**4.2**
	25/32R 7/64F 7/64EF	9%	3.93	**4.3**
	49/64R 15/128F 15/128EF	9%	3.96	**4.3**
22 - 3/4R 1/4F	7/8R 1/8F	5%	3.64	**3.8**
	13/16R 3/16F	8%	3.76	**4.0**
	25/32R 7/32F	9%	3.82	**4.1**
	49/64R 15/64F	9%	3.85	**4.2**
23 - 3/4R 1/4EF	7/8R 1/8EF	5%	3.76	**4.0**
	13/16R 3/16EF	8%	3.94	**4.2**
	25/32R 7/32EF	9%	4.03	**4.4**
	49/64R 15/64EF	9%	4.08	**4.4**

AVERAGE FIBRE DIAMETER.				
SIRE	**PROGENY**	**HETEROSIS**	**Additive FD**	**FD (um)**
1 - R	R	0%	34.5	**34.5**
	R	0%	34.3	**34.3**
	R	0%	34.1	**34.1**
	R	0%	34.1	**34.1**
2 - F	1/2R 1/2F	16%	31.5	**36.5**
	1/4R 3/4F	13%	29.8	**33.7**
	1/8R 7/8F	7%	28.9	**30.8**
	1/16R 15/16F	3%	28.4	**29.4**
3 - 1/2R 1/2F	3/4R 1/4F	10%	33.0	**36.4**
	5/8R 3/8F	13%	32.0	**36.1**
	9/16R 7/16F	13%	31.5	**35.6**
	17/32R 15/32F	13%	31.3	**35.3**
4 - EF	1/2R 1/2EF	16%	35.5	**41.2**
	1/4R 3/4EF	13%	35.8	**40.5**
	1/8R 7/8EF	7%	35.9	**38.2**
	1/16R 15/16EF	3%	35.9	**37.1**
5 - 1/2R 1/2EF	3/4R 1/4EF	10%	35.0	**38.6**
	5/8R 3/8EF	13%	35.0	**39.5**
	9/16R 7/16EF	13%	35.0	**39.5**
	17/32R 15/32EF	13%	35.0	**39.5**
6 - 1/2R 1/4F 1/4EF	3/4R 1/8F 1/8EF	10%	34.0	**37.5**
	5/8R 3/16F 3/16EF	13%	33.5	**37.8**
	9/16R 7/32F 7/32EF	13%	33.3	**37.5**
	17/32R 15/64F 15/64EF	13%	33.1	**37.4**
7 - 1/4R 1/2F 1/4EF	5/8R 1/4F 1/8EF	18%	33.3	**39.3**
	7/16R 3/8F 3/16EF	24%	32.4	**40.2**
	11/32R 7/16F 7/32EF	24%	31.9	**39.7**
	19/64R 15/32F 15/64EF	24%	31.7	**39.4**
8 - 1/4R 1/4F 1/2EF	5/8R 1/8F 1/4EF	10%	34.3	**37.7**
	7/16R 3/16F 3/8EF	13%	33.9	**38.2**
	11/32R 7/32F 7/16EF	13%	33.7	**38.0**
	19/64R 15/64F 15/32EF	13%	33.6	**37.9**
9 - 1/2F 1/2EF	1/2R 1/4F 1/4EF	18%	33.5	**39.6**
	1/4R 3/8F 3/8EF	20%	32.8	**39.3**
	1/8R 7/16F 7/16EF	16%	32.4	**37.7**
	1/16R 15/32F 15/32EF	15%	32.2	**36.9**
10 - 1/2R 3/8F 1/8EF	3/4R 3/16F 1/16EF	10%	33.5	**36.8**
	5/8R 9/32F 3/32EF	12%	32.8	**36.6**
	9/16R 21/64F 7/64EF	11%	32.4	**36.0**
	17/32R 45/128F 15/128EF	11%	32.2	**35.6**
11 - 2/3R 1/3F	5/6R 1/6F	7%	33.5	**35.8**
	3/4R 1/4F	9%	32.8	**35.8**
	17/24R 7/24F	10%	32.4	**35.7**
	11/16R 5/16F	11%	32.2	**35.6**
12 - 2/3R 1/3EF	5/6R 1/6EF	7%	34.8	**37.2**
	3/4R 1/4EF	9%	34.8	**38.0**
	17/24R 7/24EF	10%	34.7	**38.2**
	11/16R 5/16EF	11%	34.7	**38.4**
13 - 1/3R 2/3F	2/3R 1/3F	12%	32.5	**36.4**
	1/2R 1/2F	14%	31.3	**35.6**
	5/12R 7/12F	12%	30.6	**34.4**
	3/8R 5/8F	12%	30.3	**33.9**

14 - 1/3R 2/3EF	2/3R 1/3EF	12%	35.2	**39.4**
	1/2R 1/2EF	14%	35.3	**40.2**
	5/12R 7/12EF	12%	35.3	**39.7**
	3/8R 5/8EF	12%	35.3	**39.5**
15 - 4/7R 2/7F 1/7EF	11/14R 2/14F 1/14EF	9%	33.8	**36.7**
	19/28R 3/14F 3/28EF	12%	33.2	**37.2**
	35/56R 1/4F 7/56EF	13%	32.9	**37.2**
	67/112R 15/56F 15/112EF	14%	32.7	**37.2**
16 - 4/7R 1/7F 2/7EF	11/14R 1/14F 2/14EF	9%	34.4	**37.3**
	19/28R 3/28F 3/14EF	12%	34.0	**38.2**
	35/36R 7/56 1/4EF	13%	33.9	**38.3**
	67/112R 15/112F 15/56EF	14%	33.8	**38.4**
17 - 2/7R 4/7F 1/7EF	9/14R 2/7F 1/14EF	13%	32.9	**37.3**
	13/28R 3/7F 3/28EF	16%	31.9	**37.1**
	21/56R 1/2F 7/56EF	15%	31.4	**36.1**
	37/112R 15/28F 15/112EF	15%	31.1	**35.7**
18 - 2/7R 1/7F 4/7EF	9/14R 1/14F 2/7EF	13%	34.6	**39.3**
	13/28R 3/28F 3/7EF	16%	34.5	**40.0**
	21/56R 7/56F 1/2EF	15%	34.4	**39.6**
	37/112R 15/112F 15/28EF	15%	34.3	**39.4**
19 - 1/7R 4/7F 2/7EF	4/7R 2/7F 1/7EF	16%	33.1	**38.3**
	5/14R 3/7F 3/14EF	18%	32.1	**38.0**
	1/4R 1/2F 1/4EF	16%	31.6	**36.7**
	11/56R 15/28F 15/56EF	15%	31.4	**36.2**
20 - 1/7R 2/7F 4/7EF	4/7R 1/7F 2/7EF	16%	34.2	**39.6**
	5/14R 3/14F 3/7EF	18%	33.8	**40.0**
	1/4R 1/4F 1/2EF	16%	33.6	**39.1**
	11/56R 15/56F 15/28EF	15%	33.5	**38.4**
21 - 3/4R 1/8F 1/8EF	7/8R 1/16F 1/16EF	5%	34.3	**35.9**
	13/16R 3/32F 3/32EF	8%	33.9	**36.4**
	25/32R 7/64F 7/64EF	9%	33.7	**36.6**
	49/64R 15/128F 15/128EF	9%	33.6	**36.6**
22 - 3/4R 1/4F	7/8R 1/8F	5%	33.8	**35.5**
	13/16R 3/16F	7%	33.1	**35.6**
	25/32R 7/32F	8%	32.8	**35.5**
	49/64R 15/64F	9%	32.7	**35.5**
23 - 3/4R 1/4EF	7/8R 1/8EF	5%	34.8	**36.5**
	13/16R 3/16EF	7%	34.6	**37.2**
	25/32R 7/32EF	8%	34.6	**37.4**
	49/64R 15/64EF	9%	34.5	**37.5**

Appendix V

Results tables from the predicted changes in the average flock performances of the 8 ram types for :

- Total weaning weight of lambs
- Hogget ewe weight.
- MA ewe liveweight.
- Hogget fleece weight.
- MA ewe fleece weight.

Legend for Ram Option: Option 1 - Ram type 6 : 1/2R1/4F1/4EF
Option 2 - Ram type 7 : 1/4R1/2F1/4EF
Option 3 - Ram type 8 : 1/4R1/4F1/2EF
Option 4 - Ram type 19 : 1/7R4/7F2/7EF
Option 5 - Ram type 3 : 1/2R1/2F
Option 6 - Ram type 1 : R
Option 7 - Ram type 11 : 2/3R1/3F
Option 17 - Ram type 6 : 2/7R4/7F1/7EF

Change in average flock phenotypic performance from base year 0

	Change in total weight of lambs weaned (kg)	Change in average hogget liveweight (kg)	Change in average MA ewe liveweight (kg)	Change in average hogget fleeceweight (kg)	Change in average ewe fleeceweight (kg)
Base figures	**19.2**	**40**	**55**	**3**	**3.4**
Option 1a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	6.6	0.0	0.0	0.00	0.00
Year 2	9.6	10.4	0.0	0.52	0.00
Year 3	14.1	14.8	1.1	0.79	0.19
Year 4	19.4	16.3	2.8	0.83	0.44
Year 5	24.0	17.1	4.5	0.86	0.66
Option 1b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	6.6	0.0	0.0	0.00	0.00
Year 2	10.3	10.4	0.0	0.52	0.00
Year 3	16.0	14.8	1.5	0.79	0.25
Year 4	21.9	16.3	3.5	0.83	0.54
Year 5	26.8	17.1	5.4	0.86	0.80
Option 2a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	8.8	0.0	0.0	0.00	0.00
Year 2	13.9	14.6	0.0	0.72	0.00
Year 3	21.3	20.7	4.4	1.15	0.25
Year 4	30.2	22.4	10.3	1.17	0.59
Year 5	38.0	23.3	15.4	1.19	0.89
Option 2b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	8.8	0.0	0.0	0.00	0.00
Year 2	15.3	14.6	0.0	0.72	0.00
Year 3	24.8	20.7	5.8	1.15	0.34
Year 4	34.8	22.4	12.7	1.17	0.74
Year 5	43.1	23.3	18.5	1.19	1.07
Option 3a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	7.9	0.0	0.0	0.00	0.00
Year 2	11.8	13.1	0.0	0.56	0.00
Year 3	17.7	18.8	3.8	0.85	0.21
Year 4	24.7	21.0	8.9	0.91	0.48
Year 5	31.0	22.1	13.5	0.94	0.74
Option 3b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	7.9	0.0	0.0	0.00	0.00
Year 2	12.9	13.1	0.0	0.56	0.00
Year 3	20.3	18.8	5.0	0.85	0.27
Year 4	28.3	21.0	11.0	0.91	0.60
Year 5	35.0	22.1	16.3	0.94	0.89

Change in average flock phenotypic performance from base year 0

	Change in total weight of lambs weaned (kg)	Change in average hogget liveweight (kg)	Change in average MA ewe liveweight (kg)	Change in average hogget fleeceweight (kg)	Change in average ewe fleeceweight (kg)
Base figures	**19.2**	**40.0**	**55.0**	**3**	**3.4**
Option 4a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	8.2	0.0	0.0	0.00	0.00
Year 2	12.9	13.7	0.0	0.61	0.00
Year 3	19.7	18.1	4.0	0.87	0.22
Year 4	27.4	18.8	9.0	0.80	0.50
Year 5	34.1	19.1	13.0	0.76	0.71
Option 4b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	8.2	0.0	0.0	0.00	0.00
Year 2	14.2	13.7	0.0	0.61	0.00
Year 3	22.8	18.1	5.4	0.87	0.30
Year 4	31.4	18.8	11.1	0.80	0.61
Year 5	38.4	19.1	15.6	0.76	0.85
Option 5a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	5.0	0.0	0.0	0.00	0.00
Year 2	7.9	7.8	0.0	0.39	0.00
Year 3	12.2	10.7	2.1	0.59	0.15
Year 4	17.2	11.6	4.8	0.60	0.35
Year 5	21.6	12.0	7.0	0.61	0.52
Option 5b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	5.0	0.0	0.0	0.00	0.00
Year 2	8.6	7.8	0.0	0.39	0.00
Year 3	14.0	10.7	2.8	0.59	0.20
Year 4	19.7	11.6	5.9	0.60	0.43
Year 5	24.3	12.0	8.4	0.61	0.62
Option 6a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	2.4	0.0	0.0	0.00	0.00
Year 2	3.3	3.0	0.0	0.20	0.00
Year 3	4.4	4.5	0.4	0.30	0.08
Year 4	5.7	5.3	1.0	0.35	0.20
Year 5	6.8	5.6	1.6	0.38	0.31
Option 6b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	2.4	0.0	0.0	0.00	0.00
Year 2	3.3	3.0	0.0	0.20	0.00
Year 3	4.4	4.5	0.4	0.30	0.08
Year 4	5.7	5.3	1.0	0.35	0.20
Year 5	6.8	5.6	1.6	0.38	0.31

Change in average flock phenotypic performance from base year 0

	Change in total weight of lambs weaned (kg)	**Change in average hogget liveweight (kg)**	**Change in average MA ewe liveweight (kg)**	**Change in average hogget fleeceweight (kg)**	**Change in average ewe fleeceweight (kg)**
Base figures	**19.2**	**40.0**	**55.0**	**3**	**3.4**
Option 7a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	4.1	0.0	0.0	0.00	0.00
Year 2	6.3	6.2	0.0	0.33	0.00
Year 3	9.7	9.1	1.5	0.53	0.13
Year 4	13.6	10.3	3.6	0.59	0.31
Year 5	17.1	10.9	5.6	0.63	0.48
Option 7b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	4.1	0.0	0.0	0.00	0.00
Year 2	6.8	6.2	0.0	0.33	0.00
Year 3	11.0	9.1	2.0	0.53	0.17
Year 4	15.5	10.3	4.5	0.59	0.38
Year 5	19.1	10.9	6.8	0.63	0.58
Option 8a					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	6.6	0.0	0.0	0.00	0.00
Year 2	10.6	10.9	0.0	0.50	0.00
Year 3	16.3	14.7	3.1	0.74	0.19
Year 4	23.0	15.5	7.0	0.71	0.42
Year 5	28.7	15.8	10.2	0.69	0.62
Option 8b					
Year 0	0.0	0.0	0.0	0.00	0.00
Year 1	6.6	0.0	0.0	0.00	0.00
Year 2	11.6	10.9	0.0	0.50	0.00
Year 3	18.9	14.7	4.2	0.74	0.25
Year 4	26.3	15.5	8.7	0.71	0.53
Year 5	32.4	15.8	12.3	0.69	0.74

APPENDIX IV.

The ratio figures of Lamb and Wool production rates for the 8 selected rams types.

Legend for Ram Option: Option 1 - Ram type 6 : 1/2R1/4F1/4EF
Option 2 - Ram type 7 : 1/4R1/2F1/4EF
Option 3 - Ram type 8 : 1/4R1/4F1/2EF
Option 4 - Ram type 19 : 1/7R4/7F2/7EF
Option 5 - Ram type 3 : 1/2R1/2F
Option 6 - Ram type 1 : R
Option 7 - Ram type 11 : 2/3R1/3F
Option 17 - Ram type 6 : 2/7R4/7F1/7EF

RATIOS FOR KILOGRAMS OF LAMB PER KILOGRAM OF EWE LIVEWEIGHT

Ram type	1	11	6	3	7	8	17	19
YEAR 0	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
YEAR 1	0.39	0.42	0.47	0.44	0.51	0.49	0.47	0.50
YEAR 2								
Option A	0.41	0.46	0.52	0.49	0.60	0.56	0.54	0.58
Option B	0.41	0.47	0.54	0.50	0.63	0.58	0.56	0.61
YEAR 3								
Option A	0.43	0.51	0.59	0.55	0.68	0.63	0.61	0.66
Option B	0.43	0.53	0.62	0.57	0.72	0.66	0.64	0.69
YEAR 4								
Option A	0.44	0.56	0.67	0.61	0.76	0.69	0.68	0.73
Option B	0.44	0.58	0.70	0.64	0.80	0.72	0.71	0.76
YEAR 5								
Option A	0.46	0.60	0.73	0.66	0.81	0.73	0.73	0.78
Option B	0.46	0.62	0.76	0.69	0.85	0.76	0.77	0.82

RATIOS FOR GRAMS OF WOOL PER KILOGRAM OF EWE LIVEWEIGHT

Ram type	1	11	6	3	7	8	17	19
YEAR 0	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8
YEAR 1	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8
YEAR 2	61.8	61.8	61.8	61.8	61.8	61.8	61.8	61.8
YEAR 3								
Option A	62.8	62.4	63.9	62.2	61.5	61.4	61.7	61.4
Option B	62.8	62.6	64.5	62.3	61.4	61.2	61.7	61.2
YEAR 4								
Option A	64.3	63.2	66.4	62.7	61.2	60.8	61.6	60.9
Option B	64.3	63.5	67.4	62.9	61.1	60.6	61.6	60.7
YEAR 5								
Option A	65.7	64.0	68.4	63.2	60.9	60.4	61.6	60.5
Option B	65.7	64.4	69.6	63.4	60.8	60.2	61.6	60.2