ASPECTS OF SELECTION IN AN INTERBRED FLOCK BASED ON PERENDALES CROSSED WITH MERINO X ROMNEY EWES

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ABSTRACT

Genetic, phenotypic and environmental parameters were estimated from hogget traits recorded on 237 Perendale x (Merino x Romney) ewe hoggets between 1977 and 1984. Non-genetic effects on weaning weight (WW) for 634 ewe and ram lambs were analysed. A selection objective and criteria was defined and appraised for the flock.

The traits examined were hogget liveweight (HLW), greasy fleece weight (GFW), clean fleece weight (CFW), quality number (QN), character grade (CHG), handle grade (HG), cotting grade (CG), soundness grade (SG), greasy colour grade (GCG), scoured colour grade (SCG), staple length (SL), total crimp number (TCN), clean scoured yield (Y), mean fibre diameter (MFD) and crimps per centimetre (CPC).

The least squares method of fitting constants was used to estimate the major environmental factors influencing the traits studied. Heritabilities (h^2) were obtained by the daughter-dam regression (DDR) and daughter-dam correlation (DDC) methods. The genetic (r_G), phenotypic (r_P) and environmental (r_E) correlations were calculated by the daughter-dam method.

The estimates of environmental effects agree in most cases with the published estimates. Between year differences were important sources of variation and had a highly significant effect on all traits except SCG. Rearing rank effect was found to be the most important source of variation for WW and HLW. Age of dam and sex had a highly significant effect on WW. Neither rearing rank nor age of dam exerted any significant influence on wool traits.

The estimates of heritability calculated by daughter-dam regression method were: HLW (0.16), GFW (0.17), CFW (0.24), QN (0.42), CHG (0.38), SG (0.02), GCG (0.38), SCG (0.09), SL (0.12), TCN (0.08), Y (0.41) and MFD (0.29).

Genetic and phenotypic correlations calculated among some hogget traits were respectively: HLW x GFW (0.67 and 0.66); HLW x CFW (0.62 and 0.56); HLW x SL (0.79 and 0.44); HLW x MFD (-0.45 and 0.24); GFW x CFW (0.87 and 0.94); GFW x SL (0.37 and 0.60); GFW x MFD (-0.98 and 0.38); CFW x GCG (0.52 and 0.02); QN x MFD (-0.79 and -0.30); SG x MFD (0.73 and -0.21); GCG x SCG (0.87 and 0.38); GCG x Y (0.96 and 0.04) and SCG x Y (0.77 and 0.00).

Lifetime economic weights derived using the marginal profit method were calculated to define a selection objective for the flock studied. The traits included in the objective were number of lambs weaned (NLW (dam)), WW, CFW, MFD and SCG. Besides the traits in the objective, HLW, GFW, QN and GCG were included as selection criteria. The appropriate selection indices for ram hoggets (I_1), ewe hoggets (I_2) and lambs (I_3) were respectively:

$$I_1 = 4.66 \text{ NLW (dam)} + 0.62 \text{ HLW} + 0.10 \text{ WW} + 3.91 \text{ GFW} - 1.70 \text{ MFD} + 0.50 \text{ GCG}.$$

$$I_2 = 4.79 \text{ NLW (dam)} + 0.61 \text{ HLW} + 0.04 \text{ WW} + 1.99 \text{ GFW} + 0.23 \text{ QN} + 1.60 \text{ GCG}.$$

$$I_3 = 4.87 \text{ NLW (dam)} + 0.48 \text{ WW}.$$

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

Modern animal breeding involves considerable use of computers in the accumulation of pedigree and performance records and in the translation of these records into predictions of the genetic worth (breeding values) of the animals. The breeding values are frequently derived from records of several traits which have been collected from each animal.

In several countries, complex systems of sheep recording using large mainframe computers have been developed. The New Zealand National Flock Recording Scheme (Sheeplan) is an example. A difficulty with this approach is that sophisticated services are required and these can only be justified if the industry is highly developed and if there are many potential users. The rapid development of microcomputers is likely to allow the use of somewhat similar procedures in less sophisticated environments. However, the use of microcomputers in the estimation of breeding values for sheep is still in its infancy.

In planning sheep selection programmes it is necessary to choose appropriate selection objectives. This is normally done on the basis of the relative economic values of the various production traits (Rae, 1974; Wickham and McPherson, 1985). It is then necessary to decide which traits (selection criteria) should be considered when choosing which animals to retain.

Ideally selection decisions should be based on overall breeding values where, for each sheep, information on several traits is used to calculate a single number (selection index). Choice of the selection criteria and the importance given to each criterion, will depend on the economic values and the phenotypic, genetic and environmental parameters of the various traits (Hazel, 1943; Henderson, 1963).

The principle objective of the present study was to give the author experience in various aspects of sheep recording including the establishment of the data base, estimation of environmental and genetic parameters and relative economic values, construction of selection indices and choosing between alternative indices. Special emphasis was placed on using a microcomputer for recording and, wherever possible, analysis.

The data were provided by a small flock of interbred Perendale x (Merino x Romney) sheep (Merpers) on the Massey University Research Farm. This flock was maintained in order to investigate the establishment of an apparel-woolled strain of sheep based on this gene pool. An empirical selection objective had been devised and this aimed to improve lamb production, fleece weight, wool fineness, whiteness and resistance to foot-rot. However, at the onset of the present study the economic weights had not been carefully analysed, no genetic parameters were available for this genotype and no attempt had been made to derive an accurate selection index.

Having reviewed performance recording in sheep with particular attention to the potential of microcomputers, the study concentrated on the Merper data in order to:

(i) Estimate non-genetic effects which could be used to adjust data for differences induced by environmental factors such as birth rank.

(ii) Estimate heritabilities of productive traits and the genetic, phenotypic and environmental correlation between traits.

(iii) Estimate economic weights and use these to define potential selection objectives.

(iv) Derive likely selection indices from the economic weights and parameters assessed.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 SHEEP PERFORMANCE RECORDING

2.1.1 What is Performance Recording

AAABG (1979) defined recording as the collection of measurements and their organization into a form which enables the breeder to select the desirable animals and evaluate genetic change. Moreover, performance recording consists of obtaining, recording and processing (either at central location or on the farm) measurements of characteristics which contribute to productivity.

Owen (1971) stated that performance recording usually implies the measurement of traits that are considered important using unequivocal techniques that do not depend on the art of the skilled breeder in appreciating and integrating a number of rather ill-defined standards. However, Clarke (1967) argued that scoring systems based on hand and eye evaluation often have to be used for practicability and speed of operation. Dawes (1975) agrees with Owen and adds that by using objective methods it is possible, through capitalising on selection differential to obtain around 80% of the theoretical maximum genetic improvement for a single character, rather than the 30 to 40% obtained on visual appraisal in selecting the superior producing sheep.

Turner (1968) stressed that effective performance recording depends on:

(i) A clear definition of production, in a few terms as possible, both quality and quantity being considered.

(ii) Consideration of the environment and management under which the sheep are run.

(iii) Development of measurement techniques for traits recorded, together with facilities for making the measurements speedily and computing facilities.

(iv) Consideration of the effectiveness of selection, by estimation of phenotypic and genetic parameters for the production characteristics themselves, and others which may have to be taken into account.

(v) Decisions whether comparison within individual breeding flocks is sufficient, or whether performance testing stations are required to give comparisons between breeding flocks.

(vi) Proof that performance recording will lead to more rapid improvement in production than traditional methods of selection, and acceptance by sheepgrowers of performance recording standards when breeding animals are being acquired or distributed.

In the opinion of Turner and Young (1969) the first step in formulating a sheep breeding plan is to define its aims, and to seek increased productivity by concentrating on measured production itself, instead of trying to assess it through possibly related characteristics or wasting effort on unproductive aesthetic features.

Dalton and Callow (1976) on describing the aims of Sheeplan (New Zealand's National Flock Recording Scheme) to meet the specifications of an effective flock recording scheme pointed out the following requirements:

(i) The scheme must show genetic and financial gain.

(ii) The recording materials must be simple and clear.

(iii) The scheme must be backed by effective advice.

(iv) Rapid turn around of data is vital.

(v) Follow up advice is essential.

(vi) Records must be understood by ram buyers.

(vii) The scheme must be flexible. This feature was described by Daniell and Callow (1982) as very important as it allows breeders to choose the characters they wish to record and to get the output list they require (lambing summary, ewe summary, ewe summary cross reference, close ewe file, two tooth selection list or sire summary).

2.1.2 Objectives of Performance Recording

Turner (1968) expressed that the aim of performance recording is to increase the output of production per unit of input of materials and labour by ensuring more accurate selection of superior individuals which will not only maintain their superiority in their own lifetime but will leave superior progeny.

Owen (1971) summarizes the benefits of performance recording, particularly on an individual basis, as follows:

(i) From the point of view of the industry in the district or country, it gives an invaluable background of factual information by which current performance and in systems and techniques can be evaluated.

(ii) These records enable estimates to be made of the various genetic parameters that aid to adoption of efficient breeding schemes.

(iii) For the individual breeder, recording is valuable for day-to-day and longer term management decisions. For instance a rational culling policy, particularly for the breeding females, thus maintaining a higher level of output that would not otherwise be achieved.

Rae (1976) stated that a recording scheme which has as its objective the measurement or assessment of the traits of economic importance on individual animals and along with this, the processing and presentation of the records in a way which will assist in identifying genetically superior animals, is one of the main ingredients in a breeding plan.

Dalton and Callow (1976) stressed that Sheeplan as a recording scheme has the three following objectives:

(i) To allow ram breeders (both stud and commercial) to make more effective selection decisions which will then result in genetic improvement.

(ii) To allow buyers of rams (both stud and commercial) to see the ranking of animals within vendors' flocks and obtain value for money.

(iii) To help users define and solve management problems in their flocks.

Moreover, in the end, Sheeplan aims to help the stud breeder to help the commerical sheep farmer which, in turn, will benefit the nation.

Cunningham (1979) mentioned that the purpose of definition, measurement and recording in livestock improvement programs is to provide a quantified basis for rational decision-making. These decisions can be at the strategic level design of the program or optimization of investment. Decisions are also necessary at the operational or tactical level-selection of animals, individually or in groups.

On the other hand, Clarke (1967) pointed out that several factors may hinder immediate and important impact of performance recording on the level of production. They are:

(i) The increase in the national sheep number which means that the amount of selection in both rams and ewes is at a minimum.

(ii) In breeding, progress is measured from one generation to the next. Therefore, in sheep we would expect to see measurable progress after about three generations or about twelve years.

(iii) Apathy and possibly antipathy of breeders and farmers to accept a performance recording scheme. The sooner this can be overcome, the sooner will progress be made.

2.1.3 Types of Performance Recording

2.1.3.1 Sheep Management

According to Owen (1971) a simple form of recording is required for sheep management and it does not require any individual identification. It is used to assess the performance of a whole farm.

An example of this type of recording scheme is the one run in Great Britain by the Meat and Livestock Commission (MLC, 1972). According to Read (1974) the whole flock performance is recorded in terms of:

(i) MAKE-UP: Breeds and age structure.

(ii) MANAGEMENT: Tupping, wintering, lambing, grazing, lamb marketing.

(iii) INPUT: Feed, fertilizer, forages, medicines, replacement stock.

(iv) OUTPUT: Slaughter and breeding stock, wool, etc.

In this case records are both physical and financial. Records are analysed and returned promptly:

(i) AT TUPPING, bodyweight and condition of ewes by age and breed.

(ii) AT LAMBING, summary of winter feed usage, and cost summary of lambing performance of ewes by age and breed (including lamb mortality).

(iii) AT YEAR END, stock reconciliation, gross margin, financial analysis and a summary of key flock performance parameters.

2.1.3.2 Genetic Improvement

The New Zealand Flock Recording Scheme had as its main priority the genetic improvement of stud flocks (Dalton and Callow, 1976). The main characteristic in this type of recording is the permanent individual identification of the animals (Dalton, 1982).

2.1.3.3 Genetic and Management Improvement

Sheeplan could be cited as an example of a recording service which deals with genetic and management improvement (Dalton and Callow, 1976). This type of performance recording will be given emphasis hereafter.

2.1.4 Traits to be Recorded

AAABG (1979) reported that characters of the individual animals important in the breeding program can be divided into three areas:

(i) Traits which a breeder wishes to improve because they have an important effect on flock net income. These are called Breeding Objectives.

(ii) Those traits which a breeder will use to select replacement breeding stock. These are called Selection Criteria.

(iii) Those traits which a breeder wishes to monitor to ensure that they do not deteriorate. These could be called traits to be monitored.

A further subdivision of characters is the following: a) production, b) reproduction, and c) adaptation to the managerial and regional conditions in which the animals find themselves.

Dalton (1982) expressed the view that the success of performance recording in any flock depends on whether the trait to be recorded can be measured, whether it is of economic importance and whether it is heritable and will respond to selection. Ponzoni (1983) drew attention to the fact that it is desirable that characteristics used as a selection criteria should be genetically correlated with traits in the breeding objective.

Clarke (1967) stated that work in New Zealand and overseas clearly shows that the characters of economic importance in livestock respond to selection sufficiently rapidly to justify the inauguration of a recording scheme. Clarke's assertion is backed up by Morley (1951), Mullaney *et al.* (1970) and Turner (1977) who found moderate to high heritabilities for wool characteristics in Australian sheep. Dalton and Rae (1978) in reviewing the productive performance of the New Zealand Romney sheep suggested that hogget greasy fleece weight, staple length and quality number with medium to high heritability would respond to selection. The same will occur with staple crimps/cm, handle and hairiness which have high heritability. On the basis of a single estimate of the heritability of fibre diameter it would appear to be weakly inherited. Commenting on reproductive rate, Dalton and Rae mentioned that although it has low heritability, selection experiments show that substantial genetic improvement from within-flock selection can be achieved due to its large within flock variation. They highlighted the economic importance of reproductive rate. Elliott (1975) and Lewer (1978) working with New Zealand Perendale sheep and Blair *et al.* (1985) dealing with New Zealand Romney sheep also found high heritabilities for wool traits and that they will respond well to selection.

2.1.4.1 Traits Recorded

The next paragraphs are devoted to consideration of some individual traits which could be recorded.

(i) REPRODUCTION RATE

Reproduction rate determines the ability of a flock to maintain itself and leave a surplus for other uses (Turner, 1968). Moreover, it is defined as the number of lambs born (or weaned) by each ewe put to the ram. Dalton and Callow (1976) added that the lambing list is the basic input of Sheeplan, it records the basic fertility data of the flock and serves to establish the identity of all lambs born and records their pedigree. This could foresee the possibility of integrating breed societies and recording services (APC, 1983)

(ii) BODY WEIGHT

Liveweights of individual animals can be recorded at varying times such as weaning or later (Dalton and Callow, 1976). Turner (1968) suggested that body weights should be taken as selection criteria.

(iii) HOGGET FLEECE WEIGHT AND FLEECE CHARACTERISTICS

These traits are recorded to increase the value of wool production (Dalton and Callow, 1976).

Turner (1968) stated that wool weight per head remains the main criteria of selection for wool quantity, particularly with grazing sheep. Referring to wool quality, Turner suggested that average fibre diameter is by far the most important characteristic, followed by staple length. Owen (1971) added that where fine wool production is important a quality assessment is made on rams based mainly on percentage clean yield and fibre diameter assessed on a mid-side sample.

(iv) HEALTH AND MORTALITY RECORDS

Owen (1971) emphasised that many schemes include specific recording of illness and deaths, with the appropriate diagnosis if available. These records are mainly useful for management purposes, but may also have some genetic significance.

2.1.5 Implementation of Performance Recording

As it is of national interest the increase of sheep productivity, a government organization should take the leadership in running a performance recording scheme, at least at its inception. This can be perceived in the summary of performance recording in sheep from various countries done by Owen (1971) and also in the different papers presented at the International Sheep Breeding Congress held in Western Australia in 1976. Moreover, in some cases Universities or Breed Societies started their own selective registration scheme. Finally, stud breeders or commercial breeders who are the users of the outputs of performance recording should be the force which keep the service ongoing. Wallace (1974) called attention to the fact that flock recording services should be sensitive of user demands, which implies adequate user representation on the controlling body.

APC (1983) recommended that operational costs of central computer services should be met by the users and that the cost of an advisory service, which facilitates the collection and input of data and which advises on the use of the output, should be met by the Department of Agriculture of the State in which the flock is located.

In general, the whole sheep industry must fund the performance recording scheme.

2.2 USE OF MICROCOMPUTERS IN SHEEP BREEDING

2.2.1 Introduction

The recording system provides the information required for a breeding programme (Steine, 1982). The rapid expansion in use of electronic computers for data processing has eased the problem of dealing with a moderate amount of data from an individual farm or with a large volume of data emanating from centrally organized schemes.

Owen (1971) stated that mechanized computing can have three main advantages in sheep recording:

(i) Economy of storage space.

(ii) Speed of retrieval of items of information.

(iii) Quick processing of raw records into desired indices and summaries. This advantage is particularly important in sheep recording since many records are taken on specific occasions and need to be quickly processed and returned to the flockmaster for decision making with regard to selection.

Robinson *et al.* (1983) and Fox (1983), McGowan (1984) and Groeneveld (1985) dealing with beef cattle, dairy herds and pigs respectively have shown the effectiveness of microcomputers in recording and processing of data.

Fox (1983) expressed the view that microcomputers will increase in use and importance and will take over some of the functions performed with large computers. Further, their low cost and increasing capability make it possible for their direct use by livestock producers. The working party for the APC (1983) adds that the use of microcomputers can do both flock recording and performance recording.

The following sections discuss some relevant points about microcomputers.

2.2.2 Microcomputer Systems

Microcomputers are one broad category of computers, whereas mainframe computers and minicomputers are the two other categories.

A microcomputer can collect information, manipulate and store it, display the information in various forms (words, graphs, pictures, etc.) or create new information (Sistler, 1984). Furthermore, microcomputers perform a series of explicit instructions and can make the farmer's work, time and decision making more productive.

Sistler (1984) reviewed microcomputer systems. His comments form the basis of Sections 2.2.2 and 2.2.3 unless otherwise stated. He defined hardware as that part of the microcomputer and its accessories that can actually be touched - keyboard, central processor, printer, screen, etc.

Software consists of sets of instructions (computer programs) that tell the computer what to do and how to do it. The software should meet the needs the sheep farmer has identified, i.e. way of maintaining production records, how many sheep classes, how much and what kind of information needs to be recorded.

The three most popular types of computer programs for microcomputers are electronic spread sheets, data base management systems and word processors. The second will be given special emphasis in this section.

2.2.2.1 Data Base Management System (DBMS)

A Data Base Management System (DBMS) is a computer program, or set of programs, used to create, store, change, sort and display one or more sets of data. The data are composed of sets of entries called "records". The records are stored as a group in a file on a cassette tape, a floppy diskette or a hard disk.

Each record is made up of one or more parts called "fields". A field is a single piece of information within a record. Each record field is reserved for a particular type of information.

Separating a record into fields enables the sorting of them in different ways. Records are sorted by listing them in numerical or alphabetical order or by separating them into groups based upon some characteristic of one or more of the record fields.

Features to be considered in a Data Base Management System are:

(i) Maximum record length and maximum number of records in a file: The record length is the number of characters, including spaces, in a record. As it increases, the number of records allowed in a file decreases. Therefore, record lengths and file storage are closely related.

(ii) Maximum number of keyed and unkeyed fields: Record fields are either keyed or unkeyed. A keyed field is one that can be used for sorting and searching while the unkeyed field is one that cannot be used for sorting.

Record fields are separated into keyed and unkeyed fields because of data storage methods and program capacity. Due to the way the program stores the files, placing some of the information into unkeyed fields usually permits more records to be placed in a file and allows more information to be placed into each record.

(iii) Number of keys allowed in searching and sorting: Some systems allow multiple field sorting and searching. This allows the identification of very specific sets of data. The number of keys allowed in a search determine what kind of data sets can be identified.

(iv) Ability to add and delete fields after records have already been created: This ability is one of the most important features of any data base management program. It is quite possible that additional information may need to be added to a set of records in the future.

2.2.2.2 Basic Programming

BASIC is the main language used for programming microcomputers.

The main advantages of BASIC are that it is easy to learn, convenient to use, and particularly well suited to "conversational" programming in which the user interacts with the computer throughout the running of the program, (Mason, 1983).

Dwyer (1977) stated that a good extended BASIC allows both recursive functions and recursive subroutines which make it a powerful language. In addition BASIC excels in total efficiency, including the time of the programmer. Kember (1982) mentioned that input and output commands are more flexible but trickier to write in Fortran than in BASIC.

On the other hand, Mason (1983) cited as a major disadvantage of the simple version of BASIC its apparently commendable feature of rounding to integer values any numbers that are very close to integers.

2.2.3 Advantages and Disadvantages of Microcomputers

(i) ADVANTAGES OF THE MICROCOMPUTERS

(a) ACCESSIBILITY: The cheapness and easy location of the microcomputer on a desk and the ease of its use make it more accessible.

(b) FAST TURNAROUND TIME: The time between when a user gives the microcomputer a program to run and when he or she receives the result is shortened because the user does not have to wait for it to finish someone else's programs before it does his or hers. Moreover, programming mistakes can be found quickly and corrected and the program can be rerun right away.

(c) UP TO DATE STATISTICS: A microcomputer with sufficient memory, storage capacity, and the proper software can provide the current statistics or records in a farm whenever it is needed.

(d) INTEGRATION WITH OTHER COMPUTERS: McNicol *et al.* (1982) have demonstrated that a microcomputer-based system can be successfully integrated into an existing mainframe computing environment, and that the combined facilities provide a degree of power and flexibility which should satisfy most agricultural research applications.

(iii) DISADVANTAGES OF MICROCOMPUTERS

Although the microcomputer is a very versatile tool, it does have some disadvantages when compared with mainframe computers.

(a) SUPPORT: The microcomputer user loses the support structure of full-time operators and programmers necessary with a mainframe computer. When problems arise it may be difficult to find answers.

(b) EXPANSION CAPABILITY: The limited expansion capabilities of many microcomputers may become a hindrance when additional demands are planned on them.

(c) STORAGE: The microcomputer cannot handle very large data sets well. They do not have mass storage devices with enough capacity to store large data bases.

(d) SERVICE: Equipment repair and maintenance can be difficult with microcomputer systems. The cost of service contracts is often quite high in relation to the cost of equipment, and the equipment usually has to be returned to a service center for repair.

(e) DATA SHARING: It is harder to share data with other users when using a microcomputer. Every microcomputer has its own format for the disks and tapes.

(f) SPEED: Microcomputers are much slower than mainframe computers.

2.2.4 Use of Microcomputers in Sheep Performance Recording

Cullen (1982) reported on a programme package developed by Ruakura Biometrics Electronic Development Group for recording animal weights directly onto floppy disk storage. The package allows rapid access to any record and checking of data entered and files can be transmitted in either direction be an Apple or the ICL 293 via a PDP 11/34.

In the opinion of Parker (1983), the information storage capacity and the ability to sort numbers of the microcomputer made its use in the woolshed suitable for the fleece weighing/ culling operation that otherwise involves tedious manual recording and a large number of calculations. At the end of shearing the computer can provide a summary which includes, the number of sheep shorn, the number culled, overall range and average of the retained and culled fleece weights and a ranking of the best wool producers.

By linking electronic scales and microcomputers automatic recording systems can be developed (D. Garrick Pers. Comm.). The system at Massey University uses a highly portable Epson HX-20 which can take weaning weights of 900 animals in half a day or 600 to 700 fleece weights in a day and when the weighing has been completed the microcomputer can be connected to the mainframe for the immediate transfer of data. Moreover, the microcomputer can provide information on average liveweights, liveweight gains, number of animals present at recording, tag numbers of animals not present, weight distributions and individual means of groups that are being monitored.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 The Sheep and Their Environment

3.1.1.1 The Farm

The data investigated in the present study were collected from a flock run on the Massey University Sheep Unit "Pahiatua Block" located 0.8 km from the campus on the Aokautere Road.

The description of the "Pahiatua Block" has been reported by Blair (1981). It occupies 98 hectares and is intersected by two long deep gullies which account for about half the total area.

3.1.1.2 The Flock

The Merper Flock was derived crossing the female offspring of the superfine Merino rams x New Zealand Romney ewes (Mernies) with Perendale rams with subsequent interbreeding under closed flock circumstances.

The Merper has been developed as a dual purpose flock with emphasis on medium-to-fine wool production under North Island conditions.

The Mernies were originally established at the Whatawhata Hill Country Research Station situated 26 km west of Hamilton. Before the 1975 mating season the Mernies were transferred to Massey University where they were mated to

Perendale rams. The crossbred progeny were interbred from 1977 onward. By 1980 the whole flock became Merper.

The mating information for the Mernies and Merper flock for the years 1975 to 1984 is set out in Table 3.1.

3.1.1.3 Flock Recording and Selection

Lambing occurred between August and September. The ewes were not shepherded at lambing and no recording of lambing information took place until towards the completion when each ewe was identified with her lamb(s), the lambs were tagged and each lamb's sex and dam were recorded. Thus date of birth was not recorded and no records of lambs which did not survive until tagging were made so it was not possible to correct for lamb age of birth as a twin if the twin mate did not survive.

Lambs were weaned in December with the weaning weight being taken at this time, except for the year 1978 when lambs were not weighed. Immediately after weaning all lambs were shorn but lamb fleece weight was not completely recorded and not analyzed.

Hogget shearing took place in October with a wool growth period of nine to 10 months. Hogget greasy fleece weight included bellies and fleece skirtings.

Hogget liveweight was taken after shearing when hoggets were 13 to 14 months old.

A mid-side wool sample was collected from each fleece after shearing as it was thought to be representative of

TABLE 3.1: MATING INFORMATION FOR THE MERNIES AND MERPER FLOCK

		SIRES		DAMS		LAMBS		
YEAR	EWE "BREED"	BREED	NUMBER	YEAR OF BIRTH	NUMBER	RAM	EWE	TOTAL
1975	Mernies	Perendale	10	1972	33	13	12	25
				1973	46	14	13	27
1976	Mernies	Perendale	6	1972	30	16	17	33
				1973	42	23	21	44
1977	Mernies	Perendale	4	1972	29	13	9	22
				1973	36	12	20	32
	Merper*	Merper	1	1975	23	12	12	24
1978	Mernies	Perendale	1	1972	15	8	10	18
				1973	30	18	18	36
	Merper	Merper	1	1975	23	8	16	24
				1976	36	21	11	32
1979	Mernies	Perendale	8	1972	4	2	1	3
				1973	13	8	8	16
	Merper	Merper	2	1975	21	7	13	20
				1976	33	18	14	32
				1977	28	12	13	25
1980	Merper	Merper	2	1975	13	6	8	14
				1976	32	12	17	29
				1977	26	16	9	25
				1978	49	19	17	36
1981	Merper	Merper	2	1976	22	13	12	25
				1977	20	14	6	20
				1978	37	16	20	36
				1979	36	21	13	34
1982	Merper	Merper	2	1976	3	1	4	5
				1977	16	12	9	21
				1978	32	28	15	43
				1979	33	19	19	38
				1980	36	15	20	35
1983	Merper	Merper	2	1976	1	2	-	2
				1977	8	2	5	7
				1978	27	10	18	28
				1979	23	15	12	27
				1980	26	21	6	27
				1981	30	9	5	14
1984	Merper	Merper	2	1978	16	8	11	19
				1979	16	10	11	21
				1980	16	11	6	17
				1981	14	8	7	15
				1982	29	16	20	36
TOTAL			43		1003	509	478	987

* The data analyzed in this research pertain to the Merper mating.

the whole fleece (Turner *et al.* 1953; Turner, 1956).

About 70% of ram lambs were culled after weaning mainly on the basis of their dam's fertility. A few ewe lambs were also culled about this stage for serious fleece or body faults.

Lambing performance, greasy fleece weight and fine wool played an important role in ewe selection. For ram selection, the lamb production index based on their dam's records reported by Rae (1963) was considered. Rams were also selected for higher clean fleece weight and finer mean fibre diameter. At various stages through their lifetime sheep were culled for foot-rot.

3.1.2 The Data

Merper data were available from 1977 to 1984 inclusive under the peculiarities previously stated.

Originally weaning weight was included as a trait to be examined but finally the decision was to discard it as the 1978 data was missing and the daughter-dam pairs were reduced even more. However, the adjustment factors for 634 ewe and ram lambs were analyzed. Weaning weight (WW) was measured to the nearest 0.5 kg when the lambs were between 14 and 21 weeks.

In the calculation of the various parameters 237 ewe hogget records and 65 daughter-dam pairs were analyzed.

The different traits examined fall into two broad groups - Quantitative and Qualitative. The quantitative traits included hogget greasy and clean fleece weight (GFW, CFW), hogget post shearing liveweight (HLW), quality number (QN), staple length (SL), total crimp number and crimps per centimetre (TCN, CPC), clean scoured yield (Y) and mean fibre diameter (MFD). Qualitative traits included character grade (CHG), handle (HG), cotting (CG), soundness (SG), greasy and scoured colour grade (GCG, SCG).

Hogget greasy fleece weight (GFW) was recorded to the nearest 0.05 kg.

Hogget clean fleece weight (CFW) was calculated as:

$$CFW = \frac{GFW \times Y}{100}$$

where Y = clean scoured yield (see below)

Hogget post shearing liveweight (HLW) was measured to the nearest 0.5 kg.

Quality number (QN) was a visual assessment of the mid-side wool sample fineness, although it is commonly a bad indicator (Henderson, 1975). It was based chiefly on staple crimps per centimetre and lustre (Wickham, 1971). This subjective appraisal is described by Bradford quality numbers, where 56/58 is written as 57.

Staple length (SL) was measured to the nearest millimetre in an unstretched but flattened average selected greasy mid-side staple.

Total crimp number (TCN) was determined by counting the number of crimps along a mid-side greasy wool staple, whilst crimps per centimetre (CPC) was derived dividing TCN by SL.

Clean scoured yield (Y) was obtained after scouring the greasy mid-side samples. The samples were weighed after being conditioned in a humidity room for 48 hours at 20°C and 65% relative humidity. Scouring took place in a laboratory train of four bowls. The scouring liquor contained sodium bicarbonate in addition to the lissapol detergent. After the fourth bowl the scoured samples were put through a spin dryer and then dried at forced draught at 82°C in a drying oven before returning to the conditioned room for 48 hours to be reweighed, Elgabas and Wickham (unpublished).

Clean scoured yield (Y) was then calculated as:

$$Y = \frac{\text{weight of scoured sample} \times 100}{\text{weight of greasy sample}}$$

Mean fibre diameter (MFD) was measured by the airflow method (I.W.T.O., 1975). This technique can result in mean diameter estimates being biased downwards by the effect of medullation (Wickham, 1971); requires careful preparation of samples since the method is sensitive to fibre orientation, and it involves calibration from 'standard wools', a procedure which is not completely satisfactory (Downes, 1976).

All qualitative traits, character grade (CHG), handle (HG), cotting (CG), soundness (SG), greasy and scoured colour grade (GCG, SCG) were described by scores ranging from one (inferior) to nine (superior grade) according to the grading system stated by Sumner (1969).

3.2 STATISTICAL METHODS

3.2.1 Estimate of Non-Genetic Effects

The least squares method of fitting constants (Kempthorne, 1952) was used to estimate the major factors influencing weaning weight, ewe hogget live and fleece weight and ewe hogget wool traits.

Since Ch'ang and Rae (1961), Newman *et al.* (1983) and Rendel (1985) found that interactions controlled little variation, these were not included in the model.

The fixed effects model fitted to estimate the environmental effects for weaning weight was:

$$y_{ijk\ell m} = \mu + t_i + s_j + r_k + a_\ell + e_{ijk\ell m}$$

where

$y_{ijk\ell m}$ is the record of the m^{th} individual specified by the i^{th} year, j^{th} sex, k^{th} rearing rank and ℓ^{th} age of dam;

μ is the general mean;

t_i is the fixed effect of the i^{th} year of record ($i = 1, \ldots, 8$);

s_j is the fixed effect of the j^{th} sex ($j = 1, 2$ where 1 = ewe and 2 = ram);

r_k is the fixed effect of the k^{th} rearing rank ($k = 1, 2$ where 1 = single and 2 = twin);

a_ℓ is the fixed effect of the ℓ^{th} dam age (k = 1, 2, 3 where 1 is a two year old dam, 2 is a three year old dam and 3 is a four year old or older dam);

$e_{ijk\ell m}$ is the error peculiar to each $y_{ijk\ell m}$, it is assumed to be normally and independently distributed with a mean zero and with constant variance σ_e^2.

The effect of each i, j etc. class was calculated as the deviation from the mean of all i or j etc. classes; i.e. the estimates of all i effects summed to zero.

The rationale to separate dams into three age groups is that two year old ewes are handicapped when compared to mature ewes (Hazel and Terrill, 1946). It has also been found that the peak is reached at four years old (Holtman and Bernard, 1969) although Ch'ang and Rae (1961) found it at five years old and then diminishing with the increase in age while three years old is intermediate.

The fixed effects model fitted for hogget live and fleece weight and hogget wool traits was similar to that for weaning weight except that sex was omitted and the i^{th} year of record (i = 1, ..., 7).

The phenotypic records were adjusted to a common environmental influence by adding or subtracting the correction factor once the environmental estimates were obtained.

3.2.2 Estimate of Genetic, Phenotypic and Environmental Parameters

3.2.2.1 Introduction

The phenotypic variance partitioned into additive, dominance, epistatic interaction, genotype-environment interaction and temporary and permanent environmental variance components allows the derivation of variation between animals, for a particular trait, in a population.

The data used to obtain these parameters were those previously corrected for the major environmental factors.

3.2.2.2 Heritability

The method of regressing offspring on dam, ignoring sires, was used. Turner and Young (1969) stated that, with this technique between-sire components in the covariance analysis have zero expectation, so that the offspring on parent regression can be used under field conditions.

A ewe is mated several times during her life and twin offspring are expected. Since all suitable offspring were included in this analysis the measurement of the dam was repeated. Although Kempthorne and Tandon (1953) argued about the validity of using a female's record repeatedly, Bohren *et al.* (1961) and McKean and Bohren (1961) suggested that a serious loss of efficiency with this practice is unlikely to take place.

The parental and progeny sum of squares, the sum of cross products, the estimated variance of parental and progeny records and the estimated covariance between parent and progeny records were computed. The formula used for the estimation of heritability is that given by Turner and Young (1969)

$$h^2 = \frac{2\ \text{Cov (PaO)}}{\sigma_P^2}$$

where h^2 = heritability for a trait.

Cov (PaO) = covariance between parent and offspring record for the same trait.

σ_P^2 = variance of the parent record.

In this study the parent was the dam and the offspring were daughters.

The standard error (S.E) for heritability was computed by the formula given by Falconer (1981)

$$S.E = \sqrt{\frac{1}{N-2}\left[\frac{\sigma_y^2}{\sigma_x^2} - b^2\right]}$$

where N = Number of paired observations of parent and offspring

σ_y^2 = Variance of offspring

σ_x^2 = Variance of parent

b = The regression of y on x

Heritabilities were also estimated by the parent-offspring correlation method. That is, by doubling the phenotypic correlation between dam and daughter (Turner and Young, 1969) for the same trait.

$$h^2 = \frac{2 \text{ Cov (PaO)}}{\sqrt{\sigma^2_{Pa}\ \sigma^2_O}}$$

where Cov (PaO) = Covariance between parent and offspring record for the same trait

σ^2_{Pa} = Variance of the parent record

σ^2_O = Variance of the offspring record.

The confidence limits (P = 0.99) for the heritabilities estimated by the daughter-dam correlation were determined as detailed by Snedecor and Cochran (1982).

3.2.2.3 Genetic Correlation

The sum of parents and offspring records, the sum of cross products and the estimated covariances Pa_1O_2, Pa_2O_1, Pa_1O_1, Pa_2O_2 were computed. The formula used for the estimation of genetic correlations for all combinations of traits 1 and 2 is that proposed by Hazel (1943)

$$r_G = \frac{\text{Cov}(Pa_1O_2) + \text{Cov}(Pa_2O_1)}{2\sqrt{\text{Cov}(Pa_1O_1) \times \text{Cov}(Pa_2O_2)}}$$

where r_G = Genetic correlation

Pa_1 and Pa_2 = Refer to different traits observed in parents

O_1 and O_2 = Refer to different traits observed in offspring

Cov = Covariance

The standard error (S.E) of the genetic correlation was estimated following the formula given by Reeve (1955)

$$S.E = \sqrt{\frac{1}{n}\left[\frac{1}{2}(1 - r_G^2)^2 + \frac{2(1 - r_G^2)(1 - r_P^2)}{C^2} + 4\left(\frac{r_G}{D} - \frac{r_P}{C}\right)^2\right]}$$

where n = Number of parent-offspring pairs

$c = h_1 h_2$

$\frac{1}{D} = \frac{1}{2}\left(\frac{1}{h^2_1} + \frac{1}{h^2_2}\right)$

h^2 = Heritability

r_G = Genetic correlation

r_P = Phenotypic correlation

3.2.2.4 Phenotypic Correlation

The sum of cross products and sum of squares of two different traits P_1 and P_2 on the same animal, the variances of P_1 and P_2 and the covariance between P_1 and P_2 were computed to find the phenotypic correlations. The formula used is that given by Turner and Young (1969):

$$r_P = \frac{Cov\ (P_1 P_2)}{\sqrt{\sigma^2_{P_1}\ \sigma^2_{P_2}}}$$

where r_P = Phenotypic correlation

Cov = Covariance

$\sigma^2_{P_1}$ = Variance of P_1 (trait 1)

$\sigma^2_{P_2}$ = Variance of P_2 (trait 2)

The standard error was estimated using Fisher's (1946) "z" transformation, cited by Turner and Young (1969)

$$S.E = \frac{1 - r_P^2}{\sqrt{n - 1}}$$

where r_P = Phenotypic correlation

n = is the number of pairs

3.2.2.5 <u>Environmental Correlation</u>

In an effort to obtain some understanding of possible causes of the differences between the genetic and phenotypic correlations, the environmental correlations were calculated using the formula reported by Searle (1961):

$$r_E = (r_P - r_G\sqrt{h_1 h_2})/\sqrt{(1 - h_1)(1 - h_2)}$$

where r_E = Environmental correlation between two traits

r_P = Phenotypic correlation calculated by the daughter-dam regression method

r_G = Genotypic correlation calculated from the same data and method as r_P; and

h_1 and h_2 = the heritabilities of the two traits in the narrow sense.

Standard errors were not estimated for the environmental correlations.

CHAPTER FOUR

NON-GENETIC EFFECTS

4.1 INTRODUCTION

The value of a metric character is conditioned not only by the animal's genotype but also by the environment in which it is reared (Turner and Young, 1969).

It is possible by means of suitable statistical methods to obtain quantitative estimates of the various sources of variance to which an animal's phenotypic variance is classified. In cases where genotype and environment are not correlated, Turner and Young (1969) have described the phenotypic variance (σ^2_P) as:

$$\sigma^2_P = \sigma^2_A + \sigma^2_D + \sigma^2_{AA} + \sigma^2_{AD} + \sigma^2_{DD} + \sigma^2_{GE_p} + \sigma^2_{GE_t} + \sigma^2_{E_p} + \sigma^2_{E_t}$$

where σ^2_A is the additive variance component

σ^2_D is the dominance variance component

σ^2_{AA} is the additive x additive epistatic variance component

σ^2_{AD} is the additive x dominance epistatic variance component

σ^2_{DD} is the dominance x dominance epistatic variance component

$\sigma^2_{GE_p}$ is the genotype-permanent environment interaction variance component

$\sigma^2_{GE_t}$ is the genotype-temporary environment interaction variance component

$\sigma^2_{E_p}$ is the permanent environmental variance component

$\sigma^2_{E_t}$ is the temporary environmental variance component

The environmental contribution to the record of an individual is very complex, as an animal is exposed to different factors from the time of fertilization to the time when the character is measured.

Turner and Young (1969) have classified specific environmental factors influencing production characteristics in sheep into:

(i) EXTERNAL: Those affecting the mean value of production for the whole flock, though there may be minor interactions with individual sheep, e.g. regions, climate, management, seasonal differences from year to year on the same property. These factors influence genetic comparison of breeds, strains or flocks.

(ii) INTERNAL: Those which affect individuals but not the whole flock, e.g. sex, material effects (age of dam and type of birth or rearing), the animal's own age and previous reproductive status of a ewe. Inbreeding of the animal or its dam is also included in this group. These factors may influence estimates of heritability, repeatability or correlations.

In turn, Rae (1982), referring to traits such as fleece weight and number of lambs born (or reared) which can be measured from year to year on the same animal, considered it convenient to subdivide the environmental variation into two parts:

(i) PERMANENT ENVIRONMENTAL VARIATION: A part which is common to all of the records of the particular sheep but differs from sheep to sheep. For instance, liver damage due to facial eczema toxin, which may limit the fertility of a ewe over the rest of its lifetime or a depression in fleece weight as a result of a sheep being limited in size due to malnutrition early in its lifetime.

(ii) TEMPORARY ENVIRONMENTAL VARIATION: A part which is peculiar to the particular record of the individual sheep and differs from record to record of that individual, i.e. temporary reduction in fleece weight due to level of nutrition in the year the fleece is being grown.

Many of the differences in environment to which animals are subjected cannot be specified. Variation due to these factors cannot be separated from that due to errors of observation and measurement of the character concerned (Bowman, 1974).

Both internal or external, permanent or temporary environmental factors may mask genetic differences between individuals. Therefore, adjustment of production records for known environmental sources of variation prior to their use in estimating breeding values increases the accuracy of selection and culling procedures.

4.2 RESULTS AND DISCUSSION

The estimates of environmental effects expressed as deviations from the overall mean with their standard errors, and their standard deviations derived from the error mean square, for each trait, are presented in Table 4.1. The standard errors are relatively high in many cases.

The percentage of variation controlled by the main effects estimated as the sum of squares attributable to that factor divided by the total sum of squares, and the statistical significance of the main effects are set out in Table 4.2.

From Table 4.2, two points should be highlighted:

(i) Between year differences were important sources of variation and had a highly significant effect on all traits except scoured colour grade. While these are generally thought to be of nutritional, climatic or managemental origin they could also be due to varying standards of assessment from year to year.

(ii) Most of the variation appeared in the residual component. This can be further partitioned into between-animal differences of genetic origin and those

TABLE 4.1: LEAST SQUARES ESTIMATES AND STANDARD ERRORS OF THE ENVIRONMENTAL EFFECTS

FACTOR \ TRAIT	WW (KG)		HLW (KG)		GFW (KG)		CFW (KG)		QN		CHG	
General Mean	22.22 ± 0.15		34.77 ± 0.27		3.00 ± 0.03		2.25 ± 0.02		53.74 ± 0.20		5.57 ± 0.07	
Standard Deviation	3.13		3.48		0.37		0.30		2.59		0.90	
Year												
1977	1.26 ±	0.59	1.33 ±	1.02	0.26 ±	0.11	0.27 ±	0.09	-0.39 ±	0.76	0.66 ±	0.26
1978	n.r		-4.22	0.76	-0.33	0.08	-0.22	0.07	0.51	0.57	-0.03	0.20
1979	-0.57	0.34	4.65	0.57	0.31	0.06	0.14	0.06	0.41	0.42	-0.61	0.15
1980	-1.65	0.31	-0.12	0.54	-0.12	0.06	-0.09	0.05	-0.17	0.40	0.00	0.14
1981	2.50	0.29	-1.02	0.50	-0.23	0.05	-0.16	0.04	1.08	0.37	-0.48	0.13
1982	-0.07	0.27	0.89	0.51	0.16	0.05	0.11	0.04	-3.55	0.38	0.33	0.13
1983	-1.88	0.31	-1.50	0.62	-0.06	0.07	-0.04	0.06	2.12	0.46	0.13	0.16
1984	0.41	0.33	n.r		n.r		n.r		n.r		n.r	
Sex												
Ewe	-0.85	0.12	n.f		n.f		n.f		n.f		n.f	
Ram	0.85	0.12	n.f		n.f		n.f		n.f		n.f	
Rearing Rank												
Single	2.24	0.13	0.99	0.24	0.04	0.02	0.03	0.02	-0.00	0.18	-0.00	0.06
Twin	-2.24	0.13	-0.99	0.24	-0.04	0.02	-0.03	0.02	0.00	0.18	0.00	0.06
Age of Dam												
2 Year Old	-0.98	0.19	-0.34	0.35	-0.03	0.04	-0.04	0.03	-0.55	0.26	-0.20	0.09
3 Year Old	0.20	0.20	-0.36	0.35	0.01	0.04	-0.00	0.03	0.27	0.26	0.11	0.09
4+Year Old	0.78	0.18	0.70	0.34	0.02	0.04	0.04	0.03	0.28	0.25	0.09	0.09

n.r = no records for this year

n.f = not fitted in the model

TABLE 4.1: (CONTINUED)

FACTOR / TRAIT	HG		CG		SG		GCG		SCG	
General Mean	5.14 ± 0.09		6.22 ± 0.07		5.87 ± 0.10		4.94 ± 0.08		5.56 ± 0.07	
Standard Deviation	1.13		0.93		1.23		1.01		0.89	
Year										
1977	-0.46 ±	0.33	-0.36 ±	0.27	-0.38 ±	0.36	-0.59 ±	0.30	-0.14 ±	0.26
1978	0.42	0.25	0.47	0.20	0.66	0.27	0.40	0.22	0.25	0.20
1979	0.14	0.18	0.26	0.15	-0.38	0.20	0.38	0.16	0.04	0.16
1980	-0.07	0.17	-0.70	0.14	-0.25	0.19	-0.58	0.15	-0.18	0.14
1981	-0.22	0.16	-0.23	0.13	0.57	0.18	-0.01	0.15	0.02	0.13
1982	0.90	0.17	-0.08	0.14	-0.18	0.18	0.07	0.15	0.06	0.13
1983	-0.72	0.20	0.64	0.17	-0.04	0.22	0.33	0.18	-0.05	0.16
Rearing Rank										
Single	0.03	0.08	0.10	0.06	-0.12	0.08	-0.07	0.07	-0.06	0.06
Twin	-0.03	0.08	-0.10	0.06	0.12	0.08	0.07	0.07	0.06	0.06
Age of Dam										
2 Year Old	-0.11	0.11	0.06	0.09	0.01	0.12	-0.10	0.10	-0.06	0.09
3 Year Old	0.08	0.11	-0.06	0.09	0.01	0.12	0.02	0.10	-0.07	0.09
4+Year Old	0.03	0.11	0.00	0.08	-0.02	0.12	0.08	0.10	0.13	0.09

TABLE 4.1: (CONTINUED)

FACTOR / TRAIT	SL (cm)		TCN		Y (%)		MFD (microns)		CPC	
General Mean	10.44 ± 0.10		25.50 ± 0.38		74.93 ± 0.31		28.99 ± 0.17		2.48 ± 0.04	
Standard Deviation	1.28		4.90		3.92		2.17		0.57	
Year										
1977	0.22 ±	0.38	0.54 ±	1.44	2.15 ±	1.16	1.24 ±	0.64	-0.07 ±	0.17
1978	-0.46	0.28	-0.00	1.07	0.99	0.86	0.03	0.48	0.11	0.12
1979	1.37	0.21	2.34	0.80	-3.69	0.71	0.56	0.39	-0.08	0.09
1980	0.25	0.20	1.02	0.75	-0.32	0.60	0.57	0.33	0.06	0.09
1981	-1.20	0.18	0.38	0.71	0.78	0.57	-1.35	0.31	0.36	0.08
1982	0.26	0.19	-3.53	0.72	-0.27	0.58	-0.17	0.32	-0.41	0.08
1983	-0.44	0.23	-0.74	0.87	0.36	0.71	-0.88	0.39	0.03	0.10
Rearing Rank										
Single	-0.12	0.09	-0.03	0.33	0.00	0.27	-0.04	0.15	0.03	0.04
Twin	0.12	0.09	0.03	0.33	-0.00	0.27	0.04	0.15	-0.03	0.04
Age of Dam										
2 Year Old	0.02	0.13	-0.52	0.49	-0.43	0.40	0.26	0.22	-0.04	0.06
3 Year Old	0.05	0.13	0.43	0.50	-0.33	0.40	-0.27	0.22	0.03	0.06
4+Year Old	-0.07	0.12	0.09	0.47	0.76	0.39	0.01	0.21	0.01	0.06

TABLE 4.2: PERCENTAGE OF TOTAL VARIANCE AND SIGNIFICANCE OF THE ENVIRONMENTAL EFFECTS ON THE TRAITS ANALYZED

TRAIT	MAIN EFFECT							
	YEAR		SEX		REARING RANK		AGE OF DAM	
	%	SIGNIFICANCE	%	SIGNIFICANCE	%	SIGNIFICANCE	%	SIGNIFICANCE
WW	13	***	3	***	24	***	3	***
HLW	29	***		n.f	5	***	1	n.s
GFW	25	***		n.f	1	n.s	0	n.s
CFW	16	***		n.f	1	n.s	1	n.s
QN	35	***		n.f	0	n.s	1	n.s
CHG	14	***		n.f	0	n.s	2	n.s
HG	18	***		n.f	0	n.s	0	n.s
CG	17	***		n.f	1	n.s	0	n.s
SG	9	**		n.f	1	n.s	0	n.s
GCG	12	***		n.f	1	n.s	0	n.s
SCG	2	n.s		n.f	0	n.s	1	n.s
SL	29	***		n.f	1	n.s	0	n.s
TCN	13	***		n.f	0	n.s	1	n.s
Y	12	***		n.f	0	n.s	1	n.s
MFD	13	***		n.f	0	n.s	1	n.s
CPC	18	***		n.f	0	n.s	0	n.s

*** = 0.001 ≥ P

** = 0.01 ≥ P

n.s = not significant

n.f = not fitted in the model

of chance environmental origin together with observational and recording errors.

The results agree in most cases with the published estimates reported in Tables 4.3 and 4.4.

Year of observation was confounded with the year of birth. There was considerable variation in the effect of year of record on performance. There was a range of 4.32 kg (between 1981 and 1983) for WW; 8.87 kg (1979-1978) for HLW; 0.64 kg (1979-1978) for GFW; 0.49 kg (1977-1978) for CFW; 5.67 units (1983-1982) for QN; 1.27 grades (1977-1979) for CHG; 1.62 grades (1982-1983) for HG; 1.34 grades (1983-1980) for CG; 1.04 grades (1978-1977) for SG; 0.99 grades (1978-1977) for GCG: 0.43 grades (1978-1980) for SCG; 2.57 cm (1979-1981) for SL; 5.87 units (1979-1982) for TCN; 5.84% (1977-1979) for Y; 2.59 microns (1977-1981) for MFD and 0.77 units (1981-1982) for CPC.

These year of record effects, although significant, are specific to the flock and year in which they are taken, so that they cannot be generalized as correction factors.

Before dealing with the individual wool traits it should be stated that neither rearing rank nor age of dam exerted any significant influence on them. The rearing rank effect on wool traits was of the order of 0 to 1% while age of dam reached 2% for character grade.

4.2.1 Weaning Weight

The estimate of standard deviation for WW (3.13 kg) falls

TABLE 4.3: MEAN, STANDARD DEVIATION AND ADJUSTMENT FACTORS FOR WEANING AND HOGGET LIVEWEIGHT (KG)

BREED	MEAN	STANDARD DEVIATION	BIRTH-REARING RANK SINGLE-TWIN	DAM 4-2	AGE 4-3	SEX R-E	REFERENCE
WEANING WEIGHT							
Romney	24.1	3.5	4.5	1.5	0.8	2.3	Ch'ang and Rae (1961)[1]
	-	-	4.5	2.3	0.9	1.8	Clarke (1967)
	25.26	3.50	4.2	2.0	0.4	-	Ch'ang and Rae (1970)
	25.53	-	4.41	2.04	0.59	1.58	Lundie (1971)
	19.32	2.9	3.4	1.5	0.4	-	Hight and Jury (1971)
	20.4	3.2	4.2	1.3	0.2	1.9	Baker *et al.* (1974)
	-	-	4.2	1.3	0.2	-	Clarke and Rae (1976)
	21.4-27.0	2.8-3.7	4.2	1.3	0.3	2.1	Jury *et al.* (1979)[2]
	21.08	4.24	3.59	2.13	0.19	1.68	Tait (1983)
	22.3	2.61	3.77	0.52	-0.34	1.54	Newman *et al.* (1983)
	-	3.59	4.2	1.2	-0.2	3.6	Wewala (1984)
Perendale	22.8	3.0	4.2	1.44	0.53	-	Elliott (1975)[3]
	26.3	3.33	4.05	1.21	-1.03	1.85	Newman *et al.* (1983)
Merino	27.4	3.0	3.0	1.5	-	-	Young *et al.* (1965)[4]
	17.0	-	4.14	0.94	0.33	1.16	Ransom and Mullaney (1976)
HOGGET LIVEWEIGHT							
Romney	38.9	-	2.22	1.71	0.81	-	Tripathy (1966)[5]
	39.1	5.0	2.2	2.4	1.45	-	Ch'ang and Rae (1970)[5]
	35.1	3.7	0.09	-0.14	0.4	-	Hight and Jury (1971)
	43.2	4.7	2.1	1.3	0.4	10.8	Baker *et al.* (1974)
	-	-	2.2	2.4	1.0	-	Clarke and Rae (1976)
	30.68	4.23	1.05	-0.69[8]	-1.7[8]	-	Tait (1983)[5]
Perendale	37.3	3.9	2.12	0.98	0.35	-	Elliott (1975)[5]
Merino	32.44	-	1.63	0.98	1.09	-	Lax and Brown (1967)[6]
	48.58	-	2.09	1.18	0.42	15.35	Gregory and Ponzoni (1981)[7]

1 = Average of estimates from 2 flocks, over 9 years.

2 = Average of 12 flocks.

3 = Rearing rank only.

4 = Male lambs of pooled genetically distinct groups.

5 = Ewes only.

6 = Ewes and type of birth only.

7 = Type of birth only.

8 = Progeny of 4-year old ewes 1.0 kg lighter than progeny of 5-year old.

TABLE 4.4: MEAN, STANDARD DEVIATION AND ADJUSTMENT FACTORS FOR HOGGET WOOL TRAITS (KG)

BREED	TRAIT	MEAN	STANDARD DEVIATION	BIRTH-BEARING RANK SINGLE-TWIN	DAM AGE 4-2	DAM AGE 4-3	SEX R-E	REFERENCE
Romney	GFW	3.6	-	0.17	0.23	0.07	-	Tripathy (1966)
	GFW	3.3	-	0.21	0.22	0.04	-	Lundie (1971)[1]
	GFW	3.1	0.48	0.14	-0.04	0.02	-	Hight and Jury (1971)[2]
	GFW	3.9	0.5	0.1	0.0	0.0	-	Baker *et al.* (1974)
	GFW	-	-	0.26	-	-	-	Clarke and Rae (1976)
	GFW	1.86	0.54	0.02	-	-	-	Tait (1983)[1]
	QN	48.02	1.90	0.09	-	-	-	Tait (1983)
	CHG[3]	4.01	0.80	-0.05	-	-	-	Tait (1983)
	GCG[3]	4.03	0.66	0.01	-	-	-	Tait (1983)
	SL	14.14	-	0.41	-0.01	-0.12	-	Tripathy (1966)
	SL	10.99	1.89	-0.48	-	-	-	Tait (1983)
	MFD	35.81	-	0.11	0.31	-0.19	-	Tripathy (1966)
	CPI[4]	3.25	-	-0.24	0.07	0.05	-	Tripathy (1966)
Perendale	GFW	2.4	0.4	0.12	0.07	0.03	-	Elliott (1975)
	QN	52.24	1.9	0.20	0.09	0.02	-	Elliott (1975)
	CHG	5.03	1.12	-0.14	0.01	-0.02	-	Elliott (1975)
	SL	11.75	1.43	-0.20	0.00	0.02	-	Elliott (1975)
	MFD	30.98	2.22	-0.06	0.30	0.22	-	Elliott (1975)
Merino	GFW	4.11	-	0.23	0.21	0.12	-	Lax and Brown (1967)[5]
	GFW	6.01	-	0.39	0.16	0.07	1.06	Gregory and Ponzoni (1981)
	CFW	2.56	-	0.14	0.14	0.09		Lax and Brown (1967)
	CFW	3.80	-	0.18	0.06	0.03	0.48	Gregory and Ponzoni (1981)
	CHG[6]	3.80	-	-0.02	0.01	0.02	0.08	Gregory and Ponzoni (1981)
	SL	9.01	-	0.13	-0.04	-0.16		Lax and Brown (1967)
	SL	11.91	-	-0.05	0.00	0.00	0.17	Gregory and Ponzoni (1981)
	Y	63.69	-	-0.02	0.13	0.13	-	Lax and Brown (1967)
	Y	63.46	-	-0.51	-0.73	-0.19	-3.06	Gregory and Ponzoni (1981)
	MFD	21.55	-	-0.25	0.12	-0.10		Lax and Brown (1967)
	MFD	25.77	-	-0.29	0.28	0.12	0.62	Gregory and Ponzoni (1981)
	CPI	12.25	-	0.12	-0.38	-0.21		Lax and Brown (1967)

1 = Ewes only.
2 = Large standard errors and rearing rank only.
3 = Scores ranged from 1 to 5.
4 = Crimps per inch.
5 = Ewes and type of birth only.
6 = Scores ranged from 1 to 7.

among the range found by Jury *et al.* (1979) for Romneys, Elliott (1975) and Newman *et al.* (1983) for Perendales and Young *et al.* (1965) for Merinos.

In an analysis of a large amount of data from National Flock Recording Schemes, Clarke and Rae (1976) found that 40 to 45% of the total within flock variation in WW was controlled by environmental effects. Eikje (1971) and Jury *et al.* (1979) indicated that it ranged from one third to one half. Although the present study does not include date of birth of the lamb, 43% of total within flock variation is controlled by fixed environmental effects.

The present estimates of the effect of year to year variation are large as was found by Ch'ang and Rae (1970). This emphasises the necessity of expressing corrected weights as a deviation from the flock-year average in selective breeding programs.

Sex accounted for 3% of the total variance. At weaning ram lambs were 1.70 kg heavier than ewes. This is in agreement with most published estimates (see Table 4.3).

Sex adjustments are needed when assessing a dam's maternal performance or in progeny testing.

At weaning the rearing rank effect was found to be the most important source of variation (24%). This result is in line with Ch'ang and Rae (1961), Clarke (1967), Hight and Jury (1971), Jury *et al.* (1979), Baker *et al.* (1979) and Newman *et al.* (1983).

Lambs reared as twins were about 18% lighter at weaning than single lambs. This difference was reduced to 6% at the hogget stage. Drinan (1968) reported that a difference of 17.4% between single and twin born Merinos at weaning was reduced to 3.2% at 18 months of age. The handicap of being reared as a twin (4.48 kg) agrees with the 4.5 kg found by Clarke (1967) and Ch'ang and Rae (1961) and is close to the 4.2 kg assumed by Sheeplan.

Selection for WW without adjustment for type of birth and rearing rank will result in selection against lambs born as twins.

Age of dam had a highly significant effect on weaning weight. The average WW of lambs increased with age of dam. The finding that four-year old ewes reared heavier lambs than two-year old ewes is in agreement with Jury *et al.* (1979). The 1.76 kg depression due to two-year old dams falls between the 2.0 kg found by Ch'ang and Rae (1970) and the 1.3 kg estimate assumed by Sheeplan (Clarke and Rae, 1976). The age of dam effect decreased from 3% to 1% from weaning to yearling weight.

As also found by Ch'ang and Rae (1970) it appeared that the age of dam effect (1.76 or 0.58 kg) was insufficient to trigger post-weaning compensatory growth although compensatory growth in twins resulted in single-twin liveweight differences narrowing between weaning and hogget weighing.

The effects of age of dam and type of birth and rearing are thought to reflect the pre-weaning maternal handicap (Ch'ang and Rae, 1970) resulting, in part, from the lower milk production of younger ewes (Barnicoat *et al.*, 1949; Owen, 1957) or in the case of twins from competition for nutrients in utero and while suckling (Hunter, 1956).

Failure to adjust for age of dam will result in selection against the progeny of younger ewes. This will give an increase in generation length as well as reducing the selection differential.

Sex will be omitted in the analysis of the following traits as only ewe hoggets were analyzed.

4.2.2 Hogget Liveweight

The standard deviation found for HLW (3.48 kg) is lower than the estimates for Romney and Perendale sheep summarized in Table 4.3.

Year was a significant source of variation in ewe hogget liveweight. This finding is in agreement with Hight and Jury (1971). Chopra (1978) suggested that HLW is easily affected by environmental conditions peculiar to each year such as pasture availability differences due to variation in the amount and distribution of the rainfall.

The rearing rank effect on HLW was significant, in agreement with the results of Hight and Jury (1971).

Single reared ewe hoggets had heavier liveweights than those reared as twins (1.98 kg). This finding is within the range of the estimates reported in Table 4.3.

The age of dam effects on HLW, although non-significant, were within the range shown in Table 4.3.

4.2.3 Greasy Fleece Weight

Year had a significant effect on greasy fleece weight. As pointed out by Chopra (1978) adverse environmental conditions during the year could depress the GFW indirectly through the rate of growth in HLW and the development of secondary follicles. Moreover, Lewer *et al.* (1983) emphasized that GFW of younger ewes may be more affected by nutritional level in the year of rearing or while the wool is growing. Shearing dates also differed slightly from year to year.

Hogget greasy fleece weight was not significantly influenced by age of dam effects. This is in agreement with the results obtained by Hight and Jury (1971) and Tait (1983). Furthermore, Sheeplan makes no adjustment to GFW for age of dam effects.

4.2.4 Clean Fleece Weight

There are few New Zealand estimates of environmental effects on clean fleece weight for comparison with present results.

The effect of age of dam was close to that reported by Gregory and Ponzoni (1981) for Merinos (see Table 4.4). The difference between CFW in progeny of four years or older ewes and those in three and two-year old ewes was greater than the equivalent differences for greasy fleece weight (see Table 4.1).

Turner (1961) showed that the lowered clean wool weight in twins and the progeny of two-year old Merino ewes was mainly due to fewer follicles developing.

4.2.5 Quality Number

The standard deviation found (2.59 units) for quality number is higher than those reported by Elliott (1975) for Perendales and Tait (1983) for Romneys (see Table 4.4).

Years accounted for 35% of the total variation in QN. This finding is in agreement with the results of Chopra (1978) and Lewer *et al.* (1983) who reported that year effects accounted for 20 to 36% of the total variation.

Years 1982 and 1983 were remarkable for their very large effects on QN. Ryder and Stephenson (1968) stated that good feeding tends to lower QN, presumably due to an increase in length growth rate. An alternative explanation is that the standards of subjective grading differed from year to year.

Comparison with related traits is interesting. Respectively estimated means of 1977-1983, 1982 and 1983 values of relevant traits are: QN 53.7, 50.2, 55.9; MFD 29.0, 28.8, 28.1; SL 10.4, 10.7, 10.0; CPC 2.5, 2.1, 2.5; TCN 25.5, 22.0, 24.8. It appears that, in 1982, the coarser quality was not associated with a change in diameter and the increase in length was not large or significant. The coarser quality number arose from a substantial reduction in crimping as revealed both in TCN and CPC. Wickham (1971) has shown the importance of CPC in the assessment of QN. Conversely the 1983 increase in QN was associated with finer diameter and slower length growth although CPC did not change.

4.2.6 Character Grade

The standard deviation for character grade in this study (0.90 grade) lies in between those reported by Tait (1983) and Elliott (1975) for Romneys and Perendales respectively (see Table 4.4).

The year effect was highly significant and explained 14% of the total variation in character grade. Ryder and Stephenson (1968) indicated that nutrition effects would reduce character only if the stress was severe and prolonged and Chopra (1978) reported that evaluation differences between observers may contribute to year-to-year variation in this trait.

Both Elliott (1975) and Tait (1983) found that singles have lower CHG, while in this study there was no variation of CHG due to rearing rank. This result is also at variance with the finding of Chopra (1978) who found a significant effect of birth rank.

4.2.7 Handle Grade

Year effects explained 18% of the variation in handle grade. Chopra (1978) attributed such variations to:

(i) An indirect effect through harshness caused by weathering (climatic conditions).

(ii) Subjective assessment of the trait.

(iii) Differences in the standards of scoring.

In contrast to the result of this study where rearing rank had no effect on handle grade, Chopra (1978) found a highly significant effect of birth rank on HG.

Hoggets born to two-year old ewes tended to have slightly harsher wool than progeny of older dams.

4.2.8 Cotting Grade

The year effect explained 17% of the total observed variation in cotting grade. Joyce (1961) found that the incidence of CG was affected by season and nutrition as well as breed, age and reproductive performance.

Sumner and Wickham (1969) noticed that a higher stocking rate resulted in increased cotting through a greater amplitude of the seasonal rhythm. Wickham and Bigham (1973) stated that shedding of fine fibres and the migration of the shed fibres to entangle with other fibres in the fleece are the main causes. This process could be accelerated by wetting and drying of the fleece.

4.2.9 Soundness Grade

Year effect accounted for 9% of the total variation in soundness. Varying patterns of feed supply (Horton and Wickham, 1979) or varying grading standard could be the explanation.

4.2.10 Greasy Colour Grade

The standard deviation in this study (1.01 grade) is higher than values reported by Chopra (1978) and Tait (1983).

Between year differences contributed 12% of the variation in greasy colour grade. These could have arisen due to climate variations. Henderson (1968) stated that periods of prolonged wetness are causal factors.

4.2.11 Scoured Colour Grade

The standard deviation found in this study (0.89 grade) for scoured colour grade is close to the highest estimate (0.94 grade) reported by Chopra (1978).

The year effect was not significant, accounting for only 2% of the total variation. Chopra (1978) found that year effect though highly significant was comparatively less important than in GCG. The same trend was observed in this work.

4.2.12 Staple Length

Between-year effects were highly significant and contributed 29% to the total variation in staple length. Again these probably reflect differences in the feed supply between years. Variation in staple length could also be due to variation in the time between shearings (Wickham and Bigham, 1973).

Singles had slightly shorter staple length than twins (0.24 cm) but this effect was not significant. Terrill *et al.* (1947), Rae (1950), Lax and Brown (1967), Elliott (1975) and Chopra (1978) who worked with Targhees and Columbias, New Zealand Romney Marsh, Merinos, Perendales and New Zealand Romney sheep respectively reported twins had longer staples. A lower total follicle number of twins could be the explanation for those results. Schinckel and Short (1961) indicated that longer fibres may be produced by sheep with lower follicle population.

Although age of dam did not have a significant effect, progeny of two-year old ewes had higher staple length. Similar findings were reported by Rae (1950) for New Zealand Romney and Lax and Brown (1967) for Merinos.

4.2.13 Total Crimp Number

The year effect accounted for 13% of the total variation in total crimp number, such variation could result from year to year environmental differences in addition to variations due to observer and inaccuracies of measurement.

Hoggets from two-year old dams tended to have lower total crimp number, although this was not significant.

4.2.14 Clean Scoured Yield

The standard deviation found for yield (3.92%) falls within the range of values obtained by Chopra (1978).

The year effect explained 12% of the total observed variation in yield. Differences in rainfall and other flimatic factors between years are the likely explanations. Management practices which favour fleece impurities (mud, sand, dust or vegetable matter) could also result in a depressed yield.

Rearing rank did not have a significant effect on yield. Gregory and Ponzoni (1981) reported that in Merino sheep type of birth had a highly significant effect but age of dam did not.

4.2.15 Mean Fibre Diameter

The between-sheep standard deviation for mean fibre diameter

(2.17 microns) is close to that reported by Elliott (1975) for the Perendales (see Table 4.4).

The effect of years was highly significant and accounted for 13% of the total observed variation in MFD. Season and level of nutrition are the most important factors influencing mean fibre diameter.

The between-year variation of mean fibre diameter (objective fineness), quality number (subjective fineness) and its corresponding microns range is shown in Table 4.5.

TABLE 4.5: YEARLY VARIATION IN MEAN FIBRE DIAMETER AND QUALITY NUMBER

YEAR	MFD (MICRONS)	QN (UNITS)	CORRESPONDING MICRONS RANGE
1977	30.23	53.35	29.8 - 30.4
1978	29.02	54.25	28.4 - 29.0
1979	29.55	54.15	28.4 - 29.0
1980	29.56	53.57	29.8 - 30.4
1981	27.64	54.82	28.4 - 29.0
1982	28.82	50.19	31.3 - 32.1
1983	28.11	55.86	28.4 - 29.0
Mean	28.99	53.74	29.8 - 30.4

From Table 4.5 some points could be highlighted:

(i) Mean fibre diameter tended to become finer, possibly a response to selection.

(ii) Among years there was a wide divergence between mean fibre diameter and quality number, especially in year 1982.

(iii) 1981 when MFD was finest was also a year of low hogget liveweight, the lightest greasy fleece weight and shortest staple length. This finding is in agreement with Coop (1953) and Ryder (1956) who suggested that the length and diameter of fibres are affected similarly by poor nutrition.

(iv) The results agree with the assertion of Roberts (1970) that the sensitivity of MFD to lower nutrition is greater than would be expected from quality number assessment.

There was a non-significant tendency for MFD to be slightly higher for twins. Lax and Brown (1967) also found a lower MFD for singles.

In this study as in that of Gregory and Ponzoni (1981) age of dam did not have a significant effect on MFD.

4.2.16 Crimps per Centimeter

The year effect was highly significant and explained 18% of the total variation in crimps per centimeter. This percentage is higher than the estimate found for total crimp number. The same trend was observed by Chopra (1978).

Roberts and Dunlop (1957) mentioned that CPC is little, if at all, affected by nutrition.

Wickham and Bigham (1973) suggested that the staple crimp can be affected by disorientation of crimp-waves which results from several environmental conditions such as weathering and brushing of the fleece against objects.

In this study rearing rank did not show a significant effect on CPC whereas Lax and Brown (1967) and Gregory and Ponzoni (1981) found that type of birth had a highly significant effect on crimps per inch.

CHAPTER FIVE

HERITABILITY

5.1 INTRODUCTION

Wright (1939) stated that estimates of heritability are essential in planning efficient breeding systems, while Hazel (1943) noted that estimates of heritability are indispensable in determining the relative emphasis to be given to each of several traits when breeding animals are selected.

Lush (1945) indicated that the resemblance between closely-related animals is mainly due to the additive effects of genes that are common to these relatives. According to Lush (1949) heritability in the "narrow" sense is the ratio:

$$\frac{\sigma^2_G}{\sigma^2_G + \sigma^2_D + \sigma^2_I + \sigma^2_{GE} + \sigma^2_E}$$

where σ^2_G = Variance due to additive genetic deviations

σ^2_D = Variance due to dominance deviations

σ^2_I = Variance due to epistatic interactions

σ^2_{GE} = Variance due to interactions between hereditary and environmental effects

σ^2_E = Variance due to temporary and permanent environmental variations

The variances mentioned in the denominator of the ratio add up to the phenotypic variance (σ_P^2). Depending on the method of estimation, the estimates obtained contain varying proportions of σ_D^2, σ_I^2 and even some σ_{GE}^2 in the numerator.

Turner and Young (1969) stated that, in selection, breeders are more interested in improving the next generation than the current flock so that, to predict genetic changes, the breeder needs to know the proportion of the differences between sheep which are of genetic origin, i.e. the heritability. Turner and Young classified heritabilities as high, intermediate or weak when their values were 0.3 to 1.0, 0.1 to 0.3 or 0.0 to 0.1 respectively.

Rae (1982) stressed that heritability is a property of a particular trait in a specified population and may change through alterations in the additive genetic variation (e.g. through in-breeding) or in the environmental variation.

Heritability estimates for a trait may also differ according to factors such as the method used in their estimation (Lewer *et al.*, 1983), the age of the animals (Lewer, 1978), the type of selection practiced in the flock (Blair, 1981) and the number of observations considered (Rae, 1958a).

The heritability estimates for a range of traits reported by the literature and listed in Table 5.1 are confined to ewe hoggets of the breeds from which the Merpers have originated.

TABLE 5.1: HERITABILITY ESTIMATES FOR EWE HOGGET LIVEWEIGHT AND VARIOUS EWE HOGGET WOOL TRAITS IN ROMNEY, PERENDALE AND MERINO SHEEP

TRAIT AND BREEDS	ESTIMATE	METHOD	AGE (MONTHS)	REFERENCE
HOGGET LIVEWEIGHT				
Romney	0.46	DDR	14	Tripathy (1966)
	0.51	PHS	13	Ch'ang and Rae (1970)
	0.46	DDR	13	" " " "
	0.21 - 0.72	PHS	14	Chopra (1978)[1]
	0.31	PHS	13	Baker *et al.* (1979)
	0.06 - 0.52	PHS	13	Blair (1981)[2]
	0.24 - 0.25	PHS	14	Tait (1983)[3]
Perendale	0.27	PHS	15 - 16	Elliott *et al.* (1979)
	0.44	DDR	15 - 16	" " " "
Merino	0.36	DDR	12	Morley (1951)
	0.21	PHS	12	Morley (1951)
	0.58 - 0.72	DDC	15 - 16	Young *et al.* (1960)[4]
	0.65	DDR	15 - 16	Brown and Turner (1968)
	0.37	PHS	15 - 16	Gregory (1982a)[5]
	0.56	DDR	15 - 16	" "
GREASY FLEECE WEIGHT				
Romney	0.26	PHS	14	McMahon (1943)
	0.01 - 0.15	DDR	14	Rae (1948)
	0.32	PHS	14	Rae (1958a)
	0.31	PHS	14	Rae (1958a)
	0.43	PHS	14	Tripathy (1966)
	0.23	PHS	14	Lundie (1971)
	0.38 - 0.61	PHS	14	Chopra (1978)
	0.41	PHS	13	Baker *et al.* (1979)
	0.28 - 0.34	PHS	13	Blair (1981)
	0.30	PHS	14	Tait (1983)
Perendale	0.32	PHS	15 - 16	Elliott *et al.* (1979)
	0.30	DDR	15 - 16	" " " "
Merino	0.39	DDR	12	Morley (1951)
	0.67	PHS	12	" "
	0.40	DDR	12	Morley (1955a)
	0.44	PHS	12	" "
	0.36 - 0.50	DDC	15 - 16	Young *et al.* (1960)
	0.42	DDR	15 - 16	Brown and Turner (1968)
	0.27	PHS	15 - 16	Gregory (1982a)
	0.52	DDR	15 - 16	" "
CLEAN FLEECE WEIGHT				
Romney	0.23 - 0.36	PHS	13	Blair (1981)

TABLE 5.1: (CONTINUED)

TRAIT AND BREEDS	ESTIMATE	METHOD	AGE (MONTHS)	REFERENCE
Merino	0.47	DDR	12	Morley (1955a)
	0.28	DDR		Schinckel (1958)
	0.45	DDR	15 - 16	Young *et al.* (1960)
	0.16	PHS	15 - 16	Gregory (1982a)
	0.33	DDR	15 - 16	" "
QUALITY NUMBER				
Romney	0.35 - 0.40	PHS	14	McMahon (1943)
	0.47	PHS	14	Rae (1958a)
	0.34	DDR	14	Rae (1958a)
	0.46 - 0.72	PHS	14	Chopra (1978)
	0.31 - 0.39	PHS	13	Blair (1981)
	0.55 - 0.56	PHS	14	Tait (1983)
Perendale	0.26	PHS	15 - 16	Elliott *et al.* (1979)
	0.31	DDR	15 - 16	Elliott *et al.* (1979)
Merino	0.40	DDR	12	Morley (1951)
	0.28	PHS	12	" "
CHARACTER GRADE				
Romney	0.20 - 0.38	DDR	14	Rae (1948)[6]
	0.24 - 0.34	PHS	14	Chopra (1978)
	0.25 - 0.50	PHS	13	Blair (1981)
	0.18 - 0.19	PHS	14	Tait (1983)
Perendale	0.23	PHS	15 - 16	Elliott *et al.* (1979)
	0.23	DDR	15 - 16	Elliott *et al.* (1979)
Merino	0.38	PHS	12	Morley (1955b)
	0.21	PHS	15 - 16	Gregory (1982a)
	0.37	DDR	15 - 16	Gregory (1982a)
SOUNDNESS GRADE				
Romney	0.00 - 0.22	PHS	14	Chopra (1978)
GREASY COLOUR GRADE				
Romney	0.00	DDR	14	Rae (1947)
	0.22 - 0.44	PHS	14	Chopra (1978)
	0.25 - 0.26	PHS	14	Tait (1983)
Merino	0.63	PHS	12	Morley (1955b)
SCOURED COLOUR GRADE				
Romney	0.10 - 0.39	PHS	14	Chopra (1978)

TABLE 5.1: (CONTINUED)

TRAIT AND BREEDS	ESTIMATE	METHOD	AGE (MONTHS)	REFERENCE
Merino	0.20	-	12 - 16	Jackson (1973) cited by Turner and Dunlop (1974)
STAPLE LENGTH				
Romney	0.16 - 0.19	DDR	14	Rae (1946)
	0.21	DDR	14	Rae (1947)
	0.50	DDR	14	Rae (1958a)
	0.48	DDR	14	Rae (1958a)
	0.46	DDR	14	Tripathy (1966)
	0.54 - 0.63	PHS	14	Chopra (1978)
	0.09 - 0.33	PHS	13	Blair (1981)
Perendale	0.49	PHS	15 - 16	Elliott *et al.* (1979)
	0.35	DDR	15 - 16	Elliott *et al.* (1979)
Merino	0.22	DDR	12	Morley (1951)
	0.24	PHS	12	Morley (1951)
	0.56	DDR	12	Morley (1955a)
	0.52	PHS	12	" "
	0.30 - 0.44	DDC	15 - 16	Young *et al.* (1960)
	0.43	DDR	15 - 16	Brown and Turner (1968)
	0.36	PHS	15 - 16	Gregory (1982a)
	0.51	DDR	15 - 16	Gregory (1982a)
TOTAL CRIMP NUMBER				
Romney	0.65 - 1.09	PHS	14	Chopra (1978)
	0.27 - 0.33	PHS	13	Blair (1981)
CLEAN SCOURED YIELD				
Romney	0.19 - 0.53	PHS	14	Chopra (1978)
	0.04 - 0.40	PHS	13	Blair (1981)
Merino	0.39	DDR	12	Morley (1955a)
	0.75	PHS	12	" "
	0.41 - 0.64	DDC	15 - 16	Young *et al.* (1960)
	0.49	DDR	15 - 16	Brown and Turner (1968)
	0.57	PHS	15 - 16	Gregory (1982a)
	0.47	DDR	15 - 16	" "
MEAN FIBRE DIAMETER				
Romney	0.17	DDR	14	Tripathy (1966)[7]
	0.34 - 0.87	PHS	14	Chopra (1978)[7]
	0.21 - 0.64	PHS	13	Blair (1981)[7]

TABLE 5.1: (CONTINUED)

TRAIT AND BREEDS	ESTIMATE	METHOD	AGE (MONTHS)	REFERENCE
Perendale	0.47	DDR	15 - 16	Elliott *et al.* (1979)[8]
	0.54	PHS	15 - 16	Elliott *et al.* (1979)[8]
Merino	0.26	PHS	12	Morley (1951)[9]
	0.52	DDR	-	Schinckel (1958)
	0.29 - 0.56	DDC	15 - 16	Young *et al.* (1960)
	0.47	DDR	15 - 16	Brown and Turner (1968)
	0.88	PHS	15 - 16	Gregory (1982a)[7]
	0.42	DDR	15 - 16	Gregory (1982a)[7]

DDR = Daughter-dam regression

PHS = Paternal half sib

DDC = Daughter-dam correlation

1 includes estimates from different stocking rates; genotype x environmental interaction included with sire variance in some estimates.

2 includes fleece weight, face cover and control groups.

3 heritabilities from different methods of variance component estimation.

4 includes half sib, mass selection and control groups.

5 obtained from unadjusted data.

6 includes three positions: forequarter, hindquarter and side.

7 obtained by microprojection.

8 obtained by airflow.

9 obtained by crimp fineness relationship.

5.2 RESULTS AND DISCUSSION

Estimates of the heritabilities (h^2) from the daughter-dam correlation (DDC) and daughter-dam regression (DDR) methods together with their confidence limits and standard errors respectively for quantitative and qualitative traits are presented in Table 5.2.

Apart from the estimates for HLW, QN and Yield estimates by the two methods were similar.

Lush (1940) established that in the general situation only a small proportion of the epistatic effects contribute to the parent-offspring correlation. Rae (1946) added that the major difficulty in the interpretation of DDC estimates is that of appraising correctly the environmental contributions between the environment of the dam and daughter. Moreover, Ronningen (1972) pointed out that the only case in which twice the phenotypic correlation between parent and offspring gives unbiased estimate of the h^2 is when no selection is made.

Morley (1951) stated that the offspring on parent regression method to calculate h^2 has the advantage that the estimate is not biased by selection of parents. Nevertheless, Bowman (1968) expressed the view that the h^2 estimated by the DDR can be biased upwards by environmental effects between paired individuals of the two generations. Since records were from different years this is not likely to lead to serious bias in the present estimates.

The standard errors as indicators of the precision of the

TABLE 5.2: ESTIMATES OF HERITABILITIES FROM DIFFERENT METHODS FOR THE MERPERS

TRAIT	PAIRS	DAUGHTER-DAM CORRELATION		DAUGHTER-DAM REGRESSION	
			CONFIDENCE LIMITS (P = 0.99)		± S.E
HLW	65	0.31	(-0.006, 0.571)	0.16	0.06
GFW	65	0.24	(-0.082, 0.517)	0.17	0.09
CFW	65	0.28	(-0.039, 0.548)	0.24	0.11
QN	65	0.23	(-0.093, 0.509)	0.42	0.23
CHG	65	0.40	(0.097, 0.636)	0.38	0.12
SG	65	0.02	(-0.297, 0.333)	0.02	0.12
GCG	65	0.38	(0.073, 0.621)	0.38	0.12
SCG	65	0.13	(-0.193, 0.428)	0.09	0.09
SL	65	0.14	(-0.183, 0.436)	0.12	0.11
TCN	65	0.07	(-0.251, 0.377)	0.08	0.14
Y	65	0.54	(0.270, 0.731)	0.41	0.09
MFD	65	0.37	(0.061, 0.614)	0.29	0.10
HG	65	—[a]		—[b]	
CG	65	—[a]		—[b]	
CPC	65	—[a]		—[b]	

a = Negative daughter-dam correlation

b = Negative numerator covariance

heritabilities (Falconer, 1981) estimated by the DDR method were similar or relatively large compared with the h^2 estimates for SG, SCG, SL and TCN. Large standard errors were expected due to the small number of daughter-dam pairs available for the Merper flock and also to the inaccuracy of the methods of assessment, especially for traits estimated by eye and hand (errors in scoring).

The heritabilities obtained by the DDR method fell within the confidence limits found for the heritabilities estimated by the DDC method, thus it was apparent that significant differences did not exist between them.

The heritability estimates of various traits obtained in the present study by the DDC and DDR methods are, in general, in good agreement with those published in the revised literature (compare Tables 5.1 and 5.2).

The following conclusions are drawn from Tables 5.1 and 5.2:

(i) The estimate of h^2 for HLW obtained by DDC (0.31) compares favourably with the estimate of 0.31 for Romneys (Baker *et al.*, 1979) and with the value of 0.35 used by Sheeplan (Clarke and Rae, 1976); 0.36 for Merinos (Morley, 1951) and is in between the figures for Perendales reported by Elliott *et al.* (1979). Estimates by the PHS method are likely to be biassed upward by genotype x environment interaction (Chopra, 1978; Newman (Pers. Comm.)).

(ii) The estimates for GFW are in line with the h^2 found by McMahon (1943), Rae (1948), Lundie (1971) and the realized h^2 reported by Blair (1981) but a little lower than those of most recent studies.

(iii) The present estimates of h^2 for CFW, QN, CHG and Y are comparable with most of the published values.

(iv) The h^2 found for MFD fall in the range reported in the literature for Romneys and Merinos but they are lower than those reported by Elliott *et al.* (1979) for Perendales.

(v) The heritabilities of staple length found for Merpers are lower than the estimates for other breeds, except the lower limit reported by Blair (1981) for Romneys.

(vi) The estimates of heritability of greasy colour grade of 0.38 (DDC and DDR methods) are comparable with the upper limit found by Chopra (1978) for Romneys.

(vii) The h^2 estimates obtained for SCG are lower than those found for GCG. This supports the findings of Chopra (1978).

(viii) The heritabilities of total crimp number are low when related to estimates of Chopra (1978) for New Zealand Romney sheep.

(ix) The values calculated for the heritabilities of SG and SCG are comparable with the lower limits of the heritabilities found by Chopra (1978) for Romneys.

5.3 APPLICABILITY OF RESULTS

Rae (1946) stated that an estimate of heritability is applicable only to populations which have a genetic makeup and environmental treatment similar to the population from which the estimates were derived.

Prediction of genetic gain is possible with assistance of heritability estimates (Turner and Young, 1969). Calculations of improvement per generation by selection alone within the Merper flock, assuming 70% of ewe hoggets and 3% of ram hoggets are retained for breeding, are presented in Table 5.3. It includes the improvement per generation using heritabilities estimated by the DDC and DDR methods. The proportion of replacement correspond to selection differentials of 0.50 and 2.27 (Pearson, 1931) respectively in normally distributed populations. Selection differential is defined as intensity of selection (proportion of population selected) x standard deviation for the trait (figures reported in Table 4.1).

The expected gain can then be obtained from the equation:

$$\text{Gain/Generation} = \text{heritability} \times \text{standard deviation} \times \left(\frac{0.50 + 2.27}{2}\right)$$

TABLE 5.3: EXPECTED IMPROVEMENT PER GENERATION BY SINGLE TRAIT SELECTION

TRAIT	STANDARD DEVIATION	D.D.C		D.D.R	
		h^2	Improvement/ Generation	h^2	Improvement/ Generation
HLW	3.48 kg	0.31	1.49 kg	0.16	0.77 kg
GFW	0.37 kg	0.24	0.12 kg	0.17	0.09 kg
CFW	0.30 kg	0.28	0.12 kg	0.24	0.10 kg
QN	2.59 units	0.23	0.83 units	0.42	1.51 units
CHG	0.90 grade	0.40	0.50 grade	0.38	0.47 grade
SG	1.23 grade	0.02	0.03 grade	0.02	0.03 grade
GCG	1.01 grade	0.38	0.53 grade	0.38	0.53 grade
SCG	0.89 grade	0.13	0.16 grade	0.09	0.11 grade
SL	1.28 cm	0.14	0.25 cm	0.12	0.21 cm
TCN	4.90 units	0.07	0.48 units	0.08	0.54 units
Y	3.92%	0.54	2.93%	0.41	2.23%
MFD	2.17 microns	0.37	1.11 microns	0.29	0.87 microns

As can be seen from Table 5.3 the possible improvement from selection on SG, SCG, SL and TCN alone is very slow.

Lush (1948) cited by Turner and Young (1969) established that mass (individual) selection should usually be more important than any of the other methods (repeated records, selection on family or progeny performance) if heritability is much higher than 0.20 and if the traits can be observed early and cheaply enough on the individuals to be selected. This is the case in the present study for most of the traits observed in ewe hoggets, especially those of economic importance (GFW, CFW, GCG, Y, MFD).

Since heritability is a function of genetic variance, any change in gene frequency as a result of artificial selection would probably alter its value. Therefore, a periodic re-estimation of heritabilities for traits of economic importance is suggested.

In coming chapters the role played by the heritability in determining correlated responses and selection indexes will be highlighted.

CHAPTER SIX

ASSOCIATION BETWEEN TRAITS

6.1 INTRODUCTION

The development of efficient breeding plans which involve selection on more than one trait requires the knowledge of genetic, phenotypic and environmental correlations in addition to heritabilities. Wickham and McPherson (1985) in reviewing the importance of wool traits as genetic improvement objectives and selection criteria for New Zealand Romney sheep concluded that the major deficiency is the lack of sufficient estimates of genetic and environmental correlations for an accurate prediction of indirect pathways of response. This assertion is applicable to other breeds.

A genetic correlation is the correlation between an animal's genetic value for one trait and the same animal's genetic value for the other trait. It arises mainly from pleiotropy (i.e. the gene having more than one phenotypic effect) and to a lesser degree from linkage (i.e. the situation where two non-allelic genes tend to appear in the same individual due to the loci being on the same chromosome). Turner (1977) enumerated three uses for genetic correlations:

(i) To indicate the change which is likely in traits other than those under selection, in future generations (correlated response).

(ii) To define what counter-selection should be applied to diminish or prevent the effect of such changes.

(iii) To judge if indirect selection on an easily

> measured trait can be used to obtain genetic gains, instead of direct selection on a trait that is more difficult (or more expensive) to measure.

Phenotypic correlation is the observed correlation between traits on the same animal arising from the combined effects of genotype and environment. Turner (1977) listed uses for phenotypic correlations that are similar to those stated above except that they do not necessarily apply to later generations.

Phenotypic correlations are also useful in assessing the association between the components of wool production (Brown and Turner, 1968) and determining its end use (Turner, 1956).

Environmental correlation is the correlation of environmental deviations together with non-additive genetic deviations (Falconer, 1981) and arises from a common environment shared by the two traits.

Genetic and phenotypic correlations between traits are needed for constructing selection indexes (Lush, 1945), and if the genetic and phenotypic correlations have different signs the selection objectives could be antagonistic.

The genetic and phenotypic correlations can be classified as suggested by Brown and Turner (1968):

-0.6 and lower	High negative
-0.4 to -0.6	Medium negative
-0.2 to -0.4	Low negative
-0.2 to +0.2	Negligible

+0.2 to +0.4	Low positive
+0.4 to +0.6	Medium positive
+0.6 and greater	High positive

Searle (1961 has summarized the relationship amongst the phenotypic (r_P), genetic (r_G) and environmental (r_E) correlations as follows:

(i) r_P, r_G and r_E are connected by the relationship:

$$r_P = r_G\sqrt{h_1 h_2} + r_E\sqrt{(1 - h_1)(1 - h_2)}$$

where h_1 and h_2 are the heritabilities of the traits involved.

(ii) r_E is negative when r_P and r_G have the same sign only if $r_P/r_G < \sqrt{h_1 h_2}$; it is negative when r_P and r_G are of opposite sign and r_P is negative.

(iii) Equality of the heritabilities implies that when any two of the correlations are equal there is equality of all three.

(iv) The r_P exceeds (or is less than) the r_G according as the ratio of the environmental to the r_G exceeds (or is less than) the value of $(1 - \sqrt{h_1 h_2})/\sqrt{(1 - h_1)(1 - h_2)}$.

As can be seen from the relationship in point (i), when either trait has a low heritability, the r_P between them is almost entirely of non-additive genetic or environmental origin; if they have high heritability, then the r_G is the more important. The dual nature of the phenotypic correlation makes it clear that the magnitude and even the sign of the r_G cannot be determined from the phenotypic correlation alone.

The computation of genetic correlations was based on the covariances between daughter-dam relatives, whereas the phenotypic correlations were estimated from the product-moment expression as detailed in the Materials and Methods chapter.

6.2 RESULTS AND DISCUSSION

The genetic and phenotypic correlations and their respective standard errors together with environmental correlations among adjusted ewe hogget traits obtained in this study are presented in Table 6.1.

In view of the large number of correlations, discussion will be confined to those which proved to be of a medium to high value, keeping in mind that a selection plan for Merpers must include traits such as HLW (meat production), GFW (wool production), CFW (trait of ultimate concern in wool production, McGuirk, 1983) and MFD, GCG and SCG (quality traits) and their possible relationship with others.

In general, genetic and phenotypic correlations were of the same sign for traits in which the environmental correlation had a lower value. However, some phenotypic correlations differed in direction and magnitude from their corresponding genetic correlations.

6.2.1 Genetic Correlations

Several estimates of genetic correlations lay outside the theoretical limits and most standard errors were relatively large compared with the corresponding estimate of the correlation. A major

TABLE 6.1: GENETIC, PHENOTYPIC (AND STANDARD ERRORS) AND ENVIRONMENTAL CORRELATIONS FOR MERPERS

TRAITS		GENETIC		PHENOTYPIC		ENVIRONMENTAL
HLW	GFW	0.67	(0.60)	0.66	(0.04)	0.66
	CFW	0.62	(0.59)	0.56	(0.05)	0.55
	QN	-0.66	(0.76)	-0.14	(0.06)	0.04
	CHG	-0.09	(0.71)	-0.10	(0.06)	-0.11
	HG	a		0.11	(0.06)	-
	CG	a		-0.01	(0.07)	-
	SG	0.30	(4.45)	-0.31	(0.06)	-0.36
	GCG	-0.08	(0.72)	-0.02	(0.07)	-0.0004
	SCG	-0.65	(1.69)	-0.06	(0.07)	0.02
	SL	0.79	(0.95)	0.44	(0.05)	0.38
	TCN	0.46	(1.58)	0.13	(0.06)	0.09
	CPC	a		-0.18	(0.06)	-
	Y	0.04	(0.75)	-0.33	(0.06)	-0.48
	MFD	-0.45	(1.08)	0.24	(0.06)	0.44
GFW	CFW	0.87	(0.16)	0.94	(0.01)	0.96
	QN	-0.59	(0.58)	-0.34	(0.06)	-0.26
	CHG	0.17	(0.68)	0.16	(0.06)	0.16
	HG	a		0.18	(0.06)	-
	CG	a		0.09	(0.06)	-
	SG	<-1.5		-0.28	(0.06)	-
	GCG	0.04	(0.69)	0.04	(0.07)	0.04
	SCG	<-1.5		-0.13	(0.07)	-
	SL	0.37	(1.00)	0.60	(0.04)	0.64
	TCN	1.47	(3.11)	-0.07	(0.07)	-0.28
	CPC	a		-0.46	(0.05)	-
	Y	-0.08	(0.66)	-0.21	(0.06)	-0.27
	MFD	-0.98	(1.57)	0.38	(0.06)	0.78
CFW	QN	-0.34	(0.49)	-0.38	(0.06)	-0.41
	CHG	0.40	(0.52)	0.29	(0.06)	0.25
	HG	a		0.18	(0.07)	-
	CG	a		0.07	(0.07)	-
	SG	<-1.5		-0.22	(0.06)	-
	GCG	0.52	(0.65)	0.02	(0.07)	-0.20
	SCG	-1.36	(2.09)	-0.13	(0.07)	0.08
	SL	-0.004	(1.17)	0.51	(0.05)	0.62
	TCN	1.35	(2.94)	-0.20	(0.07)	-0.46
	CPC	a		-0.51	(0.05)	-
	Y	0.44	(0.56)	0.14	(0.07)	0.003
	MFD	-1.03	(1.31)	0.37	(0.06)	0.87
QN	CHG	-0.26	(0.42)	-0.25	(0.06)	-0.24
	HG	a		-0.55	(0.05)	-
	CG	a		0.22	(0.07)	-
	SG	>1.5		0.10	(0.07)	-
	GCG	1.19	(0.66)	0.04	(0.07)	-0.73

TABLE 6.1: (CONTINUED)

TRAITS		GENETIC		PHENOTYPIC		ENVIRONMENTAL
QN	SCG	>1.5		0.04	(0.07)	-
	SL	<-1.5		-0.41	(0.06)	-
	TCN	0.22	(0.85)	0.55	(0.05)	0.70
	CPC	a		0.70	(0.04)	-
	Y	0.48	(0.51)	-0.09	(0.07)	-0.49
	MFD	-0.79	(0.46)	-0.30	(0.06)	-0.04
CHG	HG	a		0.23	(0.07)	-
	CG	a		0.10	(0.07)	-
	SG	<-1.5		0.02	(0.07)	-
	GCG	0.21	(0.47)	0.07	(0.07)	-0.02
	SCG	0.03	(0.95)	0.03	(0.07)	0.03
	SL	0.77	(1.19)	-0.02	(0.07)	-0.25
	TCN	-0.44	(1.00)	-0.24	(0.07)	-0.22
	CPC	a		-0.22	(0.07)	-
	Y	0.40	(0.42)	0.22	(0.07)	0.10
	MFD	-0.30	(0.57)	0.05	(0.07)	0.23
HG	CG	a		-0.12	(0.07)	-
	SG	a		0.01	(0.07)	-
	GCG	a		0.18	(0.07)	-
	SCG	a		0.17	(0.07)	-
	SL	a		0.31	(0.06)	-
	TCN	a		-0.22	(0.07)	-
	CPC	a		-0.38	(0.06)	-
	Y	a		-0.02	(0.07)	-
	MFD	a		-0.04	(0.07)	-
CG	SG	a		0.08	(0.07)	-
	GCG	a		0.29	(0.06)	-
	SCG	a		0.01	(0.07)	-
	SL	a		-0.05	(0.07)	-
	TCN	a		-0.001	(0.07)	-
	CPC	a		0.02	(0.07)	-
	Y	a		-0.03	(0.07)	-
	MFD	a		-0.04	(0.07)	-
SG	GCG	>1.5		0.14	(0.07)	-
	SCG	>1.5		0.13	(0.07)	-
	SL	>1.5		-0.30	(0.06)	-
	TCN	>1.5		0.09	(0.07)	-
	CPC	a		0.28	(0.06)	-
	Y	-0.78	(5.85)	0.24	(0.07)	0.41
	MFD	0.73	(5.73)	-0.21	(0.07)	-0.32
GCG	SCG	0.87	(1.07)	0.38	(0.06)	0.29
	SL	0.06	(0.82)	0.13	(0.07)	0.16

TABLE 6.1: (CONTINUED)

TRAITS		GENETIC		PHENOTYPIC		ENVIRONMENTAL
GCG	TCN	>1.5		-0.01	(0.07)	-
	CPC	a		-0.10	(0.07)	-
	Y	0.96	(0.59)	0.04	(0.07)	-0.56
	MFD	-1.41	(0.68)	-0.30	(0.06)	0.25
SCG	SL	<-1.5		0.05	(0.07)	-
	TCN	>1.5		0.05	(0.07)	-
	CPC	a		0.01	(0.07)	-
	Y	0.77	(1.42)	0.00	(0.07)	-0.20
	MFD	-1.47	(1.85)	-0.33	(0.06)	-0.12
SL	TCN	>1.5		0.08	(0.07)	-
	CPC	a		-0.60	(0.04)	-
	Y	-0.64	(0.81)	-0.27	(0.07)	-0.18
	MFD	-1.02	(2.00)	0.39	(0.06)	0.73
TCN	CPC	a		0.73	(0.03)	-
	Y	-0.16	(0.92)	-0.32	(0.06)	-0.40
	MFD	-0.67	(1.41)	-0.12	(0.07)	-0.02
CPC	Y	a		-0.09	(0.07)	-
	MFD	a		-0.35	(0.06)	-
Y	MFD	-0.06	(0.52)	-0.04	(0.07)	-0.03

a = Negative denominator covariance

factor in this would be the low number of daughter-dam pairs (65). Genetic correlations estimated by the daughter-dam regression method are computed as a function of four covariances each of which has its own sampling error so large sampling variances are to be expected (Rae, 1958a). Daughter-dam correlation estimates may also be biased upwards by maternal effects (Robertson, 1959) or a small number of records and a low heritability of at least one trait (Van Vleck and Henderson, 1961). It appears that the most erratic correlations involve subjectively assessed traits. Traits which show a low DDR heritability such as SG (0.02), TCN (0.08), SCG (0.09) and SL (0.12) tend to have higher standard errors.

Due to a negative denominator covariance, it was impossible to obtain genetic correlations between HG, CG and CPC with all other traits.

The genetic correlations of HLW with GFW, CFW and SL are high positive. According to the present results, selection for GFW will increase HLW. Barlow (1974) and Blair (1981) showed little or no increase in body weight from selecting for higher fleece weight, supporting the absence of any sizeable genetic correlation.

There is a high positive genetic correlation between GFW and CFW indicating that selection for GFW should be adequate to improve CFW. The genetic correlations of GFW or CFW with other wool traits are variable and can be antagonistic to some extent. The genetic correlation between GFW and SL (0.37) indicates that selection for GFW will increase SL but the genetic correlation between CFW and SL is only -0.004. The genetic correlation between GFW and GCG is negligible whereas the correlation between CFW and GCG (0.52) indicates that selection for CFW could result in whiter wool. The high correlations of Y with GCG (0.96) and SCG (0.77) suggest that a non-fibre component of the greasy wool is associated with the discoloration.

Striking and consistent negative genetic correlations have been found between MFD and all other traits except SG. High negative genetic correlations between HLW and MFD, CFW and MFD could be due to selection for clean fleece weight and fineness exerted on the Merpers, as suggested by Morley (1951) for Merinos and later confirmed by Turner *et al.* (1968) and Turner *et al.* (1970). However, Hancock *et al.* (1979) working with South Australian Merinos found a negative genetic correlation of -0.46 between MFD and CFW in ewes.

As both QN and MFD are estimates of wool fineness, a large negative correlation is expected between them (-0.79 in the present study). Since soundness is highly correlated with MFD (0.73) selection for fine wool would adversely affect SG.

Results that are difficult to explain are those shown by the simultaneously negative genetic correlations among the traits GFW/MFD (-0.98), GFW/QN (-0.59) and QN/MFD (-0.79). If GFW and QN were both so negatively correlated with MFD it seems that the GFW/QN would have to be positive, or at least only weakly negative. Comparison with other estimates in the literature, however, show that the GFW/QN correlation from the Merper data, while more strongly negative than most estimates, is within the previously reported range. The MFD/QN correlation is more negative than other estimates and looks questionable. But it is GFW/MFD that looks aberrant since most previously reported estimates are medium positive.

Colour after scouring (SCG) or degree of whiteness is of importance since pure white wool can be dyed to any other colour. In the present study SCG was highly correlated (0.87) with colour before scouring (GCG) thus indicating the possibility of improving SCG by selecting for GCG; a similar result was reported by Chopra (1978). The correlation of SCG with HLW (-0.65) indicates that selection for whiteness in wool could decrease HLW.

Except the genetic correlation between CHG and SL (0.77) and CHG and TCN (-0.44) all other correlations involving CHG are negligible or low, suggesting that CHG is not a good selection criteria.

Table 6.2 summarizes published estimates of genetic correlations. They are confined to breeds which were used to derive the Merpers and cover the same flocks reported in the previous chapter.

Table 6.2 highlights:

(i) High negative correlations between GFW/QN and CFW/QN for Merinos.

(ii) High positive correlations between GFW/MFD and CFW/MFD for Romneys.

(iii) The correlations between GFW and SL range from negligible to high positive.

(iv) A medium to high positive correlation between MFD and SL for Romneys but low for Merinos.

TABLE 6.2: GENETIC CORRELATION ESTIMATES BETWEEN EWE HOGGET LIVEWEIGHT AND VARIOUS WOOL TRAITS IN ROMNEY, PERENDALE AND MERINO SHEEP

TRAITS	ESTIMATE	AGE (MONTHS)	METHOD	BREED	REFERENCE
HLW x GFW	0.54	14	DDR	Romney	Tripathy (1966)
	0.11	14	PHS	"	Chopra (1978)
	0.41	13	PHS	"	Baker *et al.* (1979)
	-0.04	13	DDR	"	" " " "
	0.02	13	SDR	"	" " " "
	0.40	16	PHS	"	" " " "
	0.26	16	DDR	"	" " " "
	-0.14	16	SDR	"	" " " "
	0.64 - 0.89	13	PHS	"	Blair (1981)
	-0.07	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.18	14 - 15	DDR	"	" " " "
	-0.11		DDR	Merino	Morley (1955a)
	-0.20		DDR	"	Beattie (1962)
	0.26	16	DDR	"	Brown and Turner (1968)
	0.21	15 - 16	DDR	S.A. Merino	Gregory (1982b)
	0.03	15 - 16	PHS	" " "	" "
HLW x CFW	0.22	14	PHS	Romney	Chopra (1978)
	0.47 - 0.75	13	PHS	Romney	Blair (1981)
	-0.12		DDR	Merino	Morley (1955a)
	0.27	16	DDR	"	Brown and Turner (1968)
	0.04	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.13	15 - 16	DDR	" " "	" "
HLW x QN	0.37	14	PHS	Romney	Chopra (1978)
	-0.18 - 0.47	13	PHS	"	Blair (1981)
	0.37	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	-0.10	14 - 15	DDR	"	" " " "
HLW x CHG	0.44	14	PHS	Romney	Chopra (1978)
	-0.07 - 0.42	13	PHS	"	Blair (1981)
	-0.47	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	-0.31	14 - 15	DDR	"	" " " "
	0.04	15 - 16	PHS	S.A. Merino	Gregory (1982b)
HLW x SG	0.20	14	PHS	Romney	Chopra (1978)
HLW x GCG	0.30	14	PHS	Romney	Chopra (1978)
	0.11		PHS	Merino	Morley (1955b)
HLW x SCG	0.26	14	PHS	Romney	Chopra (1978)
HLW x SL	0.21	14	DDR	Romney	Tripathy (1966)
	0.50	14	PHS	"	Chopra (1978)
	-0.20 - 0.77	13	PHS	"	Blair (1981)
	-0.06	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.22	14 - 15	DDR	"	" " " "
	-0.26		DDR	Merino	Morley (1955a)

TABLE 6.2: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	METHOD	BREED	REFERENCE
HLW x SL	-0.06	16	DDR	Merino	Brown and Turner (1968)
	0.10	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	-0.03	15 - 16	DDR	" " "	" "
HLW x TCN	0.53	14	PHS	Romney	Chopra (1978)
	-0.16 - 0.48	13	PHS	"	Blair (1981)
HLW x Y	0.06	14	PHS	Romney	Chopra (1978)
	-0.33	13(FC)	PHS	"	Blair (1981)
	-0.08		DDR	Merino	Morley (1955a)
	0.11		DDR	"	Beattie (1962)
	0.09	16	DDR	"	Brown and Turner (1968)
	-0.14	15 - 16	DDR	S.A. Merino	Gregory (1982b)
	0.03	15 - 16	PHS	" " "	" "
HLW x MFD	0.16	14	DDR	Romney	Tripathy (1966)
	0.02	14	PHS	"	Chopra (1978)
	-0.12 - 0.28	13	PHS	"	Blair (1981)
	-0.02	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.00	14 - 15	DDR	"	" " " "
	0.12	16	DDR	Merino	Brown and Turner (1968)
	-0.08	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.06	15 - 16	DDR	" " "	" "
GFW x CFW	0.98	14	PHS	Romney	Chopra (1978)
	0.96 - 1.00	13	PHS	"	Blair (1981)
	0.95	14	PHS	Romney x	Bigham *et al.* (1983)
	0.65		DDR	Merino	Morley (1955a)
	0.82		DDR	Merino	Beattie (1962)
	0.80	15 - 16	DDR	"	Brown and Turner (1968)
	0.76	18	DDR	"	Mullaney *et al.* (1970)
	0.62	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.79	15 - 16	DDR	" " "	" "
GFW x QN	-0.62	14	PHS	Romney	Rae (1958a)
	-0.49	14	DDR	"	" "
	-0.47	14	DDR	"	" "
	0.02	14	PHS	"	Chopra (1978)
	-0.43 - 0.07	13	PHS	"	Blair (1981)
	-0.48	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.09	14 - 15	DDR	"	" " " "
	-0.75	18	DDR	Merino	Mullaney *et al.* (1970)
GFW x CHG	0.27	14	PHS	Romney	Rae (1958a)
	-0.16	14	DDR	"	" "
	0.08	14	DDR	"	" "
	0.24	14	PHS	"	Chopra (1978)
	-0.17 - 0.39	13	PHS	"	Blair (1981)

TABLE 6.2: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	METHOD	BREED	REFERENCE
GFW x CHG	-0.17 - 0.39	13	PHS	Romney	Blair (1981)
	0.52	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.32	14 - 15	DDR	"	" " " "
	-0.54	18	DDR	Merino	Mullaney *et al.* (1970)
	-0.06	15 - 16	PHS	S.A. Merino	Gregory (1982b)
GFW x GCG	-0.19	14	PHS	Romney	Chopra (1978)
	-0.28		PHS	Merino	Morley (1955b)
	-0.42	18	DDR	"	Mullaney *et al.* (1970)
GFW x SL	0.60	14	PHS	Romney	Rae (1958a)
	0.21	14	DDR	"	" "
	0.25	14	DDR	"	" "
	0.40	14	DDR	"	Tripathy (1966)
	0.58	14	PHS	"	Chopra (1978)
	0.35 - 0.58	13	PHS	"	Blair (1981)
	0.76	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.44	14 - 15	DDR	"	" " " "
	-0.02		DDR	Merino	Morley (1955a)
	0.70		DDR	"	Beattie (1962)
	0.29	16	DDR	"	Brown and Turner (1968)
	0.13	18	DDR	"	Mullaney *et al.* (1970)
	0.16	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.19	15 - 16	DDR	" " "	" "
GFW x TCN	0.69	14	PHS	Romney	Chopra (1978)
	-0.42 - 0.23	13	PHS	"	Blair (1981)
GFW x Y	0.14	14	PHS	Romney	Chopra (1978)
	-0.40 - 0.36	13	PHS	"	Blair (1981)
	-0.05		DDR	Merino	Morley (1955a)
	-0.22		PHS	"	" "
	-0.09	16	DDR	"	Schinckel (1958)
	0.06		DDR	"	Beattie (1962)
	-0.09	16	DDR	"	Brown and Turner (1968)
	-0.18	18	DDR	"	Mullaney *et al.* (1970)
	-0.39	15 - 16	PHS	S.A. Merino	Gregory (1982b)
GFW x MFD	0.58	14	DDR	Romney	Tripathy (1966)
	0.81	14	PHS	"	Chopra (1978)
	0.34 - 0.82	13	PHS	"	Blair (1981)
	0.43	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.44	14 - 15	DDR	"	" " " "
	0.19		DDR	Merino	Beattie (1962)
	0.13	16	DDR	"	Brown and Turner (1968)
	0.47	18	DDR	"	Mullaney *et al.* (1970)
	-0.17	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.14	15 - 16	DDR	" " "	" "

TABLE 6.2: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	METHOD	BREED	REFERENCE
CFW x QN	-0.02	14	PHS	Romney	Chopra (1978)
	-0.52 - -0.26	13	PHS	"	Blair (1981)
	-0.91	18	DDR	Merino	Mullaney *et al.* (1970)
CFW x CHG	0.18	14	PHS	Romney	Chopra (1978)
	-0.25 - 0.28	13	PHS	"	Blair (1981)
	-0.41	18	DDR	Merino	Mullaney *et al.* (1970)
	-0.19	15 - 16	DDR	S.A. Merino	Gregory (1982b)
CFW x GCG	0.13	14	PHS	Romney	Chopra (1978)
	0.17	18	DDR	Merino	Mullaney *et al.* (1970)
CFW x SCG	-0.22	14	PHS	Romney	Chopra (1978)
	0.8			Merino	Jackson (1973) (Cited by Turner (1977)
CFW x SL	0.66	14	PHS	Romney	Chopra (1978)
	0.45 - 0.85	13	PHS	"	Blair (1981)
	0.39		DDR	Merino	Morley (1955a)
	0.37	16	DDR	"	Schinckel (1958)
	0.89		DDR	"	Beattie (1962)
	0.46	16	DDR	"	Brown and Turner (1968)
	0.37	18	DDR	"	Mullaney *et al.* (1970)
	0.41	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.29	15 - 16	DDR	" " "	" "
CFW x TCN	0.43	14	PHS	Romney	Chopra (1978)
	-0.37 - 0.10	13	PHS	"	Blair (1981)
CFW x Y	0.89	14	PHS	Romney	Chopra (1978)
	-0.31 - 0.46	13	PHS	"	Blair (1981)
	0.56		DDR	Merino	Morley (1955a)
	0.64		DDR	"	Beattie (1962)
	0.53	16	DDR	"	Brown and Turner (1968)
	0.51	18	DDR	"	Mullaney *et al.* (1970)
	0.47	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.17	15 - 16	DDR	S.A. "	" "
CFW x MFD	0.88	14	PHS	Romney	Chopra (1978)
	0.45 - 0.82	13	PHS	Romney	Blair (1981)
	0.24	16	DDR	Merino	Schinckel (1958)
	0.16		DDR	"	Beattie (1962)
	0.16	16	DDR	"	Brown and Turner (1968)
	0.39	18	DDR	"	Mullaney *et al.* (1970)
	-0.06	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.16	15 - 16	DDR	" " "	" "
QN x CHG	-0.41	14	PHS	Romney	Rae (1958a)

TABLE 6.2: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	METHOD	BREED	REFERENCE
QN x CHG	0.21	14	DDR	Romney	Rae (1958a)
	0.61	14	PHS	"	Chopra (1978)
	0.42 - 0.70	13	PHS	"	Blair (1981)
	-0.13	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.44	14 - 15	DDR	"	" " " "
	0.26	18	DDR	Merino	Mullaney *et al.* (1970)
QN x GCG	0.02	14	PHS	Romney	Chopra (1978)
	-0.03	18	DDR	Merino	Mullaney *et al.* (1970)
QN x TCN	1.00	14	PHS	Romney	Chopra (1978)
	0.35 - 0.94	13	PHS	"	Blair (1981)
QN x Y	-0.43	14	PHS	Romney	Chopra (1978)
	-0.95 - -0.75	13	PHS	"	Blair (1981)
	-0.37	18	DDR	Merino	Mullaney *et al.* (1970)
QN x MFD	-0.09	14	PHS	Romney	Chopra (1978)
	-0.64 - -0.49	13	PHS	"	Blair (1981)
	-0.46	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	-0.27	14 - 15	DDR	"	" " " "
	-0.30	18	DDR	Merino	Mullaney *et al.* (1970)
CHG x GCG	0.57	14	PHS	Romney	Chopra (1978)
	0.18		PHS	Merino	Morley (1955b)
	0.39	18	DDR	"	Mullaney *et al.* (1970)
CHG x SCG	0.20	14	PHS	Romney	Chopra (1978)
CHG x SL	0.74	14	PHS	Romney	Rae (1958a)
	0.13	14	DDR	"	" "
	-0.28	14	PHS	"	Chopra (1978)
	-0.78 - -0.06	13	PHS	"	Blair (1981)
	0.47	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.03	14 - 15	DDR	"	" " " "
	-0.16	18	DDR	Merino	Mullaney *et al.* (1970)
	-0.01	15 - 16	PHS	S.A. Merino	Gregory (1982b)
CHG x TCN	0.54	14	PHS	Romney	Chopra (1978)
	0.31 - 0.54	13	PHS	"	Blair (1981)
CHG x Y	0.15	14	PHS	Romney	Chopra (1978)
	-0.53 - 0.38	13	PHS	"	Blair (1981)
	0.09	18	DDR	Merino	Mullaney *et al.* (1970)
	-0.20	15 - 16	PHS	S.A. Merino	Gregory (1982b)
CHG x MFD	0.54	14	PHS	Romney	Chopra (1978)
	-0.29 - 0.20	13	PHS	"	Blair (1981)

TABLE 6.2: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	METHOD	BREED	REFERENCE
CHG x MFD	-0.29 - 0.20	13	PHS	Romney	Blair (1981)
	0.09	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.10	14 - 15	DDR	"	" " " "
	-0.46	18	DDR	Merino	Mullaney *et al.* (1970)
	0.07	15 - 16	PHS	S.A. Merino	Gregory (1982b)
SG x Y	0.36	14	PHS	Romney	Chopra (1978)
SG x MFD	0.46	14	PHS	Romney	Chopra (1978)
GCG x SCG	0.85	14	PHS	Romney	Chopra (1978)
GCG x SL	-0.06	14	PHS	Romney	Chopra (1978)
	-0.36	14	PHS	Romney x	Bigham *et al.* (1983)
	0.40	18	DDR	Merino	Mullaney *et al.* (1970)
GCG x Y	0.67	14	PHS	Romney	Chopra (1978)
	0.82	18	DDR	Merino	Mullaney *et al.* (1970)
GCG x MFD	0.43	14	PHS	Romney	Chopra (1978)
	-0.53	14	PHS	Romney x	Bigham *et al.* (1983)
	-0.32	18	DDR	Merino	Mullaney *et al.* (1970)
SCG x Y	0.44	14	PHS	Romney	Chopra (1978)
SCG x MFD	0.30	14	PHS	Romney	Chopra (1978)
SL x Y	0.03	14	PHS	Romney	Chopra (1978)
	0.53 - 0.95	13	PHS	"	Blair (1981)
	0.63		DDR	Merino	Morley (1955a)
	0.54		DDR	"	Beattie (1962)
	0.36	16	DDR	"	Brown and Turner (1968)
	0.42	18	DDR	"	Mullaney *et al.* (1970)
	0.27	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.13	15 - 16	DDR	" " "	" "
SL x MFD	0.68	14	DDR	Romney	Tripathy (1966)
	0.41	14	PHS	"	Chopra (1978)
	0.43 - 0.82	13	PHS	"	Blair (1981)
	0.53	14 - 15	PHS	Perendale	Elliott *et al.* (1979)
	0.31	14 - 15	DDR	"	" " " "
	0.44	16	DDR	Merino	Schinckel (1958)
	-0.11		DDR	"	Beattie (1962)
	0.03	16	DDR	"	Brown and Turner (1968)
	0.01	18	DDR	"	Mullaney *et al.* (1970)
	0.24	15 - 16	DDR	S.A. Merino	Gregory (1982b)
	0.24	15 - 16	PHS	" " "	" "

TABLE 6.2: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	METHOD	BREED	REFERENCE
TCN x Y	-0.36	14	PHS	Romney	Chopra (1978)
	-0.34 - 0.50	13	PHS	"	Blair (1981)
TCN x MFD	0.93	14	PHS	Romney	Chopra (1978)
	-0.50 - -0.37	13	PHS	"	Blair (1981)
Y x MFD	0.33	14	PHS	Romney	Chopra (1978)
	0.27 - 0.96	14	PHS	"	Blair (1981)
	0.03		DDR	Merino	Beattie (1962)
	0.12	16	DDR	"	Brown and Turner (1968)
	-0.03	18	DDR	"	Mullaney *et al.* (1970)
	0.15	15 - 16	PHS	S.A. Merino	Gregory (1982b)
	0.00	15 - 16	DDR	" " "	" "

See Table 5.1 for Legend

SDR = Sire-Daughter Regression

(v) The correlations for HLW/QN, HLW/CHG, HLW/SL, HLW/Y, GFW/CHG, CHG/QN, CHG/SL, CHG/Y, CHG/MFD, GCG/SL, GCG/MFD, TCN/Y and TCN/MFD showed a swing from positive to negative values for different breed calculations.

The following conclusions are drawn from Tables 6.1 and 6.2:

(i) The estimates obtained in this study for the genetic correlations between greasy fleece weight and other fleece traits are in line with the reviewed range of estimates reported by the literature, except those with MFD.

(ii) The correlation between HLW and SL compares well with Chopra's (1978) finding and the upper value reported by Blair (1981).

(iii) The high negative correlation (-1.02) found for MFD/SL is at variance with previous findings except that Beattie (1962) reported a value of -0.11 for Merinos which is in the same direction but of higher magnitude.

(iv) The correlation between CFW and GCG (0.52) is higher than the values of 0.13 obtained for Romneys by Chopra (1978) and 0.17 derived for Merinos by Mullaney *et al.* (1970).

(v) The genetic correlation between SCG and Y (0.77) is higher than the value of 0.44 reported by Chopra (1978) who worked with Romneys.

(vi) The high positive correlation between GCG and Y (0.96) is in line with the results obtained by Chopra (1978) for Romneys and Mullaney *et al.* (1970) for Merinos.

Some other comparisons of the results found in this study and published estimates are:

(i) Turner (1977) observed that clean scoured yield increased under selection for high clean wool weight and reported an average of 0.5 for the genetic correlation between CFW and Y, value similar to the 0.44 found for Merpers. Moreover, Turner (1977) suggested that if Y became too high some fibre damage may result from weathering and dust, therefore it is necessary to impose a ceiling on Y when selecting for CFW.

(ii) Negative genetic correlations of MFD with SL and MFD with CHG were also reported by Mullaney *et al.* (1970) for Polwarths aged 30 months and Merinos aged 18 months old respectively.

(iii) Although it is not reported in Table 6.2 the genetic correlation between SL and QN is medium to high negative as reported by Chopra (1978) for Romneys (-0.53), Elliott *et al.* (1979) for Perendales (-0.63) and Mullaney *et al.* (1970) for Merinos (-0.66). In the present study the figure is <-1.5.

(iv) Though the present genetic correlations do not permit precise conclusions to be drawn, an outline of the general pattern of direct and indirect response to selection with reference to genetic improvement of hogget liveweight and wool traits has been carried out.

6.2.2 Phenotypic Correlations

According to the criteria defined by Brown and Turner (1968) the phenotypic correlations shown in Table 6.1 can be classified as:

HIGH NEGATIVE:	SL/CPC.
MEDIUM NEGATIVE:	GFW/CPC, CFW/CPC, QN/HG and QN/SL.
LOW NEGATIVE:	HLW/SG, HLW/Y, GFW/QN, GFW/SG, GFW/Y, CFW/QN, CFW/SG, CFW/TCN, QN/CHG, QN/MFD, CHG/TCN, CHG/CPC, HG/TCN, HG/CPC, SG/SL, SG/MFD, GCG/MFD, SCG/MFD, SL/Y, TCN/Y and CPC/MFD.
LOW POSITIVE:	HLW/MFD, GFW/MFD, CFW/CHG, CFW/MFD, QN/CG, CHG/HG, CHG/Y, HG/SL, CG/GCG, SG/CPC, SG/Y, GCG/SCG and SL/MFD.
MEDIUM POSITIVE:	HLW/CFW, HLW/SL, CFW/SL and QN/TCN.
HIGH POSITIVE:	HLW/GFW, GFW/CFW, GFW/SL, QN/CPC and TCN/CPC.

The other correlations fall into the negligible range from -0.2 to +0.2.

Table 6.1 deserves some comments in relation to the phenotypic correlations:

(i) As expected, GFW and CFW have medium to high positive correlations with MFD and SL (0.38 and 0.37, and 0.60 and 0.51 respectively), and negative correlations with QN and CPC.

(ii) The low correlation between MFD and QN (-0.30) indicates that, for accurate assessment of wool fineness, fibre diameter should be measured.

(iii) The correlations show that the sheep with the heaviest fleeces are those with the highest liveweight, coarse wool, long staples and less crimp per centimetre.

(iv) GFW and CFW had negligible correlations with HG, CG, GCG, SCG, TCN and Y, low positive with CHG and low negative with SG whereas MFD had a negligible negative correlation with HG.

(v) The correlation between colour before scouring and after scouring (0.38) suggests that a certain amount of yellow discoloration may be obscured by grease and fleece contaminants. It is lower than the values of 0.60 and 0.62 derived for Romneys by Sumner (1969). However, Turner (1977) suggested that due to the low correlation greasy colour is not a useful guide of scoured colour.

(vi) The correlation between CG and GCG (0.29) found in this study supports Sumner's (1969) conclusion that cotting is associated with discoloration.

Table 6.3 shows the range of phenotypic correlations reviewed in the literature for the breeds which originated the Merpers. It is noticeable that for some wool traits, the only source is Sumner's (1969) study of the effect of two stocking levels (control and intensive) on wool production.

On comparing the phenotypic correlations reported in Tables 6.1 and 6.3, it can be seen that:

(i) There is general agreement between the estimates of this study and their corresponding estimates in Table 6.3. Some exceptions are HLW/SG, GFW/HG, GFW/SG, CFW/CHG, QN/CHG, QN/HG, CHG/TCN, HG/CG, HG/SL, HG/CPC, SG/SL, SG/CPC, SL/TCN and SL/Y.

(ii) The high correlation between HLW and GFW (0.66) is in agreement with previous estimates of 0.61 and 0.52 (Tripathy, 1966 and Sumner, 1969 respectively) derived from Romney ewe hogget data whereas the moderately correlation (0.56) between HLW and CFW is similar to the upper value reported by Blair (1981).

(iii) The high positive correlation between GFW and CFW (0.94) is similar to the estimates derived by Blair (1981) for the Romneys while the low association between GFW and MFD (0.38) is in good agreement with the figure presented by Mullaney *et al.* (1970) for Merinos and the lower limit reported by Blair (1981)

TABLE 6.3: PHENOTYPIC CORRELATION ESTIMATES BETWEEN EWE HOGGET LIVEWEIGHT AND VARIOUS WOOL TRAITS IN ROMNEY, PERENDALE AND MERINO SHEEP

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
HLW x GFW	0.61	14	Romney	Tripathy (1966)
	0.50 - 0.52	14	"	Sumner (1969)
	0.44	13	"	Baker *et al.* (1979)
	0.40	16	"	" " " "
	0.47 - 0.55	13	"	Blair (1981)
	0.39	14 - 15	Perendale	Elliott *et al.* (1979)
	0.36		Merino	Morley (1955a)
	0.24	16	"	Brown and Turner (1968)
	0.37	15 - 16	S.A. Merino	Gregory (1982b)
HLW x CFW	0.41 - 0.50	13	Romney	Blair (1981)
	0.37		Merino	Morley (1955a)
	0.23	16	"	Brown and Turner (1968)
	0.36	15 - 16	S.A. Merino	Gregory (1982b)
HLW x QN	0.08 - 0.10	14	Romney	Sumner (1969)
	-0.07 - -0.02	13	"	Blair (1981)
	-0.03	14 - 15	Perendale	Elliott *et al.* (1979)
HLW x CHG	0.21 - 0.26	14	Romney	Sumner (1969)
	-0.02 - 0.07	13	"	Blair (1981)
	0.00	14 - 15	Perendale	Elliott *et al.* (1979)
	-0.08	15 - 16	S.A. Merino	Gregory (1982b)
HLW x HG	0.01 - 0.05	14	Romney	Sumner (1969)
HLW x CG	0.08 - 0.25	14	Romney	Sumner (1969)
HLW x SG	0.11 - 0.29	14	Romney	Sumner (1969)
HLW x GCG	-0.06 - 0.33	14	Romney	Sumner (1969)
HLW x SCG	-0.30 - 0.09	14	Romney	Sumner (1969)
HLW x SL	0.24	14	Romney	Tripathy (1966)
	0.01 - 0.18	14	"	Sumner (1969)
	0.15 - 0.26	13	"	Blair (1981)
	0.13	14 - 15	Perendale	Elliott *et al.* (1979)
	0.10		Merino	Morley (1955a)
	0.06	16	"	Brown and Turner (1968)
	0.14	15 - 16	S.A. Merino	Gregory (1982b)
HLW x TCN	0.04 - 0.08	13	Romney	Blair (1981)
HLW x CPC	-0.09	14	Romney	Tripathy (1966) [1]
	0.04 - 0.17	14	"	Sumner (1969) [1]
	-0.07 - -0.05	13	"	Blair (1981) [1]

TABLE 6.3: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
HLW x CPC	0.05		Merino	Morley (1955a)[1]
	0.04	16	"	Brown and Turner (1968)[1]
	0.05	15 - 16	S.A. Merino	Gregory (1982b)[1]
HLW x Y	0.06 - 0.11	14	Romney	Sumner (1969)
	-0.04 - 0.04	13	"	Blair (1981)
	0.09		Merino	Morley (1955a)
	0.06	16	"	Brown and Turner (1968)
	0.03	15 - 16	S.A. Merino	Gregory (1982b)
HLW x MFD	0.29	14	Romney	Tripathy (1966)
	0.19 - 0.27	13	"	Blair (1981)
	0.15	14 - 15	Perendale	Elliott *et al.* (1979)
	0.13	16	Merino	Brown and Turner (1968)
	0.03	15 - 16	S.A. Merino	Gregory (1982)
GFW x CFW	0.94 - 0.97	13	Romney	Blair (1981)
	0.81		Merino	Morley (1955a)
	0.85	16	"	Brown and Turner (1968)
	0.82	15 - 16	S.A. Merino	Gregory (1982b)
GFW x QN	-0.33	14	Romney	Rae (1958a)
	-0.07 - -0.03	14	"	Sumner (1969)
	-0.26 - -0.22	13	"	Blair (1981)
	-0.16	14 - 15	Perendale	Elliott *et al.* (1979)
	-0.36		Merino	Mullaney *et al.* (1970)
GFW x CHG	0.15	14	Romney	Rae (1958a)
	0.12 - 0.22	14	Romney	Sumner (1969)
	0.06 - 0.07	13	"	Blair (1981)
	0.23	14 - 15	Perendale	Elliott *et al.* (1979)
	-0.09		Merino	Mullaney *et al.* (1970)
	-0.18	15 - 16	S.A. Merino	Gregory (1982b)
GFW x HG	-0.35 - -0.32	14	Romney	Sumner (1969)
	-0.16		Merino	Mullaney *et al.* (1970)
GFW x CG	-0.10 - 0.23	14	Romney	Sumner (1969)
GFW x SG	0.26 - 0.27	14	Romney	Sumner (1969)
GFW x GCG	-0.06 - 0.03	14	Romney	Sumner (1969)
	-0.12		Merino	Mullaney *et al.* (1970)
GFW x SCG	-0.26 - -0.15	14	Romney	Sumner (1969)
GFW x SL	0.45	14	Romney	Rae (1958a)
	0.48	14	"	Tripathy (1966)

TABLE 6.3: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
GFW x SL	0.22 - 0.51	14	Romney	Sumner (1969)
	0.40 - 0.50	13	"	Blair (1981)
	0.44	14 - 15	Perendale	Elliott *et al.* (1979)
	0.30		Merino	Morley (1955a)
	0.25	16	"	Brown and Turner (1968)
	0.23		"	Mullaney *et al.* (1970)
	0.19	15 - 16	S.A. Merino	Gregory (1982b)
GFW x TCN	-0.01 - 0.08	13	Romney	Blair (1981)
GFW x CPC	-0.17	14	Romney	Tripathy (1966) [1]
	-0.08 - 0.07	14	"	Sumner (1969) [1]
	-0.26 - -0.19	13	"	Blair (1981) [1]
	-0.21		Merino	Morley (1955a) [1]
	-0.21	16	"	Brown and Turner (1968) [1]
	-0.15	15 - 16	S.A. Merino	Gregory (1982b) [1]
GFW x Y	0.17 - 0.29	14	Romney	Sumner (1969)
	0.13 - 0.16	13	"	Blair (1981)
	-0.10		Merino	Morley (1955a)
	-0.05	16	"	Brown and Turner (1968)
	0.04		"	Mullaney *et al.* (1970)
	-0.16	15 - 16	S.A. Merino	Gregory (1982b)
GFW x MFD	0.53	14	Romney	Tripathy (1966)
	0.37 - 0.56	13	"	Blair (1981)
	0.50	14 - 15	Perendale	Elliott *et al.* (1979)
	0.13	16	Merino	Brown and Turner (1968)
	0.36		"	Mullaney *et al.* (1970)
	0.13	15 - 16	S.A. Merino	Gregory (1982b)
CFW x QN	-0.35 - -0.33	13	Romney	Blair (1981)
	-0.45		Merino	Mullaney *et al.* (1970)
CFW x CHG	0.01 - 0.06	13	Romney	Blair (1981)
	-0.02		Merino	Mullaney *et al.* (1970)
	-0.24	15 - 16	S.A. Merino	Gregory (1982)
CFW x HG	-0.12		Merino	Mullaney *et al.* (1970)
CFW x GCG	0.10		Merino	Mullaney *et al.* (1970)
CFW x SL	0.46 - 0.55	13	Romney	Blair (1981)
	0.39		Merino	Morley (1955a)
	0.37	16	"	Brown and Turner (1968)
	0.37		"	Mullaney *et al.* (1970)
	0.32	15 - 16	S.A. Merino	Gregory (1982b)

TABLE 6.3: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
CFW x TCN	-0.08 - -0.01	13	Romney	Blair (1981)
CFW x CPC	-0.34 - -0.30	13	Romney	Blair (1981) [1]
	-0.32		Merino	Morley (1955a) [1]
	-0.37	16	"	Brown and Turner (1968) [1]
	-0.28	15 - 16	S.A. Merino	Gregory (1982b) [1]
CFW x Y	0.39 - 0.46	13	Romney	Blair (1981)
	0.49		Merino	Morley (1955a)
	0.48	16	"	Brown and Turner (1968)
	0.41	15 - 16	S.A. Merino	Gregory (1982b)
CFW x MFD	0.42 - 0.59	13	Romney	Blair (1981)
	0.14	16	Merino	Brown and Turner (1968)
	0.31		"	Mullaney *et al.* (1970)
	0.13	15 - 16	S.A. Merino	Gregory (1982)
QN x CHG	0.06	14	Romney	Rae (1958)
	0.39 - 0.58	14	"	Sumner (1969)
	1.11 - 1.13	13	"	Blair (1981)
	0.13	14 - 15	Perendale	Elliott *et al.* (1979)
	0.29		Merino	Mullaney *et al* (1970)
QN x HG	0.15 - 0.43	14	Romney	Sumner (1969)
	0.43		Merino	Mullaney *et al.* (1970)
QN x CG	0.20 - 0.23	14	Romney	Sumner (1969)
QN x SG	-0.16 - -0.07	14	Romney	Sumner (1969)
QN x GCG	0.02 - 0.15	14	Romney	Sumner (1969)
	0.05		Merino	Mullaney *et al.* (1970)
QN x SCG	-0.04 - 0.09	14	Romney	Sumner (1969)
QN x SL	-0.54	14	Romney	Rae (1958a)
	-0.49 - -0.46	14	"	Sumner (1969)
	-0.58 - -0.53	13	"	Blair (1981)
	-0.45	14 - 15	Perendale	Elliott *et al.* (1979)
	-0.30		Merino	Mullaney *et al.* (1970)
QN x TCN	0.62 - 0.66	13	Romney	Blair (1981)
QN x CPC	0.75 - 0.83	14	Romney	Sumner (1969) [1]
	0.79 - 0.80	13	"	Blair (1981) [1]
	0.60		Merino	Mullaney *et al.* (1970) [1]

TABLE 6.3: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
QN x Y	-0.45 - -0.19	14	Romney	Sumner (1969)
	-0.43 - -0.39	13	"	Blair (1981)
	-0.32		Merino	Mullaney *et al.* (1970)
QN x MFD	-0.42 - -0.33	13	Romney	Blair (1981)
	-0.26	14 - 15	Perendale	Elliott *et al.* (1979)
	-0.31		Merino	Mullaney *et al.* (1970)
CHG x HG	0.11 - 0.41	14	Romney	Sumner (1969)
	0.60		Merino	Mullaney *et al.* (1970)
CHG x CG	0.32 - 0.52	14	Romney	Sumner (1969)
CHG x SG	0.03 - 0.15	14	Romney	Sumner (1969)
CHG x GCG	0.14 - 0.17	14	Romney	Sumner (1969)
	0.15		Merino	Mullaney *et al.* (1970)
CHG x SCG	0.08 - 0.15	14	Romney	Sumner (1969)
CHG x SL	0.20	14	Romney	Rae (1958a)
	-0.26 - -0.11	14	"	Sumner (1969)
	-0.15 - -0.09	13	"	Blair (1981)
	0.10	14 - 15	Perendale	Elliott *et al.* (1979)
	0.16		Merino	Mullaney *et al.* (1970)
	-0.12	15 - 16	S.A. Merino	Gregory (1982b)
CHG x TCN	0.40 - 0.44	13	Romney	Blair (1981)
CHG x CPC	0.56 - 0.61	14	Romney	Sumner (1969)[1]
	0.32 - 0.39	13	"	Blair (1981)[1]
	0.19		Merino	Mullaney *et al.* (1970)[1]
	0.04	15 - 16	S.A. Merino	Gregory (1982b)[1]
CHG x Y	-0.16 - -0.02	14	Romney	Sumner (1969)
	-0.11 - 0.01	13	"	Blair (1981)
	0.11		Merino	Mullaney *et al.* (1970)
	-0.13	15 - 16	S.A. Merino	Gregory (1982b)
CHG x MFD	-0.06 - -0.02	13	Romney	Blair (1981)
	0.12	14 - 15	Perendale	Elliott *et al.* (1979)
	-0.34		Merino	Mullaney *et al.* (1970)
	-0.20	15 - 16	S.A. Merino	Gregory (1982b)
HG x CG	0.21	14	Romney	Sumner (1969)
HG x SG	-0.24 - 0.03	14	Romney	Sumner (1969)

TABLE 6.3: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
HG x GCG	0.05 - 0.16	14	Romney	Sumner (1969)
	0.23		Merino	Mullaney *et al.* (1970)
HG x SCG	0.14 - 0.20	14	Romney	Sumner (1969)
HG x SL	-0.43 - -0.13	14	Romney	Sumner (1969)
	0.06		Merino	Mullaney *et al.* (1970)
HG x CPC	0.21 - 0.43	14	Romney	Sumner (1969)[1]
	0.31		Merino	Mullaney *et al.* (1970)[1]
HG x Y	-0.35 - -0.12	14	Romney	Sumner (1969)
	0.04		Merino	Mullaney *et al.* (1970)
HG x MFD	-0.41		Merino	Mullaney *et al.* (1970)
CG x SG	0.09 - 0.13	14	Romney	Sumner (1969)
CG x GCG	0.21 - 0.25	14	Romney	Sumner (1969)
CG x SCG	0.06 - 0.21	14	Romney	Sumner (1969)
CG x SL	-0.02	14	Romney	Sumner (1969)
CG x CPC	0.25 - 0.36	14	Romney	Sumner (1969)[1]
CG x Y	-0.07 - 0.10	14	Romney	Sumner (1969)
SG x GCG	-0.02 - 0.25	14	Romney	Sumner (1969)
SG x SCG	0.04 - 0.24	14	Romney	Sumner (1969)
SG x SL	0.22 - 0.32	14	Romney	Sumner (1969)
SG x CPC	-0.13 - -0.07	14	Romney	Sumner (1969)[1]
SG x Y	0.02 - 0.14	14	Romney	Sumner (1969)
GCG x SCG	0.60 - 0.62	14	Romney	Sumner (1969)
GCG x SL	0.13 - 0.25	14	Romney	Sumner (1969)
	0.16		Merino	Mullaney *et al.* (1970)
GCG x CPC	-0.03 - 0.08	14	Romney	Sumner (1969)[1]
	0.07		Merino	Mullaney *et al.* (1970)[1]
GCG x Y	-0.03 - 0.30	14	Romney	Sumner (1969)
	0.42		Merino	Mullaney *et al.* (1970)

TABLE 6.3: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
GCG x MFD	-0.13		Merino	Mullaney *et al.* (1970)
SCG x SL	0.04 - 0.14	14	Romney	Sumner (1969)
SCG x CPC	-0.03 - 0.08	14	Romney	Sumner (1969) [1]
SCG x Y	0.03 - 0.21	14	Romney	Sumner (1969)
SL x TCN	-0.17 - -0.11	13	Romney	Blair (1981)
SL x CPC	-0.63	14	Romney	Tripathy (1966) [1]
	-0.55 - -0.40	14	"	Sumner (1969) [1]
	-0.64 - -0.58	13	"	Blair (1981) [1]
	-0.19		Merino	Mullaney *et al.* (1970) [1]
	-0.28	15 - 16	S.A. Merino	Gregory (1982b) [1]
SL x Y	0.18 - 0.39	14	Romney	Sumner (1969)
	0.29 - 0.36	13	"	Blair (1981)
	0.25		Merino	Morley (1955a)
	0.29	16	"	Brown and Turner (1968)
	0.35		"	Mullaney *et al.* (1970)
	0.25	15 - 16	S.A. Merino	Gregory (1982b)
SL x MFD	0.48	14	Romney	Tripathy (1966)
	0.37 - 0.51	13	"	Blair (1981)
	0.34	14 - 15	Perendale	Elliott *et al.* (1979)
	0.11	16	Merino	Brown and Turner (1968)
	-0.04		"	Mullaney *et al.* (1970)
	0.13	15 - 16	S.A. Merino	Gregory (1982b)
TCN x CPC	0.81 - 0.87	13	Romney	Blair (1981)
TCN x Y	-0.29 - -0.24	13	Romney	Blair (1981)
TCN x MFD	-0.22 - -0.20	13	Romney	Blair (1981)
CPC x Y	-0.35 - -0.18	14	Romney	Sumner (1969) [1]
	-0.40 - -0.36	13	"	Blair (1981) [1]
	-0.26		Merino	Morley (1955a) [1]
	-0.34	16	"	Brown and Turner (1968) [1]
	-0.20		"	Mullaney *et al.* (1970) [1]
	-0.25	15 - 16	S.A. Merino	Gregory (1982b) [1]
CPC x MFD	-0.37	14	Romney	Tripathy (1966) [1]
	-0.43 - -0.35	13	Romney	Blair (1981) [1]
	-0.13	16	Merino	Brown and Turner (1968) [1]
	-0.25		"	Mullaney *et al.* (1970) [1]
	-0.20	15 - 16	S.A. Merino	Gregory (1982b)

TABLE 6.3: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
Y x MFD	0.21 - 0.32	13	Romney	Blair (1981)
	0.05	16	Merino	Brown and Turner (1968)
	0.01 (-0.08 0.07)		"	Mullaney *et al.* (1970)
	0.04	15 - 16	S.A. Merino	Gregory (1982b)

[1] = Crimps per inch

for Romneys.

(iv) The correlations between HLW and SL, and GFW and SL found in the present study are higher than the values reported in Table 6.3.

(v) The negative association between GFW and QN, and CFW and QN agrees with the values reported by Rae (1958a) and Blair (1981) for Romneys and Mullaney *et al.* (1970) for Merinos.

(vi) MFD and SL tend to be positively associated (0.39), figure which is in agreement with the lower limit (0.37) found by Blair (1981) for Romneys and the estimate (0.44) reported by Elliott *et al.* (1979) for Perendales.

(vii) Brown and Turner (1968) showed similar negative correlations for CPC with GFW, CFW, Y and SL for Medium Peppin Merinos as observed in the Merpers. In their data there was a negligible negative correlation between CPC and MFD (-0.13) while Mullaney *et al.* (1970) derived a correlation of -0.25 for the same traits working with Merinos. For Merpers the correlation was still negative but lower in magnitude (-0.35), hence, as has been suggested by Roberts and Dunlop (1957) and Brown and Turner (1968) for Merinos, crimp is also a poor indicator of fineness for Merpers.

(viii) The correlation between GCG and SCG found in this study (0.38) is lower than the figures 0.60 - 0.62 reported by Sumner (1969) for Romneys.

6.2.3 Environmental Correlations

From Table 6.1 and following Brown and Turner's (1968) classification, the environmental correlations can be summarized as:

HIGH NEGATIVE:	QN/GCG.
MEDIUM NEGATIVE:	HLW/Y, CFW/QN, CFW/TCN, QN/Y, GCG/Y and TCN/Y.
LOW NEGATIVE:	HLW/SG, GFW/QN, GFW/TCN, GFW/Y, CFW/GCG, QN/CHG, CHG/SL, CHG/TCN, SG/MFD and SCG/Y.
LOW POSITIVE:	HLW/SL, CFW/CHG, CHG/MFD, GCG/SCG and GCG/MFD.
MEDIUM POSITIVE:	HLW/CFW, HLW/MFD, SG/Y.
HIGH POSITIVE:	HLW/GFW, GFW/CFW, GFW/SL, GFW/MFD, CFW/SL, CFW/MFD, QN/TCN and SL/MFD.

All other combinations fall into the negligible range from -0.2 to +0.2.

Hogget liveweight, greasy and clean fleece weight and staple length will improve under favourable environments due to the moderate to high environmental and phenotypic correlations among HLW/GFW, HLW/CFW, HLW/SL, GFW/CFW and GFW/SL, as can be seen in Table 6.1.

Published environmental correlations between hogget liveweight and other wool traits are listed in Table 6.4. The information available on this type of correlation is scarce. In most cases the figures found in this study are in the same direction but are higher than those reported in the literature whereas others have a different sign, e.g. HLW/QN, HLW/Y, CFW/CHG, QN/CHG, QN/MFD, CHG/Y and SL/Y.

Table 6.1 shows a difference in sign and magnitude between some environmental and genetic correlations, indicating that genetic and environmental sources of variation affect the traits through different physiological mechanisms.

6.3 APPLICABILITY OF RESULTS

In the previous chapter, the use of heritability in conjunction with a known selection differential allowed the prediction of the rate of genetic gain resulting from selecting for one trait alone but calculations to indicate the effect which selection pressure applied to one trait may have on another trait were not carried out.

Knowledge of the genetic correlation between traits plus heritabilities for both traits allows the evaluation of the relative efficiency of selection in terms of genetic gain in the two traits.

Turner and Young (1969) discussed the relative gains under indirect and direct selection. Since a correlated trait, 2, can change when another 1, is under selection and if traits 2 and 1 have heritabilities h^2_2 and h^2_1 respectively and a genetic correlation r_G, then the relative efficiency of the two methods of selection, in terms of genetic gain can be simply compared by calculating the

TABLE 6.4: ENVIRONMENTAL CORRELATION ESTIMATES BETWEEN EWE HOGGET LIVEWEIGHT AND VARIOUS WOOL TRAITS IN ROMNEY, PERENDALE AND MERINO SHEEP

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
HLW x GFW	0.12	14 - 15	Perendale	Elliott (1975)
	0.48	15 - 16	S.A. Merino	Gregory (1982b)
HLW x CFW	0.46	15 - 16	S.A. Merino	Gregory (1982b)
HLW x QN	-0.04	14 - 15	Perendale	Elliott (1975)
HLW x CHG	0.14	14 - 15	Perendale	Elliott (1975)
	-0.11	15 - 16	S.A. Merino	Gregory (1982b)
HLW x SL	0.06	14 - 15	Perendale	Elliott (1975)
	0.15	15 - 16	S.A. Merino	Gregory (1982b)
HLW x Y	0.04	15 - 16	S.A. Merino	Gregory (1982b)
HLW x MFD	0.12	14 - 15	Perendale	Elliott (1975)
	0.10	15 - 16	S.A. Merino	Gregory (1982b)
GFW x CFW	0.87	15 - 16	S.A. Merino	Gregory (1982b)
GFW x QN	-0.11	14 - 15	Perendale	Elliott (1975)
GFW x CHG	0.03	14 - 15	Perendale	Elliott (1975)
	-0.21	15 - 16	S.A. Merino	Gregory (1982b)
GFW x SL	0.00	14 - 15	Perendale	Elliott (1975)
	0.20	15 - 16	S.A. Merino	Gregory (1982b)
GFW x Y	-0.07	15 - 16	S.A. Merino	Gregory (1982b)
GFW x MFD	0.04	14 - 15	Perendale	Elliott (1975)
	0.31	15 - 16	S.A. Merino	Gregory (1982b)
CFW x CHG	-0.25	15 - 16	S.A. Merino	Gregory (1982b)
CFW x SL	0.29	15 - 16	S.A. Merino	Gregory (1982b)
CFW x Y	0.40	15 - 16	S.A. Merino	Gregory (1982b)
CFW x MFD	0.26	15 - 16	S.A. Merino	Gregory (1982b)
QN x CHG	0.11	14 - 15	Perendale	Elliott (1975)
QN x MFD	0.03	14 - 15	Perendale	Elliott (1975)
CHG x SL	0.03	14 - 15	Perendale	Elliott (1975)
	-0.15	15 - 16	S.A. Merino	Gregory (1982b)

TABLE 6.4: (CONTINUED)

TRAITS	ESTIMATE	AGE (MONTHS)	BREED	REFERENCE
CHG x Y	-0.11	15 - 16	S.A. Merino	Gregory (1982b)
CHG x MFD	0.01	14 - 15	Perendale	Elliott (1975)
	-0.00	15 - 16	S.A. Merino	Gregory (1982b)
SL x Y	0.25	15 - 16	S.A. Merino	Gregory (1982b)
SL x MFD	0.02	14 - 15	Perendale	Elliott (1975)
	0.22	15 - 16	S.A. Merino	Gregory (1982b)
Y x MFD	-0.07	15 - 16	S.A. Merino	Gregory (1982b)

ratio (Q) of the two gains:

$$Q = \frac{\text{Gain by indirect selection}}{\text{Gain by direct selection}}$$

$$Q = r_G \frac{h_1}{h_2}$$

where $h_1 = \sqrt{h^2_1}$ and $h_2 = \sqrt{h^2_2}$

Moreover, Turner and Young (1969) pointed out that indirect selection (i.e. selection for trait 1 when a change in trait 2 is required rather than to select direct for 2 itself) has advantages:

(i) When the two traits are highly correlated genetically and h^2_1 is sufficiently greater than h^2_2 to lead to a correlated response higher than the direct response. On this topic Young *et al.* (1965) showed that if the genetic correlation is only 0.5, the ratio h^2_1/h^2_2 must be greater than 4.0 before indirect selection gives greater gains than direct.

(ii) Where trait 1 is cheaper to measure than trait 2 or becomes available earlier in life.

The relative efficiency of direct and indirect selection for some traits is given in Table 6.5. The relative efficiency was derived using genetic parameters of this study estimated by the daughter-dam regression method.

Indirect selection for CFW using GFW is 73% as efficient as direct selection. Extra genetic gain obtained by selecting for CFW would be unlikely to compensate for the extra costs incurred in

TABLE 6.5: SOME PREDICTED CORRELATED RESPONSES TO SELECTION IN MERPER SHEEP

TRAIT UNDER SELECTION	CORRELATED TRAIT	EFFICIENCY OF SELECTION
HLW	GFW	0.65
HLW	CFW	0.51
GFW	HLW	0.69
CFW	HLW	0.76
GFW	CFW	0.73
GFW	SL	0.44
GCG	SCG	1.79
MFD	SG	2.78

obtaining an estimate of the clean scoured yield. Hence, GFW is recommended for ewe and preliminary ram selection whereas CFW is useful for final ram selection.

The correlated response to selection for GCG would be 1.8 times the direct response. This indicates the possibility of achieving white wool in the Merper flock by using GCG as a selection criteria.

From the estimates of the genetic parameters between MFD and SG the ratio of the correlated response through MFD selection is about 2.8 times that of the direct response for SG.

As the degree and direction of genetic correlations may change under selection, any selection programme should include re-estimating genetic correlations every two or three generations (Bohren *et al.*,

1966) so that a real idea of the correlated responses among traits can be drawn.

Combining trait 1 and trait 2 in a selection index is always better than using trait 1 or trait 2 alone, and especially so if, for heritabilities that are similar in magnitude, the genetic correlation is small and the phenotypic correlation is close to unity, or if, for greatly disparate heritabilities, the genetic correlation is appreciably large (Searle, 1965).

The efficiency with which a selection index actually identifies the individuals of higher genetic merit, is affected by the reliability of the parameters included. The genetic and phenotypic correlations derived in this study have to be taken with caution if they are going to serve as the basis of an index calculated along the lines suggested by Hazel (1943). James (1982) has stated that too much reliance should not be placed on indirect pathways of genetic improvement since selection responses are more difficult to predict.

CHAPTER SEVEN

SELECTION OBJECTIVES AND SELECTION CRITERIA FOR THE MERPER FLOCK

7.1 INTRODUCTION

In dual purpose sheep, profitability is a function of both meat and wool production. Therefore a programme dealing with their genetic improvement should consider many different traits when defining the selection objective.

Profit maximization based on the establishment of a superior flock rather than an outstanding individual is the main aim (Rae, 1958b) and this is most rapidly achieved using a selection index (Hazel, 1943).

The aggregate genotype of an animal (H) was defined by Hazel (1943) as the sum of its several genotypes (assuming a distinct genotype for each economic trait), each genotype being weighted according to the economic weight of that trait. In mathematical terms it can be expressed as follows:

$$H = \Sigma a_i G_i$$

where a_i is the economic weight of the i^{th} trait

G_i is the genotype (additive breeding value) of the i^{th} trait.

Morris *et al.* (1982) used equation in this form to define selection objectives. Gjedrem (1972) showed that all traits with non-zero values of a_i should be included in the objective.

Selection criteria are those traits which are assessed in order to predict the objective (Morris *et al.*, 1982). Some traits in the selection objective may not be used as selection criteria. The traits considered as selection criteria may be combined in a selection index (I) where they are given suitable weights dependent upon the heritabilities, variances and economic weights of traits in the objective and upon the correlations between all the traits in the objective and all the criteria. Mathematically, it can be defined as:

$$I = \Sigma b_i X_i$$

where b_i is the weighting factor of the i^{th} trait

X_i is the record of the animal for the i^{th} trait in the index expressed as a deviation from its mean.

Ponzoni (1979) pointed out that selection criteria need to be capable of being measured preferably before breeding age, with minimum cost and technical difficulties.

According to Henderson (1963) the selection index can be used for several different purposes, e.g.:

(i) Selection on a single trait using information on the individual and certain of its relatives.

(ii) Selection on two or more traits using records made by the individual.

(iii) Selection on two or more traits using records on the individual and its relatives.

Rönningen (1974) has summarized the properties associated with the selection index as follows:

(i) The correlation between H and I is maximized.

(ii) The expected squared difference between I and H (i.e. $E(I - H)^2$) is minimal among the linea functions of the general form of the selection index.

(iii) The probability of selecting one of the largest sample values of total merit by selecting the largest value of the index criteria is maximal.

(iv) The probability of selecting the animal of higher merit when choosing between two individuals is maximal.

(v) The genetic progress in any one-round selection by the index is maximal.

7.2 METHODS

7.2.1 Definition of the Selection Objective

To define the selection objective for improvement of the Merper flock, those traits which have the most impact on net return for farmers, which will respond to genetic selection and are correlated with other important traits, were considered.

The traits chosen to form the objective of the breeding programme were:

(i) NUMBER OF LAMBS WEANED (DAM) (NLW (DAM)): This is a measure of the ewe's reproductive and maternal ability which determines the number of animals available for sale.

(ii) WEANING WEIGHT (WW): This is a measure of the potential growth rate of the lamb to weaning and an indicator of its potential selling price.

(iii) CLEAN FLEECE WEIGHT (CFW) AND MEAN FIBRE DIAMETER (MFD) which are the major determinants of wool returns provided the fleeces do not have any specific faults, i.e. coloured fibres (Turner, 1977). When wool is used for apparel MFD is the main factor determining price per kg.

(iv) SCOURED COLOUR GRADE (SCG): Wickham (1973) pointed out that colour has a significant effect on the selling price. Pure white wool can readily be dyed to any other colour while discolorations can cause problems if the wool is not being dyed to dark colours.

Hence, the sources of financial return are:

(i) WOOL: Clean fleece weight, mean fibre diameter and scoured colour grade.

(ii) SURPLUS OFFSPRING (IN EXCESS OF REPLACEMENT NEEDS): Number of lambs weaned (dam) and weaning weight.

The technique used by Morris *et al.* (1982) was followed to derive the relative economic values of the traits in the selection objective. The economic weights were determined on the basis of the extra profit over the lifetime of an animal that would accrue from each extra unit of production. Details of the calculations are given in Appendix I.

7.2.2 Definition of the Selection Criteria

Potential selection criteria were chosen on the basis that they should be easily and cheaply assessed, and contribute towards the overall rate of genetic gain, if they were included in the index.

In the present study the selection criteria included traits in the objective as well as hogget liveweight (HLW), greasy fleece weight (GFW), quality number (QN) and greasy colour grade (GCG).

The number of dam records for NLW assumed was three.

Staple length was not considered as a selection criteria since Turner (1973) indicated that selection for clean wool weight should automatically increase length.

7.2.3 Selection Index Calculations

For the selection objective defined in Section 7.3.1 a series of full, reduced and restricted selection indices were calculated using a modified version of the genetic selection index computer program, SELIND (D.J. Garrick (Pers. Comm.); Cunningham and Mahon, 1977).

The estimates of heritability, genetic and phenotypic correlations and phenotypic standard deviations needed for the construction of the indices were chosen on the basis of:

(i) A survey of published estimates from related breeds.

(ii) The present results, lowering the estimates if there was substantial doubt concerning their validity.

The estimates used are set out in Table 7.1.

7.2.3.1 Sensitivity to Change of Genetic and Phenotypic Parameters

An investigation of the effects of varying genetic and phenotypic parameters on the efficiency of selection indices was conducted.

The parameters changed were:

GENETIC CORRELATIONS	CFW x MFD from o.25 to -0.40
	GFW x MFD from 0.25 to -0.40
PHENOTYPIC CORRELATIONS	CFW x MFD from 0.25 to 0.37
	GFW x MFD from 0.25 to 0.38

7.2.3.2 Sensitivity to Change of Economic Weights

As prices of wool and meat change with time, the sensitivity of the index to changes in the economic weights was evaluated.

The modified economic weights used are reported in Appendix II; the changes were + 49.80% in NLW (dam), + 5.63% in WW, - 18.07% in CFW, + 6.36% in MFD and - 24.53% in SCG compared with the original ones reported in Table 7.2.

7.3 RESULTS AND DISCUSSION

7.3.1 Selection Objective, Economic Weights and Selection Criteria

TABLE 7.1: GENETIC AND PHENOTYPIC PARAMETERS FOR THE TRAITS USED IN THE CONSTRUCTION OF THE SELECTION INDICES

TRAITS	PHENOTYPIC S.D	HERITABILITIES AND CORRELATIONS[1]								
		NLW	WW	HLW	GFW	CFW	MFD	QN	GCG	SCG
NLW[2]	0.60 (Lamb)	*0.10*	0.12	0.20	0.00	0.00	-0.10	0.00	0.00	0.00
WW	3.00 (Kg)	0.12	*0.16*	0.70	0.20	0.20	0.00	0.00	0.00	0.00
HLW	3.48 (Kg)	0.15	0.50	*0.20*	0.30	0.30	-0.20	-0.66	-0.08	-0.50
GFW	0.37 (Kg)	0.00	0.30	0.40	*0.20*	0.87	0.25	-0.59	0.04	0.00
CFW	0.30 (Kg)	0.00	0.30	0.30	0.94	*0.24*	0.25	-0.34	0.00	0.00
MFD	2.17 (Microns)	0.00	0.10	0.13	0.25	0.25	*0.30*	-0.30	-0.40	-0.40
QN	2.59 (QN Grade)	0.01	0.01	-0.14	-0.34	-0.38	-0.30	*0.42*	0.40	0.40
GCG	1.01 (Grade)	0.00	0.00	-0.02	0.04	0.02	-0.30	0.04	*0.38*	0.70
SCG	0.89 (Grade)	0.00	0.00	-0.06	-0.13	-0.13	-0.33	0.04	0.38	*0.09*

1 Genetic correlations above the diagonal, phenotypic correlations below the diagonal and heritabilities on the diagonal.

2 Repeatability = 0.15

Given the underlying assumptions and calculations detailed in Appendix I, the final estimation of the economic weights for number of lambs weaned (NLW), weaning weight (WW), clean fleece weight (CFW), mean fibre diameter (MFD) and scoured colour grade (SCG) is shown in Table 7.2.

TABLE 7.2: LIFETIME ECONOMIC WEIGHTS[(1)] OF THE TRAITS IN THE SELECTION OBJECTIVE

TRAIT	CALCULATION	ECONOMIC WEIGHT
		$
NLW (DAM)	4.76 matings x \$8.01	38.13
WW	$3.76 \text{ lambs} \times \frac{47\%}{100} \; \frac{\$8.01}{10 \text{ kg}}$	1.42
CFW	7.64 shearings x \$4.70/kg	35.91
MFD	7.64 shearings x 3.50 kg x \$-0.20/micron	-5.35
SCG	$\frac{7.64 \text{ shearings} \times 3.50 \text{ kg} \times \$0.04/\text{SCG}}{2.0^{(2)}}$	0.53

(1) NLW (\$/lifetime/lamb weaned)
WW and CFW (\$/lifetime/kg)
MFD (\$/lifetime/μm)
SCG (\$/lifetime/grade)

(2) 2.0 Massey scoured colour grades are equivalent to one colour grade in the N.Z.W.B. fleece valuations (G.A. Wickham, Pers. Comm.).

The selection objective for the Merper flock can be defined in the form of a linear function in terms of dollars return to the farmer per ewe lifetime:

$$H = 38.13\ NLW\ (dam) + 1.42\ WW + 35.91\ CFW - 5.35\ MFD + 0.53\ SCG$$

Despite the limitations, the economic values used give an idea of the relative importance of the traits in the objective. It should be noticed the close relation between the economic weights of CFW and NLW mainly due to the high value of the fine wool produced by the Merpers, the low prices paid for lambs and the higher costs during the period of this study.

As pointed out by Rae (1958b) economic weights only define the economic environment under which animals are expected to produce, hence their use under other conditions should be restricted.

The reproductive record of the dam is the most important trait in lamb and hogget selection, so that NLW (dam) was always considered in the various indices formulated.

GFW, QN and GCG were included as selection criteria since they are correlated respectively with CFW, MFD and SCG but are more easily assessed. Similarly, HLW was included because of genetic correlations with objective traits.

7.3.2 Comparison of Selection Indices

The list of selection indices formulated using the basic genetic and phenotypic parameters reported in Table 7.1 are given in Table 7.3.

TABLE 7.3: LIST OF INDICES FORMULATED

INDEX NUMBER	TRAITS INCLUDED OR DELETED FROM INDEX 1a
1a	Selection index containing all traits in the objective.
2a	HLW, GFW and GCG introduced as selection criteria. CFW and SCG deleted.
3a	NLW and WW included as selection criteria. CFW, MFD and SCG deleted.
4a	HLW, GFW and QN included as selection criteria. CFW, MFD and SCG deleted.
5a	HLW, GFW, QN and GCG introduced as selection criteria. CFW, MFD and SCG deleted.
6a	Restricted index containing all the traits in the objective. Genetic change of zero in MFD. Economic weight of MFD is zero.

The same indices were formulated effecting the corresponding modifications after changing genetic and phenotypic parameters and economic weights.

The respective selection index solutions obtained are set out in Tables 7.4a, 7.4b and 7.4c.

Some of the terminology used in Table 7.4 need defining:

"β-VALUE" is the weight that the record of each trait is multiplied by in calculating the selection index. The set of B-values is calculated to maximize the overall genetic gain.

"VALUE OF VARIATE", i.e. value of each variate in the index, is the percent reduction in the rate of overall genetic gain that would result, if that trait was not included as a selection criterion.

"PERCENTAGE OVERALL GAIN" is the percentage of overall gain accounted for by the gain in each trait.

"GENETIC GAIN" is the gain made per generation, from using the selection index assuming a selection differential of one standard deviation.

"VALUE OF OVERALL GAIN" or "STANDARD DEVIATION OF THE INDEX" gives the value, in economic units, of the genetic gain in aggregate genotype achieved by one standard deviation of selection on the index.

7.3.2.1 Basic Indices

Table 7.4a shows six index solutions where 1a contains all the traits in the objective (i.e. basis for comparison), indices 2a to 5a were obtained for males, lambs and females selection and the last one (6a) was a restricted index.

TABLE 7.4: SELECTION INDEX SOLUTIONS

VARIATES IN OBJECTIVE	NLW		WW		CFW		MFD		SCG	VALUE OF OVERALL GAIN
VARIATES IN INDEX	NLW (DAM)	HLW	WW	GFW	CFW	QN	MFD	GCG	SCG	
(a) BASIC INDICES										
INDEX 1a										
β - Value	4.75		0.35		8.79		-1.83		-0.19	4.79
Value of Variate	8.00		2.15		13.99		35.59		0.05	
% Overall Gain	22.69		5.41		19.12		52.27		0.51	
Genetic Gain	0.03		0.18		0.03		-0.47		0.05	
INDEX 2a										
β - Value	4.66	0.62	0.10	3.91	-		-1.70	0.50	-	4.89
Value of Variate	7.35	6.81	0.13	3.46	-		27.59	0.49	-	
% Overall Gain	25.70	0.00	6.91	0.00	8.18		58.89	0.00	0.32	
Genetic Gain	0.03	0.54	0.24	0.02	0.01		-0.54	0.14	0.03	
INDEX 3a										
β - Value	4.87		0.48		-		-		-	2.41
Value of Variate	39.76		19.49		-		-		-	
% Overall Gain	66.13		18.41		10.40		5.06		0.00	
Genetic Gain	0.04		0.31		0.01		-0.02		0.00	
INDEX 4a										
β - Value	4.79	0.60	0.04	2.33	-	0.27	-		-	3.20
Value of Variate	19.35	15.40	0.06	2.71	-	2.05	-		-	
% Overall Gain	45.61	0.00	13.82	0.00	24.27	0.00	16.69		-0.39	
Genetic Gain	0.04	0.42	0.31	0.02	0.02	-0.20	-0.10		-0.02	

TABLE 7.4: (CONTINUED)

VARIATES IN OBJECTIVE	NLW		WW		CFW		MFD		SCG	VALUE OF OVERALL GAIN
VARIATES IN INDEX	NLW (DAM)	HLW	WW	GFW	CFW	QN	MFD	GCG	SCG	
INDEX 5a										
β - Value	4.79	0.61	0.04	1.99	-	0.23	-	1.60	-	3.59
Value of Variate	15.05	12.89	0.05	1.56	-	1.19	-	10.70	-	
% Overall Gain	36.70	0.00	11.18	0.00	18.61	0.00	33.10	0.00	0.41	
Genetic Gain	0.03	0.37	0.28	0.02	0.02	-0.02	-0.22	0.19	0.03	
INDEX 6a(1)										
β - Value	4.50		0.23		8.90		-0.21		0.30	3.37
Value of Variate	15.03		1.85		31.96		9.16		0.28	
% Overall Gain	30.82		8.73		60.23		0.00		0.22	
Genetic Gain	0.03		0.21		0.06		0.00		0.01	
(1) RESTRICTED DUMMY MFD	β - Value = 0.20 Value of Variate =-0.08									
(b) SENSITIVITY TO PARAMETER CHANGES										
INDEX 1b										
β - Value	4.64		0.07		22.42		-3.62		-1.02	8.35
Value of Variate	2.44		0.03		30.29		44.40		0.53	
% Overall Gain	9.12		1.93		38.05		50.60		0.29	
Genetic Gain	0.02		0.11		0.09		-0.79		0.05	
INDEX 2b										
β - Value	4.60	0.30	-0.03	15.96	-		-3.54	-0.88	-	7.95
Value of Variate	2.65	0.60	0.01	21.58	-		45.69	0.55		
% Overall Gain	10.85	0.00	2.35	0.00	34.39		52.18	0.00	0.24	
Genetic Gain	0.02	0.43	0.13	0.09	0.08		-0.78	0.09	0.04	

TABLE 7.4: (CONTINUED)

VARIATES IN OBJECTIVE	NLW		WW		CFW		MFD		SCG	VALUE OF OVERALL GAIN
VARIATES IN INDEX	NLW (DAM)	HLW	WW	GFW	CFW	QN	MFD	GCG	SCG	
INDEX 3b										
β - Value	4.87		0.48		-		-		-	
Value of Variate	39.76		19.49		-		-		-	
% Overall Gain	66.13		18.41		10.40		5.06		0.00	2.41
Genetic Gain	0.04		0.31		0.01		-0.02		0.00	
INDEX 4b										
β - Value	4.84	0.40	-0.10	9.11	-	0.56	-		-	
Value of Variate	10.69	3.66	0.17	26.73	-	5.19	-		-	
% Overall Gain	22.79	0.00	6.36	0.00	33.69	0.00	37.11		0.05	4.25
Genetic Gain	0.03	0.17	0.19	0.04	0.04	-0.14	-0.29		0.00	
INDEX 5b										
β - Value	4.84	0.42	-0.09	8.80	-	0.53	-	1.46	-	
Value of Variate	9.48	3.56	0.14	21.53	-	4.05	-	5.48	-	
% Overall Gain	20.55	0.00	5.77	0.00	29.66	0.00	43.55	0.00	0.47	4.50
Genetic Gain	0.02	0.15	0.18	0.04	0.04	-0.01	-0.37	0.18	0.04	
INDEX 6b (2)										
β - Value	4.21		0.33		4.27		0.22		-0.25	
Value of Variate	21.62		6.59		15.78		10.13		0.31	
% Overall Gain	42.45		13.61		44.28		0.00		-0.34	2.68
Genetic Gain	0.03		0.26		0.03		0.00		-0.02	

(2) RESTRICTED DUMMY MFD β - Value = -4.14
Value of Variate = -63.04

TABLE 7.4: (CONTINUED)

VARIATES IN OBJECTIVE	NLW		WW		CFW		MFD		SCG	VALUE OF OVERALL GAIN
VARIATES IN INDEX	NLW (DAM)	HLW	WW	GFW	CFW	QN	MFD	GCG	SCG	
(c) SENSITIVITY TO ECONOMIC WEIGHT CHANGES										
INDEX 1c										
β - Value	6.91		0.44		7.12		-1.85		-0.34	5.10
Value of Variate	15.51		3.06		7.81		30.98		0.15	
% Overall Gain	39.07		5.63		9.99		44.99		0.32	
Genetic Gain	0.03		0.19		0.02		-0.46		0.04	
INDEX 2c										
β - Value	6.81	0.71	0.13	2.68	-		-1.72	0.40	-	5.36
Value of Variate	13.53	7.46	0.21	1.34	-		23.15	0.25	-	
% Overall Gain	41.21	0.00	6.89	0.00	3.56		48.18	0.00	0.16	
Genetic Gain	0.04	0.54	0.25	0.01	0.01		-0.52	0.12	0.02	
INDEX 3c										
β - Value	7.04		0.52		-		-		-	3.20
Value of Variate	50.44		12.58		-		-		-	
% Overall Gain	78.54		12.33		5.25		3.88		0.00	
Genetic Gain	0.04		0.26		0.01		-0.02		0.00	
INDEX 4c										
β - Value	6.95	0.69	0.08	1.05	-	0.27	-		-	3.86
Value of Variate	29.58	13.89	0.14	0.37	-	1.42	-		-	
% Overall Gain	64.16	0.00	11.53	0.00	9.76	0.00	14.81		-0.25	
Genetic Gain	0.04	0.41	0.30	0.01	0.01	-0.15	-0.11		-0.02	

TABLE 7.4: (CONTINUED)

VARIATES IN OBJECTIVE	NLW		WW		CFW		MFD		SCG	VALUE OF OVERALL GAIN
VARIATES IN INDEX	NLW (DAM)	HLW	WW	GFW	CFW	QN	MFD	GCG	SCG	
INDEX 5c										
β - Value	6.94	0.70	0.08	0.73	-	0.23	-	1.51	-	
Value of Variate	24.89	12.56	0.12	0.15	-	0.92	-	6.97	-	4.15
% Overall Gain	55.88	0.00	10.09	0.00	8.01	0.00	25.85	0.00	0.17	
Genetic Gain	0.04	0.37	0.28	0.01	0.01	-0.01	-0.21	0.15	0.02	
INDEX 6c (3)										
β - Value	6.66		0.31		7.24		-0.16		0.17	
Value of Variate	30.27		3.04		16.34		4.04		0.08	3.67
% Overall Gain	55.95		8.87		35.08		0.00		0.09	
Genetic Gain	0.04		0.22		0.04		0.00		0.01	

(3) RESTRICTED DUMMY MFD β - Value = -0.37
Value of Variate = -0.22

The low heritability assumed for SCG resulted in it being unimportant as a selection criterion. Nevertheless, including SCG in the objective resulted in greater emphasis on MFD. This followed from the assumed genetic and phenotypic correlations of -0.40 and -0.33 respectively.

Negative index weights (β-values) were found for SCG indicating selection for poorer colour. The only SCG B-value to be positive was that in the restricted index 6a.

The rate of overall genetic gain would be reduced by 35.59%, 13.99% and 8.00% if MFD, CFW and NLW (dam) were respectively omitted from the index 1a whereas WW was of little value. It was with selection indices 1a (unrestricted) and 6a (restricted) that SCG made a negligible contribution towards genetic gain for the aggregate genotype.

The relative importance of each trait in the selection objective can be derived from the percentage of total gain in economic units (% overall gain) accounted for by gain in each trait. In index 1a the most important traits were MFD (52.27%), NLW (22.69%) and CFW (19.12%).

Assuming a generation interval of 3.5 years, index 2a would result in a genetic change of approximately 0.01 in NLW, 0.15 kg in HLW, 0.07 kg in WW, 0.01 kg in GFW, 0.003 kg in CFW, -0.15 microns in MFD, 0.04 grades in GCG and 0.01 grades in SCG.

The results showed that although HLW was not included in the selection objective (i.e. zero economic value) it was a useful selection criterion in indices 2a, 4a and 5a. This response was attributed to its medium heritability, the moderately high genetic correlation of HLW x CFW (0.30) and WW x HLW (0.70) and the generally positive association with NLW. For indices 2a, 4a and 5a a reduction of 6.81%, 15.40% and 12.89% in the rate of overall genetic gain respectively would result if HLW was omitted.

Greasy fleece weight proved to be a very useful criteron, particularly as a cost-efficient substitute for CFW. The value of variate and the percent of overall gain for GFW tended to decrease as other traits such as MFD were omitted from the indices.

7.3.2.1.1 Comparison of the Genetic Gain for CFW from Mass Selection and Index Selection

In this study indices, including a trait of interest and a correlated trait with no economic value, have been compared with direct selection for the trait of importance.

The genetic gain (ΔG) from mass selection for CFW is represented by

$$\Delta G = \sigma h^2 i$$

where σ = Phenotypic standard deviation = 0.30

h^2 = Heritability CFW = 0.24

i = Standardized selection differential = 1

Hence, $\Delta G = 0.072$

The genetic gain for CFW in an index (ΔH_i) is represented by $\Delta H_i = \beta_{H_i I}\sigma_I$

where $\beta_{H_i.I}$ = Regression of CFW on index

σ_I = Standard deviation of index

Thus,

Index Number	$\beta_{H_i.I}$	σ_I	Δ_{H_i}
1a	0.0053	4.7851	0.03
2a	0.0023	4.8924	0.01
4a	0.0068	3.2019	0.02
5a	0.0052	3.5854	0.02
6a	0.0168	3.3739	0.06

The results indicate that improvement in CFW per generation by single trait selection is higher than the genetic gains obtained using selection indices. Since with index 6a, where MFD was held constant, the genetic gain in CFW was close to that obtained by direct, single-trait selection it appears that, with the other indices it is selection for finer diameter that is the major factor limiting the improvement of CFW. This would largely result from the genetic correlation of CFW with MFD.

7.3.2.1.2 Indices for Ram and Ewe Hoggets and Lambs

James (1978) listed some reasons why it is likely that in many cases the selection index would be different in males and females.

Also early disposal of surplus lambs offer considerable advantages to the breeders (Young, 1964). Therefore an index based on traits which can be assessed early in life (e.g.

weaning weight and number of lambs weaned of the dam) is useful. However, it will reduce the rate of genetic gain compared with that which could be achieved if selection were done only at 14-18 months, when all the required information is available (Ponzoni, 1981).

The lamb index could be part of the whole index selection system as reported by Young (1964) or the first step in a two-stage selection (Ponzoni, 1981) who added that an appropriate choice of selection criteria at an early age could result in an important reduction of the budget for measurement with little loss of genetic gain.

Measuring the efficiency of the indices in Table 7.4a by means of the coefficient of determination (r^2_{HI}) between aggregate genetic value (H) and the index (I) (Gjedrem, 1967) the following results were found:

Index Number	Correlation of Index with Aggregate Genotype (r_{HI})	Efficiency of the Index (r^2_{HI})
1a	0.43	0.18
2a	0.44	0.19
3a	0.21	0.04
4a	0.29	0.08
5a	0.32	0.10
6a	0.36	0.13

Index 2a is preferred as the index for ram hogget selection, where there is an increment in the value of overall gain associated with the addition of GFW, HLW and GCG as criteria. In addition, there is a practical saving from not measuring CFW and SCG.

Hence, the recommended index for ram hogget selection is:

$$I = 4.66\ NLW\ (dam) + 0.62\ HLW + 0.10\ WW + 3.91\ GFW - 1.70\ MFD + 0.50\ GCG$$

For ewe hogget selection two indices were chosen, namely 4a and 5a. In both QN was considered as the selection criterion for MFD (Lewer, 1978) but in 5a GCG was included as criterion of whiteness. From the efficiencies 5a appears better than index 4a, thus, it seems worth assessing GCG.

The recommended index for ewe hoggets is:

$$I = 4.79\ NLW\ (dam) + 0.61\ HLW + 0.04\ WW + 1.99\ GFW + 0.23\ QN + 1.60\ GCG$$

In the case of the lamb index, Cunningham's (1969) procedure to establish the efficiency of a reduced index relative to the original index (1a) was followed. It consists in finding the ratio of the standard deviation of the indices:

Index Number	S.D	Relative Efficiency
1a	4.79	100.0%
3a	2.41	50.3%

This result is similar to that of Ponzoni (1981) who found that single-stage selection based on dam's NLW and WW was half as effective as single-stage selection based on the complete set of criteria.

Therefore, the recommended index for lambs is:

I = 4.87 NLW (dam) + 0.48 WW

7.3.2.1.3 Restricted Index

Index 6a was restricted by requiring that the genetic change produced in MFD equal zero. To impose the restriction that the index shall produce no change in Y_i (the additive genotype of MFD), the index equations were solved subject to Cov $(Y_i, I) = 0$.

The negative of the Dummy weighting factor calculated for the restricted index is the appropriate economic weight for no genetic gain to be made in that trait (Cunningham and Gjedrem, 1970). The Dummy weight for MFD was $0.20.

The consequence of maintaining constant MFD was an increment in the genetic gain in CFW.

In general from Table 7.4a, if the economic weights and genetic and phenotypic parameters are close to the real values then NLW (dam) is highly important in any selection index, MFD makes an important contribution and should be recorded for ram selection, GFW is a good selection criterion for improving CFW, QN is a useful predictor of MFD for ewe selection, GCG is a good indicator of whiteness and HLW is very useful by its association with WW, CFW, GFW and NLW.

7.3.2.2 Sensitivity to Change of Genetic and Phenotypic Parameters

Table 7.4b shows the index solutions when genetic correlations between GFW x MFD and CFW x MFD were both changed from 0.25 to -0.40 in line with the earlier estimates, and phenotypic correlations between GFW x MFD from 0.25 to 0.38 and CFW x MFD from 0.25 to 0.37.

The weighting factors of indices 2b, 4b and 5b indicate selection against WW.

Some index weightings suffered large changes. CFW changed from 8.79 in index 1a to 22.42 in index 1b; GFW changed from 1.99 in index 5a to 8.80 in index 5b.

Comparing indices 2b, 4b and 5b with their corresponding 2a, 4a and 5a, the genetic gain of MFD is increased from -0.54 to -0.78, -0.10 to -0.29 and -0.22 to -0.37 respectively. At the same time the genetic gain for CFW was at least doubled.

In order to analyse what happened, the efficiency of the indexes (Gjedrem, 1967) was calculated:

Index Number	Correlation of Index with Aggregate Genotype (r_{HI})	Efficiency of the Index (r^2_{HI})
1b	0.65	0.42
2b	0.62	0.38
3b	0.19	0.04
4b	0.33	0.11
5b	0.35	0.12
6b	0.28	0.08

There was a significant increase in efficiency for indices 1b and 2b and a decrease for index 6b. The reduced index 3b was not altered while indices 4b and 5b retained their ranking.

Index 6b was not appropriate since, with the genetic correlation between CFW and MFD negative, the correlated changes would have been in the desired direction.

7.3.2.3 Sensitivity to Change of Economic Weights

Table 7.4c lists the index solutions after increasing the economic weight of NLW by 50% and reducing the weight of SCG by 25%.

As expected, the resulting index changes caused more response in NLW and less in SCG but the effects were only small.

The efficiency of the present selection indices was:

Index Number	Correlation of Index with Aggregate Genotype (r_{HI})	Efficiency of the Index (r^2_{HI})
1c	0.38	0.14
2c	0.40	0.16
3c	0.24	0.06
4c	0.29	0.08
5c	0.31	0.10
6c	0.30	0.09

Comparing these efficiences with those found in Section 7.3.2.2, indicates that small changes in the economic weights in index selection have little effect on the efficiency of the selection indices. This was also shown by Cunningham and Gjedrem (1970), Vandepitte and Hazel (1977), Ponzoni (1979) and Smith (1983).

7.3.2.4 Further Indices Computed

Using the parameters given in Table 7.1 and the index 1a in Table 7.4a as a base, further inclusions and deletions were made to study alternative selection indices. These index solutions were not reported in Table 7.4a.

When SCG was removed from the index a very small decrease occurred in the value of overall gain.

The inclusion of HLW and GFW as criteria for WW and CFW respectively allowed satisfactory rates of improvement of these traits as reflected by the small changes in the value of overall gain. One index where HLW was included as criterion for WW resulted in a higher value of overall gain than the base index.

Selection on HLW alone resulted in a slight reduction in the genetic gain for NLW, CFW and MFD. The genetic gain for SCG was reversed from 0.05 to -0.06, whereas the genetic gain for WW was doubled. The efficiency of this reduced index was 51%.

Reducing the economic weight of MFD from \$-5.35 to \$-0.10 caused a significant reduction in the genetic gain of MFD and SCG but an increase in the genetic gain of CFW. The value of overall gain was reduced by 30%. This proves the importance of economic weights in determining the improvement through index selection.

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APPENDICES

APPENDIX I

ASSUMPTIONS AND CALCULATIONS FOR THE DERIVATION OF LIFETIME ECONOMIC WEIGHTS

The prices assumed for wool and lambs represent net prices paid to the farmer.

	$
Net value of 29 microns clean fleece weight ($ per kg)	4.70*
Value per micron of fibre diameter (price change ($) of 1 kg of clean wool per micron change in fibre diameter)	-0.20*
Export lamb YL carcass 10 kg ($)	10.24**
Store lamb price ($)	8.00
Value per grade of scoured colour (price change ($) of 1 kg of clean wool per grade change in scoured colour)	0.04*+

* Based on actual prices (October 1985, New Zealand Wool Board) after deducting the N.Z.W.B. levy, broker's commission, transport and others.

** Based on actual meat schedule prices (after deducting processing charges, drafting fee, administration, Meat Board levy, Federated Farmers levy and farm to works and works to port transport.

\+ Predicted from style according to McPherson (1982)

$$SCG = 1.89 + 0.8 \text{ (style)}$$

1. NUMBER OF MATINGS PER LIFETIME

The breeding flock consists of five groups and the mortality rate for ewes is 3%, then the proportion of two-tooth ewes in the flock can be calculated as:

$$= \frac{1}{1 + 0.97 + 0.941 + 0.913 + 0.886}$$

$$= 0.21 \quad (21\%)$$

Therefore, the number of matings per lifetime is

$$= \frac{1}{0.21}$$

$$= 4.76$$

2. FLEECE PRODUCTION PER LIFETIME

Given that the ewes are shorn after their final lambing, the number of years of fleece production per lifetime is:

$$= 4.76 + 1$$

$$= 5.76$$

Plus, credit for production from final lambing to culling = 0.5

Lambs are not shorn before being sold as weaners and only those for replacement are kept.

Plus, credit for production from culled ewe hoggets

$$\frac{0.5 \times 1 - 0.21}{0.21} = 1.38$$

Thus, fleece production per lifetime

$= 5.76 + 0.5 + 1.38$

$= 7.64$

3. LAMB PRODUCTION PER LIFETIME

The total number of lambs weaned per ewe lifetime is:

(4.76) x (1.00)* = 4.76

* Average weaning percentage = 100%

Less one replacement = 4.76 - 1 = 3.76

Hence, 3.76 is the number of lambs on which returns from greater weaning weights are based.

4. AVERAGE VALUE OF LAMBS SOLD

Given an export:store lamb ratio of 4.3:1, and an average return of \$10.24 for export lambs and \$8.00 for store lambs, the average value of lambs sold is:

$$= \frac{(10.24 \times 4.3) + (8.00 \times 1)}{5.3}$$

$= \$9.82$

5. VALUE OF AN EXTRA LAMB

The value of an extra lamb was calculated in a similar way to Cunningham and Gjedrem (1970) by accounting for the detrimental effects of twin births on lamb value.

SINGLE	80% export	0.80 x $10.24
	+ 20% store	+ 0.20 x $ 8.00
		$ 9.79
TWIN	40% export	0.40 x $10.24
	+ 60% store	+ 0.60 x $ 8.00
		$ 8.90 x 2 = $17.80

The value of an extra lamb is:

$17.80 - $9.79 = $8.01

Other costs involved with rearing twins, compared with singles, have been ignored. These include the extra feed costs of the ewe which will depend on seasonal conditions, the greater period of time twins may be kept on the farm and the greater drenching costs associated with extra lambs.

The dressing percentage of a lamb is considered to be 47% (Morris *et al.*, 1982).

6. AVERAGE ANNUAL CLEAN FLEECE WEIGHT PER LIFETIME

The average annual clean wool production per lifetime for the Merpers is assumed to be 3.5 kg (G.A. Wickham, pers. comm.). It is further assumed that the value per kg of wool from the different age categories is equivalent.

APPENDIX II

CALCULATION OF NEW ECONOMIC WEIGHTS

The assumptions and calculations for the derivation of the new economic weights were similar to those reported in Appendix I. The only changes made were:

1. Weaner lambs had 30 kg of liveweight with a price of $12.00 per head, assuming that twins could be brought to the same weight and sold for the same price as singles.

2. Fleece production from culled ewe hoggets was not credited to fleece production per lifetime.

3. Wool produced per ewe was 4 kg.

4. 2.5 Massey wool colour grades apply for one colour grade in the N.Z.W.B. fleece valuation.

Hence,

ECONOMIC VALUE OF NUMBER OF LAMBS WEANED

Number of matings per lifetime	4.76
Price of one lamb ($)	12.00
The value of each extra lamb produced is ($12.00) x (4.76) ($)	57.12

ECONOMIC VALUE OF WEANING WEIGHT

Number of lambs available for sale per ewe lifetime	3.76

ECONOMIC VALUE OF WEANING WEIGHT (CONTD)

Price per kg of live lamb $\left(\frac{\$12.00}{30\ kg}\right)$ (\$)	0.40
The value per kg change in weaning weight is (3.76) x (\$0.40) (\$)	1.50

ECONOMIC VALUE OF CLEAN FLEECE WEIGHT

Price per kg of clean wool (\$)	4.70
Number of shearings per ewe	6.26
The value of one extra kilogram of clean wool is (\$4.70) x (6.26) (\$)	29.42

ECONOMIC VALUE OF MEAN FIBRE DIAMETER

Value per micron of fibre diameter (\$)	-0.20
Number of shearings per ewe	6.26
Kilograms of wool produced per ewe	4.00
Value of one extra micron decrease in fibre diameter is (6.26) x (4.00) x (\$-0.20) (\$)	-5.01

ECONOMIC VALUE OF SCOURED COLOUR GRADE

Value per scoured colour grade (\$)	0.04
Number of shearings per ewe	6.26
Kilograms of wool produced per ewe	4.00
The value of one extra grade increase in scoured colour is $\frac{(\$0.04) \times (6.26) \times (4.00)}{2.5}$ (\$)	0.40