OBJECTIVE MEASUREMENT OF COLOUR IN NATURALLY PIGMENTED WOOL

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ABSTRACT

This thesis examines some issues important in considering production of naturally-pigmented wools in New Zealand. Major wool characteristics are reviewed in terms of processing requirements. Statistics of New Zealand production of naturally-pigmented wools are limited, as are data relating to the number and colour of black and coloured sheep farmed in New Zealand. Objective measurements are not widely used by the wool growers; in addition, the lack of a recognised colour standard for these wools limits the marketing of sale lines.

The major characteristics of black and coloured wool samples sourced from three regions of New Zealand were analysed and presented. In the absence of a colour standard, tristimulus values (XYZ) and CIELAB (L*a*b*) values were measured using a spectrophotometer. The CIELAB scale provided better distinctions between black, brown and grey wools which had been subjectively graded into categories labelled 'light', 'medium', 'dark', and 'moorit'. CIELAB values for each colour grouping are proposed.

To meet the requirements of wool processors, sheep breeders need to supply wools to specification. Wool production objectives are discussed in line with selection objectives, selection criteria and selection methods.

The linkages between farmers and processors are reviewed in the light of existing New Zealand practices. The role of the Black and Coloured Sheep

Breeders' Association of New Zealand, wool buyers, wool brokers and auction houses is examined. In view of the limited quantity of naturally pigmented wools available in commercial (>500kg) quantities, the study suggests that the Association introduce a brand name for the wools produced by its members and establish one sale location only as a means of raising quality standards and the availability of marketable quantities.

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GLOSSARY

BCSBANZ	The Black and Coloured Sheep Breeders' Association of New Zealand.
britch	Wool from the britch or lower thigh of the sheep.
bulk	The volume occupied by wool fibres at a prescribed load. Often referred to as the 'springiness' of wool.
carding	A process whereby, after scouring, the fibres are opened out, blended and straightened.
CIE	International Commission on Illumination (Commission Internationale d'Eclairage).
combing	A process in worsted manufacture in which the fibres are straightened and laid parallel, and the short fibres removed as noils along with vegetable contaminants.
count	The thickness of a yarn
crimp	Natural undulations along wool fibres.
crossbred (XBD)	A term given to New Zealand's long staple, lustre wools specifically varying in mean fibre diameter from 27-40+μ, irrespective of breed or cross.
culling	The disposal, by slaughter or sale, of sheep no longer required in a flock.
gilling	A process of drawing slivers through machines that partially align the fibres. Used in worsted and semi-worsted processing.
greasy wool	Wool in its natural condition as shorn from the sheep.
halfbred (1/2BD)	Wool taken from sheep with half Merino in the breeding.
handle	The quality of wool as judged by touch.
hue	"That attribute of a colour by which it is recognised as a red, a green, *etc.*, and which is dependent on its dominant wavelength, and independent of intensity or lightness" (The New Shorter Oxford English Dictionary).

kemps	Straight, brittle, and often hairy, fibres which are shed in the fleece.
micron (μ)	Micrometer (one millionth of a metre). The unit of measurement of the fibre diameter of wool.
MSBSA	The Melanian Sheep Breeders' Society of Australia.
neps	Small lumps or knots of wool produced during processing.
noil	Short and broken fibres removed from wool during combing.
objective	Refers to measurements which are made according to recognised standards and means.
pilling	Appearance of small balls of 'fluff' on the surface of fabric due to wear and/or rubbing.
roving	A sliver of wool drawn out and slightly twisted.
SACSOS	The South Australian Coloured Sheep Owners' Society Inc.
saturation	The intensity of colour.
scouring	The washing of wool to remove all or most non-wool contaminants.
SDANZ	The Sheep Dairy Association of New Zealand.
skirting	The removal of processing faults from the edges and within the fleece.
sliver	A continuous strip or band of loose, untwisted fibres after carding.
sound	Wool of good tensile strength along the full length of the staple.
spinnability	The ease with which fibres are spun into yarn.
subjective	Refers to the estimation of grade by hand and eye.
suint	The water-soluble component contaminating raw wool.
tear	The ratio of tops to noils in combing.

tender	Wools which are in some degree deficient in tensile strength along the staple due to a gradual or sudden check to the growth of the fleece.
tex	a system of defining the weight (thickness) of yarn in grams per kilometre.
top	A continuous band or ribbon of combed fibres laid parallel in an untwisted condition and in ball form; all short and weak fibres (noil) and vegetable matter have been combed out.
unsound	Wools deficient in tensile strength whether by tenderness or break.
vegetable matter	A term describing varieties of vegetable matter which may contaminate wool.

INTRODUCTION

The production of black and coloured wool in New Zealand is the domain primarily of small farmers, many supplying the hand-craft market, but most is used in large-scale yarn processing. An increasing demand exists for natural-coloured wools suitable for the manufacture of apparel products. To fully satisfy those who create this demand, it is necessary to provide wools which meet processing specifications.

The requirements of the commercial (*i.e.* large scale processors and manufacturers) and hand-craft sectors differ in that commercial technology is able to both remove some 'faults' during processing and to mask others. By contrast, the hand-crafter looks for visually 'perfect' wool.

Apparel products are produced from a range of wools. Most of these wools are under 30 micron mean fibre diameter, although stronger wools may be used to achieve special effects in the finished garment, *e.g.* in tweeds. The main breeds of sheep producing wool for apparel manufacture are the Merino and its crosses (Polwarth, New Zealand Halfbred, Corriedale), plus the Down breeds, fine Perendale and fine Romney.

The methods utilised to select wool for commercial apparel processing have undergone dramatic change, particularly in the last twenty years. For centuries, the suitability of batches of wool for particular uses was assessed subjectively by 'hand and eye'. Wool characteristics were ranked by terms such as quality, style, and character. A system, known as the Bradford Quality Number or Count, was used to grade for fineness and expressed the spinning capacity of the wool in numbers ranging from 30 to 90. A fine wool, which would give a greater length of yarn, had a high number while a strong (coarse) wool, which would produce a lesser length, had a lower number. In New Zealand the numbers ranged from 36 (strong) to 90 (fine).

The assessment of Quality Number was made on the basis of staple crimp size, lustre and handle. Generally, smaller crimps and soft handle indicated a fine wool while the presence of greater lustre indicated a stronger wool. The factors had to be balanced against each other when determining the Quality Number as well as the breed/breed-type of sheep producing the wool. The skill required to assess Quality Number was learned over many years of practical experience. While those working in the wool industry understood the gradings given, such assessments lacked definite boundaries and were dependent upon not only the ability and experience of the person assessing the wool, but also the importance that person gave to particular characteristics.

The more recent development of an increasing number of objective measurement techniques, using standard and recognised means, has enabled the processors to better define parameters relating to processing performance.

This project was undertaken in five sections. The first attempts to provide production statistics for black and coloured wool in New Zealand and to estimate processor requirements in terms of means and variation in objectively measured as well as subjectively assessed traits. In Section Two the results of tests on samples of black and coloured wools sourced from throughout New Zealand are presented and discussed. Section Three concerns the establishment of an objective measurement scale for measuring colour in black and coloured wool and the variation within colour ranges. The fourth section examines potential wool production objectives for breeders of black and coloured sheep that are consistent with processor requirements, and Section Five suggests a business organisation/system providing the linkages between producers and processors with more accurate specification of the wools required.

SECTION 1:

1.0 BLACK AND COLOURED WOOL PRODUCTION IN NEW ZEALAND AND PROCESSOR REQUIREMENTS

1.1 WOOL PRODUCTION IN FLOCKS OF COLOURED SHEEP

The Black and Coloured Sheep Breeders' Association of New Zealand Inc. was established in 1976. The primary objective of the association continues to be "the encouragement of the breeding, owning and improvement of all breeds of black and coloured sheep in New Zealand and the production of good wool types suitable for hand-crafts and commercial uses" (BCSBANZ, 1999).

Many coloured sheep flocks in New Zealand originate from occasional black and coloured lambs born into white flocks rather than from coloured stock purchased from a coloured sheep stud or flock.

An opportunity exists to improve the quality of wool produced and to develop niche apparel markets suited to the black and coloured wool types grown in New Zealand and to processors'/ manufacturers' requirements. To achieve this objective, breeders need an improved method of assessing wool colour as the specifications are different from those for white wool.

Data relating to the number of black and coloured sheep in New Zealand is at best "sketchy". Currently (1999) members of the Association farm 9781 sheep in 152 flocks, varying in both breed-type and size of flock (Table 1).

Table 1: **Distribution of Breed Types and Numbers of Black and Coloured Sheep Flocks in New Zealand**
(BCSBANZ 1996 & 1999).

Percentage of Breed Type by Property		
	1999	1996
Merino/Merino cross	32%	36%
Romney/Romney cross	59%	62%
Perendale/Lincoln, English Leicester, Finn, Gotland, Down-cross	9%	2%
Number of:		
Registered Stud Flocks	24	27
Commercial Flocks	128	148
Sheep	9781	11005

The figures in Table 1 reflect only those sheep farmed by members of the BCSBANZ, although not all members supply details of breeds and the number of sheep they farm (BCSBANZ, 1999).

The genetic base for coloured sheep in New Zealand is small when compared with the number of white sheep farmed (approximately 44 million in 1999) . The small flock size (Table 2) limits genetic progress; the major criterion is often colour rather than particular wool characteristics, conformation excellence, fecundity, *etc.*

Table 2: **Size of Coloured Flocks in New Zealand**
(BCSBANZ, 1999)

% of National Coloured Flock	No. of Sheep per Farm
63%	< 50
23%	51 - 100
9%	101 - 200
2%	201 - 300
3%	301 +

The total tonnage of coloured wool production in New Zealand is, at best, a "guess-timate". The reason for the lack of accurate data relates to the various selling methods employed by growers. Private sales for hand-craft use are seldom recorded in official documents. Wools of New Zealand has no data relating to sales of coloured wool, other than the amount of black/dark fibre identified in sale lots of white wool. Throughout the country, 'pools' have become established as a means of selling pigmented wool. Growers deliver their wool to the pool where it is sorted into fineness and colour lines prior to sale or tender. The South Island Wool Pool (SIWP) is a privately-owned company which is in contrast to others in the North Island which are operated with volunteer labour provided by individual branches of the BCSBANZ. Wool brokers throughout the country also handle black and coloured wool, most of which is sold by auction. Volumes handled by the Association's pools may be included either entirely, or in part, in statistics provided by auction houses. Should a branch pool be unable to sell its wool privately, the bales may be forwarded to an auction house for selling.

1998 figures suggest approximately 110,000kg were sorted into sale lines by wool pools (Leslie, 1999; BCSBANZ, Personal Communication, 1999). The 'hobby' preference for farming black and coloured sheep contributes to the lack of reliable statistics therefore the total number of animals producing black and coloured wool in New Zealand is known with poor precision. The volume suggested here would equate to approximately 25,000 animals but no reliable data exists to confirm or deny this population estimate.

1.2 THE CHARACTERISTICS OF RAW WOOL AND THEIR PLACE IN PROCESSING

Fleeces grown by different types of sheep are identifiable by characteristics of their respective wool fibres. For example, over a twelve month period of growth some breed-types produce long, coarse, lustrous fibres while others produce shorter, finer, chalk-coloured fibres. In order to provide a description of a particular batch of wool, the characteristics considered important in textile processing are either subjectively assessed or, as is the more recent commercial practice, objectively measured. The main wool characteristics, important in apparel processes, are listed in Table 3:

Table 3: Wool Characteristics of Importance to Apparel Processors

Wool Characteristic	Abbreviation
Fineness/Mean Fibre Diameter	MFD
Staple Length/Mean Fibre Length	SL/MFL
Staple Strength/Mean Fibre Strength	SS/MFS
Colour	COL
Crimp Frequency	CRF
Bulk/Resistance to Compression	BUL/RC
Medullation	MED
Yield	YLD

The importance of a characteristic is determined by a combination of the processing system employed and the desired end-product. The major effects of each characteristic on wool processing will now be discussed.

1.2.1 Mean Fibre Diameter/Fineness

Fineness, measured by the mean fibre diameter (MFD) of a wool lot, has long been considered the most important characteristic from the standpoint of quality and commercial value in apparel wool. The MFD of a batch of raw wool largely determines the potential fineness of the yarn which can be spun and, in the final fabric, affects handle, weight and appearance. Finer diameter wools tend to give softer and, if desired, finer products.

Fibre diameter is unaltered by processing, unlike fibre length and strength. However, research into the relationship between fibre fineness, length and crimp patterns led to an understanding and appreciation of the variations which occur within and between staples, fleeces, sale lots and breeds (Roberts, 1931; Rottenbury *et al.*, 1983). The subsequent development of objective measurements has enabled processors to more easily identify such differences in wool lots.

1.2.1.1 Coefficient of Variation of Fibre Diameter (CVD)

The range and variation of fibre diameter in a batch does affect processing, frequently in conjunction with other characteristics. There is a strong correlation between the standard deviation of mean fibre diameter and the mean diameter for tops ranging from 17-30 microns mean fibre diameter (Bow & David, 1992).

For apparel wools, the coefficient of variation of fibre diameter (CVD) ranges from 20-27% (Lunney, 1983; Bow & David, 1992; Lamb, 1992). The CVD affects the number of fibres in the cross-section of a given count and therefore the probability of yarn breakage (ends-down) when spinning near the limit of the count (which is rare in practice). Use of wool with a CVD of 28%, in comparison with using wool of the same mean fibre diameter but a CVD of 25%, can increase ends-down from 10 to 14 per 100 spindle hours (Downes, 1975b). Ten ends-down per 100 spindle hours is treated as the maximum acceptable in commercial production. Allowing for a 'safety margin', a limit of 35 fibres is increased to 40-45 fibres per cross-section to allow for imperfections in the spinning machinery and abnormalities in the sliver being spun.

Yarn properties are not greatly affected by CVD, a measure considered by Lamb (1992) to be about one-fifth as important as mean fibre diameter (micron). His observations indicated that a reduction in CVD from 25% to 20% would enable a processor to use a 21 micron wool instead of a 20 micron wool. The strength and evenness of the resultant yarn, as well as spinning performance, could be expected to be the same. Alternatively, if the 20 micron wool (CVD 25%) was used, CVD would not necessarily be the sole cause of reduced spinning performance or yarn irregularity, but it could affect yarn strength and extension at break.

1.2.1.2 Handle/Fabric Prickle

The handle of woollen fabrics and garments is of major importance to manufacturers and consumers. A harsh handle or scratchy sensation experienced by some people can result in a life-time preference for other fibres, particularly cotton. Handle has not been an objectively measured trait because of the difficulty in assessing softness of handle by mechanical or technological means. Instead, handle has been assessed by asking people to rate fabrics made from differing yarns and yarn blends. This may have been according to a scale of 1-10 or simply by nominating the softer of a pair of samples. Studies of the role of fibre diameter in the perception of harshness or 'prickle' has resulted in a better understanding of the factors involved and the means by which prickle may be almost eliminated.

Coarse fibre ends tend to come to the surface of yarn during spinning creating a ‘coarse edge’. These coarser fibre ends can evoke fabric prickle and discomfort for the wearer (Holcombe, 1986; Matsudaira *et al.*, 1990; Naylor, 1992a). Finishing processes, such as singeing, cropping, pressing and raising, can significantly alter the properties of the surface of fabric. In addition, handling characteristics may be improved by chemical treatments, such as the use of softening agents, as well as by changing the structure of both the yarn and fabric, *e.g.* by altering the levels of twist (Bow & David, 1992). By contrast, dyeing can increase the number of protruding hairs and subsequently increase prickle effect.

An investigation into the effects of blending fibres of varying fineness and length on the handle of knitted vests (Rolando & Townend, 1962) indicated that as little as a 10% coarser-fibre content could be detected by both specialist as well as inexperienced textile personnel. Similar results were obtained by Baudinet & Jowsey (1978) using New Zealand wool of 23, 26, 29, 31 and 33 microns, covering most of the wool used in apparel processing in New Zealand.

There is no simple method of measuring the distribution of fibre ends protruding from a fabric but the percentage of fibres greater than 30 microns (%>30 microns) has become an indicative criterion of likely fabric-evoked prickle (PF). When 5% or more of fibres are >30 microns, prickle is assumed to be detectable to a point beyond which fabric manufacturers will receive complaints from end-users as a result of skin irritation. This is particularly so with fibres >40 microns (Naylor, 1992a; de Groot, 1992). Should the amount of coarse edge increase, even by as little as one percentage point, the perception of prickliness will increase also (Naylor, 1992b).

Naylor *et al.* (1995) studied the coarse edge of 20-24 micron Australian wool and concluded that a one micron change in MFD had the same effect on the coarse edge as an approximate 3-8 percentage point shift of CVD. This study confirmed the earlier finding by Naylor (1992) of the strong correlation between skin comfort and the coarse edge in fibre diameter distribution.

Earlier research suggested measures of CVD and %>30 microns were useful indicators of commercial significance (Lunney, 1983). Dolling *et al.* (1992) used Australian Merino fleeces to study the effects on handle, and in particular the prickle of fabrics, differing in mean fibre diameter and CVD. Two groups of fleeces with similar characteristics (mean fibre diameter, diameter distribution, staple length and strength) were selected and processed into fabrics. One group had MFD of 23.2 microns and CVD 16.4%, while the other was 21.5 microns and 21.7% respectively. The group with the higher MFD was perceived to be less prickly than the finer group, which the researchers deduced was caused by two factors. The fabric made from 23.2 micron MFD wool had a lower CVD as well as a lower %>30 microns (3.6% versus 5.0%). The combination of low variability of fibre diameter and low coarse fibre content was associated with a reduced prickle factor by assessors. For this reason, the measures of MFD, CVD and %>30 microns are considered important characteristics in apparel wool. They assume greater importance than many other characteristics because of the level of acceptance of softer, smoother fabrics by end-users.

In another comparison of three tops in which all characteristics except the CVD were matched, an association was evident also between CVD and fabric bending rigidity, smoothness and perceived prickle (de Groot, 1992).

Mean fibre diameter has a much greater effect on the softness of handle when worsted spun than any other fibre characteristic. Increasing CVD by 10% can be expected to increase fabric stiffness (rigidity) by approximately 20%, and has been likened to an increase in mean fibre diameter of around 4% (Roberts, 1961).

1.2.1.3 Summary

Mean fibre diameter is justifiably ranked as the most important characteristic in apparel processing. MFD largely determines the fineness and associated softness of the yarn which can be spun. The CVD of fibre diameter expressed in a processing batch occasionally also has an important contribution to handle and wearer comfort. Differences between lines in MFD tend to mask the effects of other properties, such as CVD, the coefficient of variation of length (CVL), and crimp frequency (CRF) (Bastawisy *et al.* 1961).

Mean fibre diameter, coefficient of variation of mean fibre diameter and the percentage of fibres greater than 30 microns can be measured using instruments such as the Optical Fibre Diameter Analyser [OFDA] (Baxter, 1992).

1.2.2 Mean Fibre Length

The importance of mean fibre length measurements is based upon the following findings (Whan, 1972; Marler, 1992;):

- mean fibre length in greasy wool is highly correlated with the mean staple length in the same greasy wool.
- between fleece wool lots of a particular style, mean fibre length of tops produced is highly correlated with the mean staple length of the greasy wool
- mean fibre length in the top is influenced by the staple strength of the greasy wool.

- the percentage of noilage achieved during processing is influenced by the staple strength of the greasy wool.

- the position of break has an influence on the mean fibre length of the top.

Fibre length is a major influence in choosing the process by which wool will be spun into yarn and is considered the second most important characteristic (after fibre diameter) influencing spinning performance and yarn properties. In all stages of processing (card sliver, tops and yarns) fibre length is measured and used to specify the material. Very good linear relationships exist between mean fibre length in tops (r=0.97) and mean staple length in greasy Merino wool (Bow 1979; Rottenbury, 1979). Processing factors, such as scour conditions, card types/settings and fibre breakage alter fibre length. Other characteristics such as fibre diameter, staple strength and VM content also contribute to the fibre length in the finished top. Fibre length tends to reduce with decreasing fibre diameter, decreasing staple strength, and increasing levels of VM contamination (due to breakages during removal of same).

1.2.2.1 Fibre Length Distribution

Fibre length distribution in combed wool samples can be measured using an almeter. The results assist in the prediction of processing performance and the mean fibre length and coefficient of variation of fibre length can be estimated. The almeter provides measures of mean fibre length in terms of both 'hauteur' and 'barbe', in addition to an estimate of short-fibre content. Barbe is based on the percentage of fibres by weight having a length equal to or larger than a given value whereas the estimation of hauteur attempts to correct for the heavier weight of longer fibres. The hauteur measure is used in Australia because of the predominance of Merino-type wool for worsted processing. The barbe measure is preferred in New Zealand and reflects the dominance of crossbred wool and the practice of blending different wool types to meet buyer specifications (Wood *et al.*, 1988).

The mean fibre length of wool top is important as it affects the strength, appearance and surface characteristics of the yarn spun from it, and therefore the quality of the final product, often a garment (Douglas et al., 1985). Over a three year period from 1981-1984, a total of 14 mills in 12 countries took part in the Trials Evaluating Additional Measurements (TEAM) Project, conducted jointly by the Australian Wool Testing Authority Ltd, CSIRO Division of Textile Physics and Australian Wool Corporation (Douglas, *et al.,* 1985). Raw wool measurements of staple length, staple strength, position of break and clean colour were made from commercial consignments of combing wool to supplement core-test information of yield, vegetable matter (VM) content and MFD. Processors co-operated by providing processing results and top measurements. The project's aim was to determine the relationships between processing performance and raw wool characteristics and thereby evaluate the usefulness or otherwise of such data for sale purposes. A further TEAM Project (TEAM-2) operated from 1986-1988 and concentrated on the analyses required to predict top hauteur, coefficient of variation of hauteur and noil (Douglas, 1989).

As a result of these extensive evaluations, it was found that the relative importance of a particular raw wool characteristic, or group of characteristics, was different in each of the participating mills in the trial, and was dependent upon the types of wool being processed. In general terms, diameter, staple length, staple strength and vegetable matter base were shown to be important raw wool characteristics affecting fibre length in the top. From this study, a general formula was derived for predicting fibre length in the top but the formula differed from mill to mill because of factors such as scouring (make and age of equipment), processing lines (e.g. differing cards and combs), influences caused by time (high and low throughputs, delayed maintenance, setting changes, new equipment), and the equipment/method of measuring fibre length in the top.

The prediction formulae published in the final TEAM Project report were:

Fleece Wool: $H = 0.70MFD + 0.45SL + 0.41SS - 5.7$

Skirtings: $H = 1.53MFD + 0.40sSL + 0.32SS - 20.1$

H = Mean Fibre Length of the top (hauteur) in mm;
MFD = Mean Fibre Diameter of the greasy wool in microns;
SL = Mean Staple Length of the greasy wool in mm;
SS = Mean Staple Strength of the greasy wool in N/ktex

Fibre diameter and percentage of middle breaks also contributed to the hauteur, while vegetable matter base had a smaller effect.

From a wide range of wool types, a reliable predictor of processing performance was derived for individual mills. Objective measurements can be important factors in the buying strategy of wool manufacturers, in quality control and in production planning (Douglas, *et al.*, 1985).

From these studies the characteristics of over-riding importance in the prediction of hauteur were staple length and staple strength. Bell (1984) estimated that, second to fibre diameter, fibre length (hauteur) and its distribution contribute about 25% of the value of a top.

1.2.2.2 The Relationship of Fibre Length Distribution to Processing

As the variance of fibre length within staples of Merino wool is so small, relative to the variation resulting from fibre breakage during processing, there is little incentive for breeders to produce sheep with fibres of more uniform length.

Some variation in fibre length is considered essential for effective spinning (Bastawisy *et al.*, 1961; Hunter, 1980). Approximately 20% of the variation in fibre length in tops is due to the variation in the raw wool; the other 80% is usually due to blending and/or fibre breakage during carding and combing. The nature and extent of fibre breakage is dependent upon mill procedures but fibre breakage during processing drastically alters the fibre length characteristic of a wool. Rottenbury *et al.* (1986) reported that in typical worsted carding, 40% of the fibres break. Breakage at the carding stage is often reflected in more noil during combing than in the mean fibre length of the top (Downes, 1975a).

Yarn breakage is increased during spinning if there are too many short fibres, while extra-long fibres can wrap around the rollers. The distribution of fibre length affects yarn appearance because short fibres tend to migrate to the outside of the yarn. If free ends of short fibres protrude from the yarn, pilling can result (Teasdale, 1985), while long, coarse fibres protruding from the yarn surface frequently cause prickle. When the coefficient of variation of fibre length (CVL) is less than 13%, spinning performance deteriorates. However, if using wool above 20% CVL, a further increase in CVL is nearly always associated with an increase in the frequency of neps in the yarn (Bastawisy *et al.*, 1961).

A study of the effect of fibre length on spinning performance when using a modern high-draft worsted-spinning method (Bastawisy, *et al.*, 1961) indicated that longer fibres can be spun to finer counts but that the number of end-breaks reaches a plateau once fibre length is longer than approximately 90mm; so that there is virtually no advantage in using fine apparel wool longer than 100mm. This research demonstrated that a decrease in fibre diameter or an increase in fibre length (up to 100mm), all other factors being constant, will result in a finer spun count.

In sale lots of greasy wool, Whan (1972) concluded that the main reduction in staple length variation resulted from the removal of the short stapled and stained wools during skirting. In addition, the uniformity of fibre-length in greasy wool lots may be quite different to the fibre-length variation in tops due to fibre breakages during processing. Indeed, the length uniformity of tops made from unskirted fleece is not significantly greater than that of tops made from skirted fleece (Lang, *et al.*, 1967). In addition, fibre-length variation in tops is only marginally affected by skirting (Teasdale, 1985). An Australian study showed an average CVL of 14% (range 7-33%) for fleece wool and 22% (range 9-50%) for skirtings, the very high values indicating unacceptable mixtures of lengths (Marler, 1992).

A study was undertaken to assess the relevance, if any, of using combing performance predictions to unusual merino and crossbred wool types (lambs wool, cast fleeces, oddments and skirtings) (Mooy, *et al.,* 1988). The results indicated that, apart from hauteur predictions, raw wool characteristics of fibre diameter, staple length, staple strength and VM content, were frequently associated with processing performance, as is the case with fleece wool. Hauteur was found to be over-predicted for short wool and under-predicted for longer wool.

1.2.2.3 Noilage

Andrews (1979) compared noil percentages from five processing batches containing long, short, medium, unclassed and a mixture of long- and short-staple length wool. The results indicated there was no difference in processing performance and that the mean noilage was the same no matter how or if the wools were classed for length. That is, a high or low variation in staple length made no difference in noilage. The first conclusion of this study was that as most of the variability of fibre length is within fleeces, classing for length can only affect variability between fleeces and not the overall variability.

A corollary was that fibre breakage during processing (particularly carding) increased variability to such an extent that it eliminated the improvement in variability achieved through classing. While classing for length is principally undertaken to increase uniformity, little is achieved by classing for length in fleece lines.

1.2.2.4 Summary

As for all traits, staple length and strength are only important if they can be related to processing performance (*e.g.* card waste, noilage, machine settings and speeds) and product properties (MFL and CVL in the top). The mean fibre length measurement of a top is important because it affects processing performance; long-fibre wools can be spun at faster speeds than wools with lower hauteur, while yarns made from long-fibre wools have increased tensile strength.

In 1985, the Australia-developed CSIRO Automatic Tester for Length and Strength (ATLAS) was introduced to assist in the marketing of Australian wool. The additional measurements of length and strength of greasy wool enabled purchasers to make processing decisions and to predict end-use performance (Thompson, *et al.*, 1988). This equipment is now available in New Zealand but staple length and strength measurements do not provide such useful information in many New Zealand wool types.

Length-after-carding (LAC) measurements have become important in New Zealand and are considered to be of more relevance to processors than measures of mean fibre length and CVL in the raw wool. However these measurements are seldom used in the primary stage of wool marketing.

1.2.3 Mean Fibre Strength

Fibre strength and its effects on manufacturing performance is a complex matter. Unsoundness can occur anywhere along the fibre and to varying degrees within a staple. Whether the area of break or tenderness will affect processing and the end-use of such wool is determined largely by the processing system employed and type of wool. Different manufacturing processes are used for different end-uses and unsoundness is not important in all processes.

In the worsted system the effect of unsound wool is highlighted, perhaps more than in any other, because of the short fibres which result mainly from breakages during processing and the loss of many of these in noil. By contrast, woollen processing does not involve combing and therefore fibre length is not such a critical factor (Wickham, 1968).

The strength of a wool staple is dependent upon the strength of the individual fibres within the staple and the total cross-sectional area of fibre being tested. Fibre diameter varies along and within the staple and thereby affects the strength of the staple. In a flock of sheep kept under identical conditions, there is likely to be a large range of staple strengths (Reis,1992). All degrees of staple weakness occur naturally and are largely controlled by husbandry factors. The importance of staple strength concerns the modification of expected processing behaviour, particularly in worsted tops and the properties of those tops (Teasdale, 1985).

1.2.3.1 Variation of Fibre/Staple Strength

Staple strength variation occurs between and within sale lots as well as between sheep in any mob and within the fleece of individual sheep. A study of sources of staple strength variation (Rottenbury, 1979) found that, on average, 61% of the total mob variation was due to differences between fleeces, the remainder due to within-fleece variation. When the fleeces were subdivided into regions, the between-fleece region effect (19%) was as large as the within-fleece-region effect (20%). Exceptions to these results could be expected where there were marked differences between different regions of the fleece (e.g. mid-back versus mid-side), possibly due to environmental factors, and resulting in more important between-region effects.

1.2.3.2 Position of Break

The position of staple/fibre break (POB), or weakness, is important in processing. Staples which break in the middle, for example, are more likely to reduce fibre length (hauteur) in the top than if the staple broke near the tip or butt.

The POB is expressed as a percentage of the overall staple length from the tip. For example, if a staple broke a quarter of the way down the staple from the tip, it would have a POB of 25%. Wool with breaks near the tip or butt tend to produce higher card losses (Rottenbury, *et al.*,1985; Teasdale, 1985).

1.2.3.4 Processing Effects

Fibre tensile strength is difficult to isolate as a single effect on spinning performance as it is usually associated with fibre diameter, finer wool tending to have less tensile strength than coarser wool.

Fibre breakage during carding is increased by fibre entanglement during scouring or dyeing, tenderness in the wool fibres, excess fibre length and high carding speeds.

Yarn tensile strength and spinning limits are primarily a function of the number of fibres in a cross section of yarn. The number of breakages increases as the number of fibres decreases (Hunter, 1980). For sound wool, the spinning potential is determined by the fibre diameter and length, the limit being around 40 fibres per cross section. Tender wools increase the percentage of short fibres; when fibres break, they may come out in the noil, leading to a higher percentage of noil and lower tear (top:noil ratio) but not necessarily shorter lengths in the top.

Weaker fibres tend to break to a greater extent during spinning. This, along with finer diameter, limits the count (thickness) to which the yarn may be spun. Should more frequent breaks occur during the drafting operation in spinning, the effect on the finest count to which the yarn may be spun is much greater (Bastawisy, *et al.,* 1961; Roberts, 1961; Hunter, 1980).

For wool processed on the woollen system, fibre strength is often relatively unimportant because length is not as important. By contrast, for worsted processing, higher strength values are required as a weak region is more than likely to reduce fibre length. Additionally, processors want to process as fast as possible and to minimise ends-down. High throughput is incompatible with efficient processing if there is too much fibre breakage.

1.2.3.5 Measurement of Staple Strength

Fibre strength is reflected in fibre breakage during processing, therefore staple length and strength measurements allow a good prediction of fibre length in the top for 'average' processing conditions (Hunter, 1980: Bigham *et al.* 1983; Ross, 1991; Butler, 1994).

Various methods, subjective and objective, have been used to measure staple strength. Staple strength is now often measured mechanically and is usually expressed in units of Newtons/kilotex (N/ktex). It is defined as the maximum force required for the fibres in the staple to rupture, corrected for thickness of staple (Rottenbury *et al.*, 1985).

Rottenbury (1979) had earlier suggested that the average force exerted by hand (subjective strength appraisal) was approximately 30 N/ktex [range 17-48 N/ktex]. Objectively measured samples of Australian wool (predominantly Merino) vary from less than 20 N/ktex to 80-90 N/ktex. This observation brings into question the use of subjective strength appraisal. The thickness of staples selected is not consistent and may affect staple strength assessments also. The maximum force normally exerted in the hand-test is 30-40 Newtons and the thinnest staples selected approximate 2 kilotex. On this basis, the upper limit of weakness detection is closer to 20 N/ktex. Above this value, the hand-test will not distinguish the staple strength and the wool could be regarded as sound simply because not enough force is exerted for the size of staples selected. The hand-test method would, on this basis, be suitable for wool below 20N/ktex only. As processing performance deteriorates progressively as staple strength weakens, a subjective assessment will not be tested for accuracy, and therefore validity, until well into processing. This represents a serious limitation of subjective strength appraisal.

1.2.3.6 Summary

Wool fibre strength is strongly associated with fibre diameter and is largely a function of MFD or more particularly, the minimum diameter or cross-section. Finer fibres are reportedly more variable in their cross-sectional area than coarser fibres which possibly explains why fibre tenacity shows an increase with increasing fibre diameter (Hunter, 1980).

Fibre strength is an important characteristic influencing the choice of process in which wool will be spun into yarn. An acceptable speed of processing is largely a function of fibre strength. Yarn strength and elasticity are functions of MFD, CVD, MFL, CVL and crimp (Bastawisy *et al.* 1961).

1.2.4 Crimp Frequency

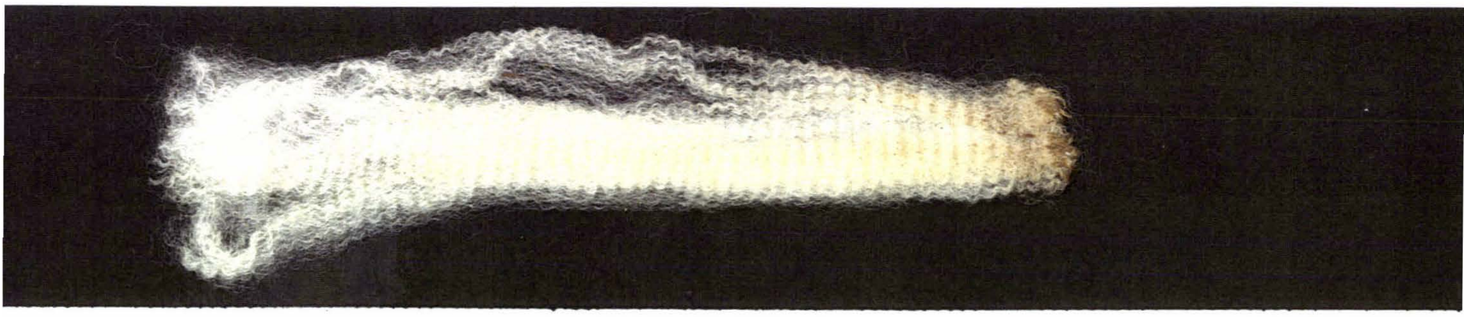
Fibre crimp is the natural waviness present in most wool fibres, the number of "waves" varying between and within sheep breeds (Figure 1 and Figure 2).

Crimp can be defined in terms of both staple crimp and fibre crimp, and some wools with high fibre crimp do not have clear staple crimp. An increase in fibre crimp generally increases resistance to compression and bulk, reduces felting of loose wool and changes the handle of loose wool.

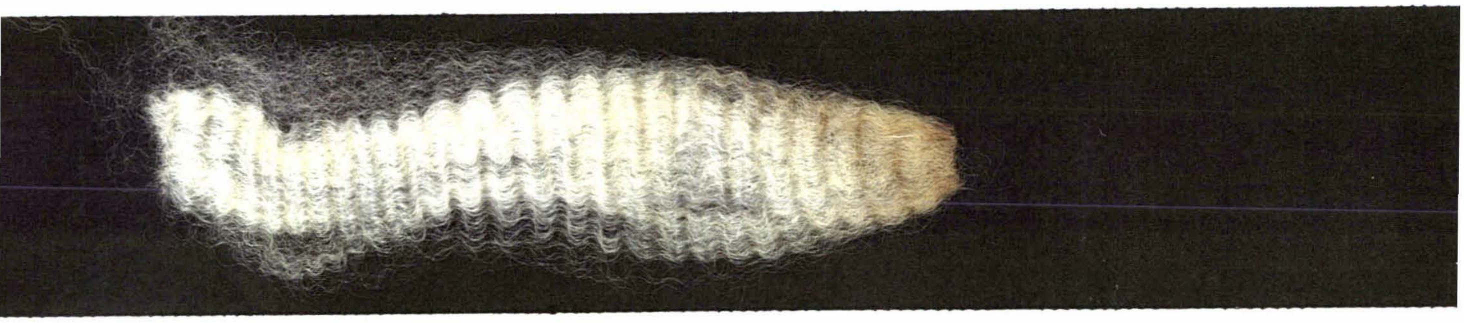
A greater number of crimps has been suggested as a means of improving the 'softness' of greasy wool and finished cloth. An increase in the number of crimps per 25mm from 10 to 15 was considered responsible for an improvement in the feel (smoothness). However, it is now considered that differences in mean fibre diameter frequently mask these effects and reduce their contribution to handle (Menkart & Detenbeck, 1957). Fibre crimp levels are usually reduced during processing but never entirely eliminated. Roberts, 1961). The significance of wool fibre crimp in worsted processing was studied by Menkart & Detenbeck (1957) and in the woollen system by Menkart and Joseph (1958). Their findings are summarised in Table 4.

Figure 1: Samples of Crimp Patterns

a) Merino: MFD = 25.5μ Bulk = 27cm3/g



b) Corriedale: MFD = 30.0μ Bulk = $28cm^3/g$



c) Perendale: MFD = 35.5μ Bulk = $26cm^3/g$

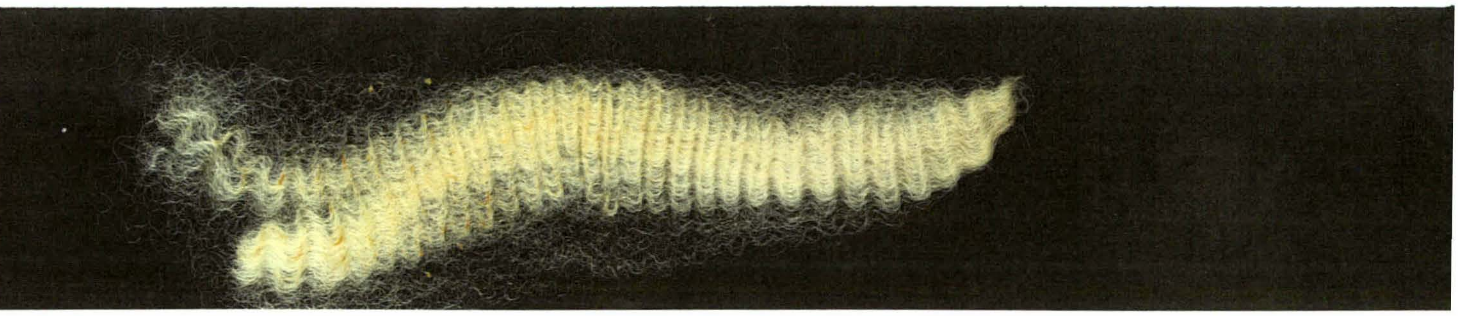
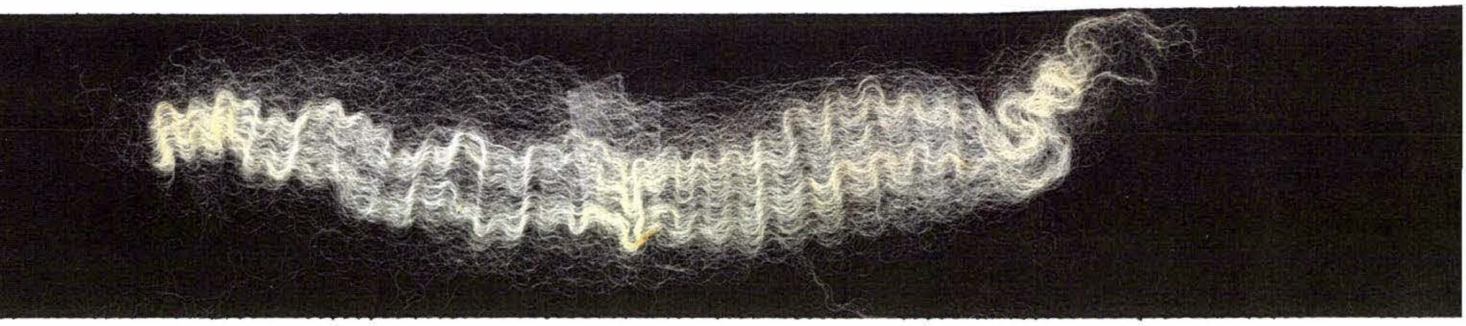


Figure 2: Samples of Crimp Patterns

d) New Zealand Romney: MFD = 36.0μ Bulk = 22cm^3/g



e) English Leicester: MFD = 40.0μ Bulk = 18cm^3/g

f) Drysdale: MFD = 44.0μ Bulk = 22.0cm^3/g

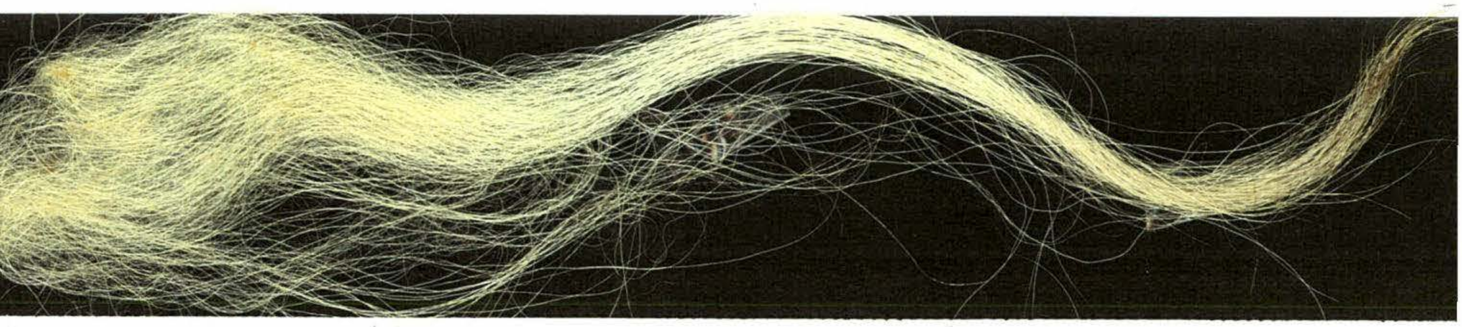


Table 4: **The Effects of High-Crimp Fibre**
(Menkart & Detenbeck, 1957; Menkart & Joseph, 1958)

Superior carding
Higher processing speed
Softer fabrics and yarns
Finer fabrics and yarns
Good wrinkle-recovery
Bulkier yarn
Lower extensional stiffness
Lower breaking extension
Lower breaking strength
Greater air permeability
Better drape
Thicker fabric (6-10%)

Overall, the two studies showed no greater effect of fibre crimp in either the woollen or worsted system. The expectation was that the more random and looser woollen structure would have allowed fibre crimp to have manifested itself more clearly.

These findings were confirmed again by Roberts (1961) who observed a detectable improvement in handle and perception of softness in both greasy wool and finished fabric where a higher number of crimps per 25mm existed.

The above results were similar to those of Lang & Sweetten (1960) following worsted processing of anomalous and normal Merino wool. The different crimp patterns were clearly seen - the anomalous-crimp wool having a lower and more irregular crimp frequency. After processing into worsted yarns and fabrics, the normal-wool products were favoured over those made using anomalous-crimp wool due to improved handle (smoother and softer) and yarn/fabric strength. The researchers noted that objective comparisons were essential to differentiate the wool for fibre diameter and strength in particular.

Bastawisy *et al.* (1961) found that with a newer high-draft spinning system low-crimp wool spun to a finer count with fewer end breakages at similar counts than high-crimp wool. They also compared low-and high-crimped nylon with low-and high-crimped wool and deduced that the more uniform roving obtained from straighter fibres (i.e. low-crimp) resulted in a more regular and stronger yarn. These results indicate that there is possibly no advantage in using high-crimp wool and that on occasion they may be inferior.

1.2.4.1 Summary

Fibre diameter is the only variable significantly correlated with fibre crimp, CVD showing no significant relation to crimp. However, despite the correlation between fibre diameter and fibre crimp, the effect on spinnability is masked when studied in conjunction with other fibre properties. Only when fibre crimp is studied on its own is the influence important. Studies have confirmed that with modern high-draft spinning systems, low crimp wools spin more evenly Bastawisy *et al.*, 1961).

1.2.5 Bulk and Resistance to Compression

There are several systems of defining the space-filling properties of wool. Bulk is the measure used in New Zealand, whereas Australians frequently measure Resistance to Compression (Lunney, 1988).

Resistance to Compression (RC) is a measure of the resistance offered by a given mass of wool when compressed to a fixed volume.

Bulk is defined as a measure of the volume occupied by a given wool mass (cm^3/gm) when compressed by a prescribed load. It can be measured in the loose wool, core sample, sliver or yarn form. Loose wool bulk ranges from 15-40 cm^3/gm while core bulk ranges from 19-39 cm^3/gm.

Bulk, often termed 'springiness' has a significant effect on woollen-spun knitwear. The higher the bulk the 'softer' the apparent handle of the garment. This can override the effect of a slightly coarser mean fibre diameter. Similarly, in carpet manufacture, bulk is an important property in the recuperation of fibres from treading action and in the quantity of wool required to give a 'bulky' pile (Carnaby & Elliott, 1980).

New Zealand wools average between 15-36 cm^3/gm when full length, scoured and carded samples are measured. The measurement of wool bulk is a valuable indication of the potential value of the finished product as there is a positive correlation between loose-wool bulk and yarn bulk, even though yarn bulk is much lower. The single most important factor governing yarn bulk is the processing system (van Luijk, 1987) but, to a limited extent, the bulk of the raw wool is reflected in the bulk of the finished product.

There are large variations in RC among and between wools of different breeds and a strong correlation exists between RC and crimp frequency. In early processing systems, using superfine apparel wool (Merino types), RC was considered important in reducing losses through topmaking and increasing yarn strength. With the advent of modern high-speed processing, the reverse has been found to be true with higher card wastes and noilages from wool of high RC (Kurdo, *et al.*, 1986).

Wools with high RC tend to give lower scouring yields, a factor which can be understood with superfine Merino wools which have a higher wax and suint content. Kurdo *et al.* (1986) found a significant influence of RC and crimp frequency (CRF) on scoured yield, card waste, noilage, top-and-noil yield and fibre-length characteristics in tops processed from a superfine wool flock. Greater breakage of high-crimp, high RC wool during processing contributed to these effects (with the exception of scoured yield). The experiments demonstrated too that while differences in mean fibre length in tops are far less than the differences in mean staple length among the raw wool, the relationships between the two length measurements are substantially modified where large variations exist in RC measurements. For example, if the staple length of a low RC wool was 3mm shorter than that of a high RC wool the difference would be likely to increase to a 7mm difference in the top. The researchers suggested than an additional 10mm in staple length for high-crimp superfine wool may be necessary to achieve the same fibre length in tops produced from low-crimp superfine wool.

While wool of low RC gave a superior top-making performance and longer fibre length in the top, it is necessary to evaluate spinning performance and yarn/fabric quality before the significance of RC in wool textile processing is understood (Kurdo *et al.*, 1986).

1.2.5.1 Summary

The results of the Australian trials referred to above support RC measurements as being useful in the prediction of the likely topmaking performance of raw wool but other characteristics are usually of more importance for most end products

1.2.6 Medullation

Medullated fibres are those which have a hollow central cellular core, termed the medulla, instead of being tightly packed with cortical cells. As a result, there is less substance to absorb dye, resulting in medullated wools that were initially white appearing a different colour from non-medullated wools in the final product. This can be a serious fault.

The presence of medullated fibres does not mean that the yarn will be hairy. Medullation and hairiness are frequently confused. Hairy yarns, in the main, have many fibre ends protruding from the yarn (Henderson, 1968).

The significance of medullation and hairiness to growers, manufacturers and consumers was the subject of New Zealand research, based on Romney hogget wool, over fifty years ago (Townend & McMahon, 1944). Hogget wool was chosen as the most suitable raw material for the test because of its fineness. Two batches of britch- and hindquarters-wool were used. They were almost identical in terms of fineness, mean fibre length and soundness, but there was a difference between the two batches of about 4.6% of coarse, medullated fibre which was clearly visible in one raw wool lot. Following processing into dyed woven and knitted fabrics, there was no marked difference in handle or appearance between those items produced from the less- or more-medullated wools. Despite the less medullated wool having a slightly superior spinning performance, the researchers concluded that the presence of up to 6% of coarse, medullated fibre did not appreciably affect the processing properties of sound, well-grown Romney hogget wool.

A follow-up project (Peryman *et al.*, 1952) processed into dyed fabric two batches of Corriedale hogget wool as near as identical in fibre diameter, length and soundness but differing in medullation by approximately 3.4% of "coarse hairy fibre". The medullation was not visually obvious in the hairier batch and was confined primarily to the tips. While there were no differences in appearance or handle in either the woven or knitted fabrics of each batch, some differences were apparent during processing. The medullated batch resulted in a more irregular roving and uneven yarn which caused more ends-down when spinning fine counts and a lower spinning limit. This result confirmed that of the earlier trials using Romney wool.

1.2.6.1 Summary

A measure of the percentage of medullated fibres in samples of a wool lot gives an indication of the effects likely to be encountered in processing and the end-product. A measure of CVD may provide much the same information.

1.2.7 Yield

Yield is expressed in several ways. The most common is clean scoured yield which may be defined as the percentage of usable fibre after the removal of contaminants.

In New Zealand, wool yields range from 59-75% for Merino types, 63-76% for Halfbred wool and 68-83% for crossbred wool, although lower and higher values may occur in particularly contaminated or extremely clean fleeces of any type.

Yield is an important factor in fibre valuation. In the white wool market, a contaminant is any substance that is not white wool. Natural contaminants include grease, dirt, suint, vegetable matter and some stains. Other contaminants include synthetic fibres from wool packs, twines, non-scourable brand marks of various colours, rubbish, metal pieces/machinery, clothing, non-wool fibres such as dog hair, and black and coloured wool. Poor shed/farm management may contribute to the extent of non-natural contaminants and increase the likelihood of spinners switching to synthetic fibres, totally free of contaminants, which can be ordered to exact measures of fineness and length for delivery.

Some contaminants can affect cost. For users of black and coloured wool, natural-colour is the primary requirement but growers of both white and coloured wool should realise that the natural advantages of wool may be outweighed and out-priced by contamination in greasy wool. Processors have to consider the cost:benefit ratio between cheap wool and high processing costs. It can be more profitable to purchase the most expensive greasy wool and have low processing costs.

Vegetable matter (VM) in raw wool has two particular effects in worsted processing (Bow *et al.*, 1989). They are:

- As VM increases, more wool is removed with the VM during processing, either as card waste or noil.
- Residual VM particles contaminate combed sliver.

One of the reasons for processing VM-contaminated wools on the worsted system is that it can handle a good proportion of VM without the need for carbonising. The woollen and semi-worsted systems offer less possibility of VM removal.

The amount of 'tip' varies greatly between wools, from less than 2% for a blocky tip (preferred by processors) to over 5% for an open, wasty tip. As about 90% of the tip is removed during processing, and particularly by carding, the yield in worsted tops is significantly affected by the tippiness of the wool (Walls, 1968).

1.2.7.1 Summary

Yield is determined by breed type and the presence of natural and environmental contaminants. VM contamination in particular influences the choice of processing system employed with the worsted system best able to handle high VM contaminated wools.

1.2.8 Colour

The majority of the world's processed wools are near-white and visual appearance is an important characteristic when supplying scoured wool to a customer. Paradoxically, Cottle & Zhao (1995) stated there is no relationship between the colour of greasy wool and the colour of scoured wool. According to Marler (1992) strong relationships exist between:

- the colour of commercially processed tops and the colour measurements made on scoured and carded greasy wool samples

- the dyeing potential of greasy wool and its clean colour measurement

The whiteness of wool has a distinct effect on the dyeing process. As a rule, the whiter the wool, the clearer and/or brighter the colour of those wools when dyed. The presence of yellow or dark fibres in raw wool intended for high-fashion apparel wear can represent a serious fault, especially when dyeing with pale colours (Lipson, 1972; Downes, 1975a; Bigham *et al.*, 1984).

1.2.8.1 The Measurement of Colour

Instruments for measuring colour are of two types. Spectrophotometers measure and record the amount of light reflected in each part of the visible spectrum while colorimeters measure the amount of light reflected in selected broader regions (rather than at each discrete point) (Stewart & Hoare, 1971).

The tristimulus colorimeter (*e.g.* Hunterlab D25DSM and ICI Digital) and spectrophotometer (*e.g.* Hunterlab ColorQuest) are the common apparati used in New Zealand for measuring the colour of near-white wool (SANZ, 1984; Hammersley, 1991). While the spectrophotometers are a recent introduction, colorimeters have been in commercial use since 1976 to measure the Commission Internationale de l'Eclairage (International Commission on Illumination)(CIE) tristimulus values X, Y, and Z which measure the reflection of white light from wool fibres in the red (X), green (Y), and blue (Z) areas of the colour spectrum. The tristimulus values are determined for Illuminant C and the CIE 1931 standard colorimetric observer (Hammersley and Thompson, 1974). Y-Z, a measure of yellowness, is used for sale purposes to identify the whiteness of wool. The Y measure is a good indicator of lightness, a high reading indicating a bright wool.

A study of fleece colour from white sheep of Romney, Coopworth and Perendale breeds (Bigham, *et al.*, 1984) found a high correlation between X and Y values and little advantage in measuring both, as X could be predicted from Y. Y and Z values were also highly correlated but neither was correlated with the Y-Z value.

A scale used more in Australia, and adopted by the CIE in 1976 for the measurement of small colour differences, is the CIELAB system, derived from the XYZ scale. This CIELAB colour space is uniform and based largely on colour differentiation systems developed by Munsell and others (Kelly & Judd, 1955). The measures are L* (lightness), a* (redness if positive, greenness if negative) and b* (yellowness if positive, blueness if negative).

After lengthy consideration, the tristimulus measure was adopted by New Zealand test houses (Hammersley, 1991) although there is a high correlation between tristimulus and CIELAB wool measurements for yellowness and lightness - b* relates to the Y-Z reading for yellowness while L* is the equivalent of the Y value.

1.2.8.2 Yellowing

Poats & Fong (1957) observed that colour was ranked third, after mean fibre diameter and mean fibre length, among the factors affecting a white wool buyer's appraisal of the quality of a lot sample. Initially, these workers used a colour comparator to rank whiteness, followed by the use of the Gardner Automatic Color Difference Meter. This instrument measured wool colour in terms of light reflectance/brightness, redness, greenness, yellowness and blueness. It was widely used to assist in the aggregation of wool colour lots sourced from regions of variable climatic conditions in the United States of America.

It is almost impossible to assess the scoured colour or yellowness of near white wool in the greasy state. Any yellow colour present may be permanent or scourable and it is for this reason that the test for yellowness is important in giving an accurate indication of the scoured colour.

For greasy near-white wool, the intrinsic colour of the wool fibres may be masked by grease, suint and dust which may be almost entirely removed in scouring. Permanent yellow staining, often caused by the action of suint in hot and humid conditions, is not removed in the scour and reduces the range of colours into which the wool can be dyed. Similarly, black and coloured fibres, by the nature of their unscourable colours, are an obvious fault to processors wishing to dye with pale colours.

In a study aimed at detecting unscourable yellowness in greasy wool, Thompson & Whiteley (1985) observed that mean yellowness measurements (Y-Z) of test-scoured core samples provided a more equitable assessment of unscourable yellowness than subjectively assessed samples.

Mahar & Osborne (1996) studied early stage processing effects on the colour of Australian Merino fleece wool and skirtings. Their analysis of measurements taken at greasy wool (core sample), combing (noil) and after the final gilling (top) stages showed a good relationship between the colour of cleaned greasy wool and the colour of the resulting top. In terms of average yellowness (Y-Z), the relationships were very strong (r=0.92). Wool brightness (Y) relationships were less strong (r=0.69) but nevertheless still significant. In analysing measures of brightness, there was a weak but significant relationship between the Y-Z and Y values at both the cleaned greasy wool (r^2=0.40) and top

(r^2=0.32) stages. Usually, a low Y-Z value is associated with a high Y value, *i.e.* a bright wool. This study identified the usefulness of raw wool measurements as predictors of post-processing colour in tops and thereby a quality control measure. The researchers suggested that, if mill processors were unable to predict colour in tops from raw wool measurements, a processing factor may be influencing the top colour (*e.g.* overheating during drying, the presence of additives such as anti-static agents, lubricants).

Warm, moist conditions can result in non-scourable yellow discolouration in susceptible fleeces. Wools which are susceptible to discolouration may change colour on the sheep, during storage and/or during processing. Wools with a low propensity to discolour can be expected to change less than susceptible wools (Reid, 1993).

1.2.8.2 Summary

The colour of wool is important to the textile industry because it affects dyeing performance. In particular, for products dyed with pastel colours, the whiter the wool, the brighter and clearer the dyed colour. While many very yellow greasy wools can scour to produce brilliantly white tops (Turk, 1993), by contrast, a wool which is cream or yellow in the scoured state, will not dye to a clear, pale colour or a bright, dark colour.

The measurement of colour is an average measure of the lot. It does not identify variability which may occur within a lot due to poor sorting. However, it is possible to estimate the dark fibre content of a lot of near-white wool using technology such as the Optical Fibre Diameter analyser (OFDA).

Processors have built up a knowledge of the range of colour readings which are acceptable for using particular dye colours and measurements falling outside these ranges are discounted.

SECTION 2:

2.0 THE CHARACTERISTICS OF BLACK AND COLOURED WOOLS GROWN IN NEW ZEALAND

2.1 INTRODUCTION

At present no official data exists concerning the characteristics of black and coloured wools grown in New Zealand. In addition, there is no record of the number and variation of colours present in the wools produced by New Zealand's coloured sheep population.

This section attempts to provide an overview of the wool characteristics currently present in sale lines.

As outlined in Section 1, growers of natural-coloured wools tend to sort their wools into sale lines of broadly-based breed types and colour groupings. For example, Fine (*i.e.* Merino and Merino-cross breeds) and Crossbred (XBD) (*i.e.* Romney, Perendale, English Leicester, Gotland) wool-types in lines of Light, Medium, Dark and Moorit (yellow-brown) colours.

At wool pools, quantities of like-coloured wools are combined in bins on the sorting room floor prior to baling. The allocation of any one fleece to a particular colour bin is at the discretion of the sorter, *i.e.* the fleeces are colour sorted by 'eye'.

To distinguish between colours, ideally a set of parameters or measurements should be utilised but as these are not currently established for naturally pigmented wools, samples of the subjectively assessed colours were obtained. The intention was to attempt an identification, by objective measurement, of the subjectively designated colours sorted on the wool shed floor.

2.2 MATERIALS AND METHODS

2.2.1 Test Samples

In order to obtain an overview of wool characteristics in current (1998/99) naturally pigmented fleece lines, a total of 268 wool samples, each weighing approximately 30gms, were randomly selected out of fleece lines at three New Zealand regional coloured wool pools as follows:

- Region 1 - Manawatu (R1)

  15 samples from each of 4 lines

  (FINE-Light, Crossbred (XBD)-Medium, XBD-Dark, XBD-Moorit)

  14 samples from 1 line

  (XBD-Light)

- Region 2 - South Island (R2)

10 samples from each of 11 lines

(Fine-Light, Fine-Medium, Fine-Dark; Halfbred (½ BD)-Light, ½ BD-Dark; Fine Crossbred (FXBD)-Light, FXBD-Medium, FXBD-Dark; XBD-Light, XBD-Medium, XBD-Dark)

9 samples from 1 line

(1/2 BD-Medium)

- Region 3 - Waikato (R3)

10 samples from each of 6 lines

(XBD-Light, XBD-Medium, XBD-Dark, XBD-Moorit; CXBD-Light, CXBD-Dark)

6 samples from 1 line

(Long Crossbred (LXBD)-Dark)

3 samples from each of 3 lines

(Fine-Medium, Fine-Dark, Coarse Crossbred (CXBD)-Medium)

To assist in the distinction of colour measurements for grey wool, an additional 15 samples (5 light grey, 5 medium grey, 5 dark grey) were obtained from a Gotland sheep breeder.

2.3 Test Methods

All samples were evaluated in the wool laboratory at Massey University.

The test methods utilised in this study were based on those developed for white wool. Any likelihood of bias or inappropriateness for coloured wool will be discussed later.

Measurements of handle, mean staple length, crimp frequency and mean staple strength were made when the samples were in the greasy state.

All other measurements were made after the samples had been scoured, dried, conditioned for 48 hours at 65% Relative Humidity and a temperature of 20° C (to give an approximate 16% regain), and carded with an Ashford drum carder.

Measurements for staple length, crimp frequency and staple strength were made on five random sub-samples of each sample, each measurement having been made on the same sub-samples. The average of the five sub-samples determined the sample measurement for each characteristic.

2.3.1 Handle (HDL)

Samples assessed individually and screened from the view of the assessor. The numerical scores given were based on the method utilised by Sumner (1969):

1. Extremely harsh
2. Markedly harsher than average
3. Clearly harsher than average
4. Slightly harsher than average
5. Average handle
6. Slightly softer than average
7. Clearly softer than average
8. Markedly softer than average
9. Extremely soft

2.3.2 Staple Length (STL)

Five random sub-samples of each sample were measured to the nearest centimetre, unstretched but flattened, using a standard ruler.

2.3.3 Crimp Frequency

The number of crimps over the whole staple length of five random sub-samples of each sample were counted, divided by the staple length (mm) and converted to crimps per 25mm.

2.3.4 Staple Strength

The test was carried out on sub-samples of 'pencil thickness' size. If unable to be broken, the staple was divided in half and, if necessary in half again. Staple strength was assessed according to an adaptation of the scale utilised by Sumner (1969):

1. Very weak
2. Break present
3. Slight pull to break
4. Good pull to break
5. Slight pull to break (1/2 staple)
6. Good pull to break (1/2 staple)
7. Slight pull to break (1/4 staple)
8. Good pull to break (1/4 staple)
9. Sound

2.3.5 Clean Scoured Yield (YLD)

The samples were weighed then scoured in a Miniature 4 Bowl Scour at temperatures of 60° C (containing 64cc of Teric GN9 detergent), 55°C (32cc), 50°C (32cc) and a cold wash, respectively. The dried, scoured samples were weighed.

Yield was assessed using the clean scoured weight as a percentage of the greasy weight.

2.3.6 Bulk (Bulk)

Bulk measurements were made on 10gm (± 0.02gm) scoured, dried, conditioned, carded sub-samples of each sample using a WRONZ Loose Wool Bulkometer (Bedford, *et al.*, (1977).

2.3.7 Mean Fibre Diameter (MFD)

Mean fibre diameter of a scoured, dried, conditioned, carded sub-sample was measured using an Optical Fibre Diameter Analyser (Baxter, 1992; IWTO, 1995).

2.3.8 Prickle Factor (PF)

Scoured, conditioned, carded sub-samples were measured for the percentage of fibres greater than 30 microns MFD, (%>30μ) using an Optical Fibre Diameter Analyser (Baxter, 1992; IWTO, 1995).

2.3.9 Medullation (MED)

Scoured, dried, conditioned, carded sub-samples were measured using an Optical Fibre Diameter Analyser (Baxter, 1992; IWTO, 1995).

2.3.10 Colour (COL)

Two 4gm (± 0.02gm) scoured, dried, conditioned, carded sub-samples of each sample were measured using a HunterLab ColorQuest spectrophotometer (Hunter Associates Ltd, Reston, VA 20190, USA).

2.4 STATISTICAL ANALYSIS

Statistical analyses were performed using the SAS General Linear Models procedure (SAS).

Preliminary analyses examined the effects of line, sub-sample, region, breed, colour and their interactions. Effects for which the significance level was greater than 5% were removed from the analysis.

For traits other than colour the final model was:

$$y_{ijk} = \mu + r_i + b_j + (rb)_{ij} + e_{ijk}$$

where y_{ijk} = the k^{th} observation in the i^{th} region and the j^{th} breed

μ = an overall mean

r_i = the fixed effect of the i^{th} region (1=Manawatu, 2=South Island, 3=Waikato)

b_j = the fixed effect of the j^{th} breed (1=FINE, 2=1/2BD,3=FXBD,4=XBD,5=CXBD, 6=LXBD)

$rb_{(ij)}$ = the fixed interaction between the i^{th} region and j^{th} breed [not all interaction sub-cells could be tested as breeds were not represented in all regions]

e_{ijk} = the random residual associated with the $y_{ijk}{}^{th}$ observation which is assumed to be normally and independently distributed with mean zero and known variance.

For the analysis of colour, the Breed, Region/Breed interaction and Region/Breed/Colour interaction were removed as they were not significant. The final model was:

$$y_{ijk} = \mu + r_i + c_j + (rc)_{ij} + e_{ijk}$$

where y_{ijk} = the l^{th} observation in the i^{th} region of the j^{th} colour

[1 = Light; 2 = Medium; 3 = Dark; 4 = Moorit]

μ = an overall mean

r_i = the fixed effect of the i^{th} region

cj = the fixed effect of the j^{th} colour

$(rc)_i$ = the random interaction between the i^{th} region and j^{th} colour [not all interaction sub-cells could be tested as some colours were not represented in all regions]

e_{ijk} = the random residual associated with the $y_{ijk}{}^{th}$ observation which is assumed to be normally and independently distributed with mean zero

and known variance

Prior to analysis, it was anticipated that a problem existed with regard to the measurements of medullation. The medulla of a medullated fibre can be fragmented, interrupted or continuous. OFDA measures medullation of fibres on the basis of their opacity, *i.e.* their ability to transmit light. With this procedure, when a fibre is above a certain threshold of opacity, it is counted as being medullated. For this reason, wool sellers and processors using naturally pigmented wool are in agreement that medullation can only be measured in light coloured samples when using OFDA in its present form (Sporle, 1999).

The naturally coloured wool samples tested in this study indicated that the majority of light colours were in the range 2-12%, colours classified as either medium or moorit were in the 15-40% range, while dark colours indicated a medullation level of 45-90%.

These bands of measurement results were common across all three regions and breed types, therefore no further analysis was undertaken for medullation.

2.5 RESULTS AND DISCUSSION

The results of individual sample tests are shown in Appendix 1.

The Least Squares means of the tests performed (Table 5) provide an overview of the major wool characteristics currently manifested in New Zealand's Fine and Crossbred wools produced by black and coloured sheep.

The significance of Region and Breed-type effects on measured wool characteristics are shown in Table 6. Not all the interaction sub-cells could be tested as breed types and wool colours were not standard in all three regions. For example, Halfbred (1/2BD), Fine Crossbred (FXBD), Coarse Crossbred (CXBD) and Long Crossbred (LXBD) samples were available in one region only thereby reducing the value of the analysis pertaining to these wool types. However, the results do provide an indication of the variation in characteristics within and between regions.

2.5.1 Mean Fibre Diameter (including SDD, CVD, PF and Handle)

As clothing designed for wearing next to the skin is required to have a low Prickle Factor (PF), the additional measures of SDD, CVD and PF must be taken into consideration by processors and manufacturers. The result means are consistent with processor requirements outlined in Section 1 with the exception of R3 CXBD.

Table 5: Comparison of least squares means (standard error) of wool characteristics between fine and crossbred wool types ($p<0.001$)

Breed-type	HDL	STL	SS	YLD	BUL	MFD	SDD	CVD	PF	CRF
Fine	8.1 (0.2)	96.6 (3.8)	6.7 (0.3)	75.5 (0.9)	28.6 (0.5)	24.3 (0.5)	5.3 (0.2)	21.9 (0.6)	18.1 (2.4)	9.7 (0.2)
Crossbred	4.7 (0.1)	122.7 (2.0)	6.8 (0.1)	79.2 (0.5)	24.2 (0.3)	33.5 (0.3)	7.8 (0.1)	23.4 (0.3)	67.0 (1.3)	3.8 (0.1)

HDL = handle; STL = staple length(mm); SS = staple strength; YLD = yield (%); BUL = bulk (cm^3/g);
CVD = coefficient of variation of fibre diameter (%); PF = prickle factor (%); CRF = crimp frequency (per 25mm).

Table 6: Least squares means (standard error) of wool characteristics by breed and region (p<0.001)
(Figures of the same colour for each characteristic indicate no significant difference between results)

BREED	REGION	HDL	STL	SS	YLD	BUL	MFD	SDD	CVD	PF	CRF
FINE	1	7.7 (0.4)	86.3 (5.8)	6.9 (0.4)	71.5 (1.4)	31.6 (0.7)	27.2 (0.8)	5.7 (0.3)	21.4 (0.9)	31.6 (3.6)	7.7 (0.3)
FINE	2	8.4 (0.3)	96.9 (4.1)	7.2 (0.3)	72.3 (1.0)	29.5 (0.5)	21.7 (0.5)	4.7 (0.2)	21.5 (0.6)	6.8 (2.5)	11.5 (0.2)
FINE	3	8.3 (0.6)	106.7 (9.1)	5.9 (0.6)	82.8 (2.2)	24.7 (1.2)	23.8 (1.2)	5.4 (0.5)	22.7 (1.4)	15.8 (5.7)	9.8 (0.5)
1/2BD	2	6.7 (0.3)	104.7 (4.1)	7.6 (0.3)	75.1 (1.0)	26.9 (0.5)	30.5 (0.5)	6.8 (0.2)	22.4 (0.6)	53.9 (2.6)	5.2 (0.2)
FXBD	2	6.0 (0.3)	122.5 (4.1)	7.7 (0.3)	79.2 (1.0)	25.1 (0.5)	33.6 (0.5)	7.6 (0.2)	22.6 (0.6)	68.2 (2.5)	4.0 (0.2)
XBD	1	5.5 (0.2)	122.2 (2.9)	7.0 (0.2)	77.0 (0.7)	25.5 (0.4)	33.2 (0.4)	7.5 (0.1)	22.6 (0.4)	66.4 (1.8)	4.1 (0.2)
XBD	2	3.5 (0.3)	130.6 (4.1)	6.8 (0.3)	82.2 (1.0)	22.1 (0.5)	34.6 (0.5)	8.7 (0.2)	25.5 (0.6)	69.3 (2.5)	2.7 (0.2)
XBD	3	5.0 (0.2)	115.3 (3.5)	6.5 (0.2)	78.3 (0.9)	25.0 (0.4)	32.9 (0.5)	7.3 (0.2)	22.2 (0.5)	65.4 (2.2)	4.6 (0.2)
CXBD	3	5.3 (0.3)	126.7 (4.6)	7.1 (0.3)	81.3 (1.1)	23.3 (0.6)	36.3 (0.6)	8.1 (0.2)	22.5 (0.7)	77.8 (2.9)	3.5 (0.3)
LXBD	3	6.2 (0.6)	132.3 (9.1)	6.6 (0.6)	79.0 (2.2)	25.6 (1.2)	32.2 (1.2)	6.3 (0.5)	19.5 (1.4)	64. (5.7)	5.2.(0.5)

Regions: 1 = Manawatu, 2 = South Island, 3 = Waikato

Breeds: FINE = Fine; 1/2BD = Halfbred; FXBD = Fine Crossbred; XBD = Crossbred; CXBD = Coarse Crossbred; LXBD = Long Crossbred

Characteristics: HDL = handle; STL = staple length (mm); SS = staple strength; YLD = yield; BUL = blk; MFD = mean fibre diameter; SDD = standard deviation of fibre diameter; CVD = co-efficient of variation of fibre diameter; PF = prickle factor; CRF = crimp frequency

The Least Squares means (Table 5) in Fine wool for MFD (24.3 ± 0.5) and handle (8.1 ± 0.2) are acceptable but with a PF score of 18.1% >30μ (± 2.4μ) there is a clear need for breeders to reduce MFD and SDD in order to lower the PF in their wool lines. As discussed earlier, higher values of PF limit the acceptability of a finished product in terms of wearer comfort. The overall CVD of the tested lines also includes the between sample component of the variation. For instance, for the R2FINE wools, the between sample variance is 2.5.

The significant difference in MFD for R1 Fine compared with R2 Fine and R3 Fine indicates possible crossbreeding of Romney breed-types with Merino/Merino-X rams, thereby contributing to the high (31.6%) PF score for R1 compared with respective results of 6.8% and 15.8% in R2 and R3. The variation between regions for these characteristics presents a problem for a processor needing to source wool from more than one region. As estimated quantities of naturally-pigmented wool of any particular breed-type are small in the New Zealand market, it would be preferable to have one location only for wool buyers to purchase from in order to offer bigger lines of like specification.

In R2 there was no significant difference between FXBD and XBD wool for MFD or PF. In R3, the lack of a significant difference between XBD and LXBD in terms of MFD supports the differentiation of these wools based on length only as there was a difference ($p<0.01$) between LXBD and CXBD for MFD.

For SDD, CVD and PF means, a difference between regions signals that buyers need to exercise care when combining lines of equal or similar MFD from different sources. The CVD measurements fall within acceptable wool industry specifications for apparel wear of 20-27% (Lunney,1983; Bow & David, 1992; Lamb, 1992) but sheep growing wool for the apparel market need to be bred for a finer mean fibre diameter.

2.5.2 Handle

Consistent with expectations, fine wool exhibited (Table 5) a softer handle than crossbred types (8.1 vs 4.7). The difference in MFD would have contributed also.

The LXBD wool of R3 scored higher for handle than XBD wool of all three regions and higher than FXBD wool of R2 (Table 6). These results illustrate the effect of the lower MFD of the R3 LXBD when compared with the measurements for XBD wool types in other regions. Length may be contributing to the softer than expected handle in this instance. In addition, the R3 LXBD wools may be from woolly hoggets.

For Fine wool, there was no significant difference in handle score between regions. XBD wools from R1 were significantly different ($p<0.0001$) from those of R2 as were XBD of R2 and R3. This could be explained by the difference in

MFD, CVD and PF. As described earlier, a combination of these measurements contributes to the level of comfort for the end user.

2.5.3 Prickle Factor (PF)

Apart from obvious differences in PF between breed-types, the only significant difference ($p<0.0001$) was between R1 Fine and R2 Fine (31.6%±3.6% and 6.8%±2.5%). This is readily understood when the MFD and SDD results are taken into consideration (27.2MFD and 5.7 SDD *vs* 21.7MFD and 4.7SDD respectively), again illustrating the importance of looking at a combination of measurements rather than individual ones. This result supports the usefulness of objective measurements. The definition of FINE without an estimate of the MFD or PF could cause an inexperienced buyer to foolishly combine these two lines with cost repercussions.

2.5.4 Staple Length (STL)

The mean STL of FINE wool in R3 (106.7mm) was longer than the average of R1 and R2 (91.6mm) and may be considered too long to be ideal for most worsted processing systems. It would be better suited to the semi-worsted process providing the tender region (indicated by the low-ish SS score) was at the tip or butt end of the staple.

A significant STL difference ($p<0.005$) was shown between XBD wool of R2 and R3, R2 wools in addition having a higher MFD (34.6μ *vs* 32.9μ).

The LXBD wools of R3 were only 2mm longer than XBD wool of R2 but 17mm longer than R3 XBD. Again the results indicate regional variations in sorting criteria.

Overall results were consistent with the general processor requirements outlined earlier for woollen, semi-worsted and worsted processes.

2.5.5 Staple Strength (SS)

The lowest score was for R3 FINE wool and the highest scores for R2 FXBD and R2 ½ BD wool. This was an unexpected result considering the generally more extreme climatic conditions prevailing in much of R2 (South Island) compared with the 'dairy land' of R3 (Waikato). Effects such as heavy rainfall, parasites or significant variations in pasture quality could have contributed to the reduced SS in R3. Unsound wools are generally shorter if the shearing interval is the same as for sound wools. XBD wools in R3 were of lower SS than the other two regions but not as much as the R3 FINE wool.

In other wool types there was no significant difference in SS between regions. Breed type differences did not reach significant levels in R1 or R3 but there were differences ($p<0.05$) between the SS of ½ BD and FXBD wool when compared with XBD in R2. These differences could have been the result of nutritional stress as the samples tested were obtained in the month of May and the sheep would most probably have been shorn in the February/March/April period, following a dry summer.

2.5.6 Crimp Frequency (CRF)

Results indicate regional differences within breed types.

There were highly significant ($p<0.0001$) differences between R1 FINE and both R2 FINE and R3 FINE. This is supported by the respective MFD measurements. However, R2 XBD wool is very different from R1 XBD and R3 XBD although their respective MFD are not dissimilar (R1=33.2μ, R2=34.6μ, R3=32.9μ). These differences probably reflect different ancestry of the black and coloured flocks in the regions.

Crimp frequency continues to be employed by people subjectively estimating MFD of wool when sorting in wool-sheds, wool pools and even when judging at some wool competitions. The rule of thumb suggests that the greater the number of crimps per 25mm, the finer the wool will be in terms of microns. In the wools examined it could be confidently expected that R1 FINE would be coarser MFD than R2 FINE and R2 XBD would have a coarser MFD than both R1 XBD and R3 XBD. The results indicate this to be true in each case but the difference in the number of microns MFD between the XBD types is not as great as it is in the FINE types. There is a greater variation in CRF in the finer wools.

2.5.7 Bulk (BLK)

For XBD wool types, R2 exhibited the lowest mean bulk result ($23.3cm^3/g$) while R1 and R3 were similar ($25.5cm^3/g$ and $25.0cm^3/g$ respectively).

In the FINE category, R1 wools were bulkier than R2 or R3. When considered alongside the MFD results in those regions, R1 farmers may have used Merino-X or Down-type rams in their breeding programme which would help to explain the coarser MFD of R1 FINE wool compared with R3 FINE.

With the exception of R2 XBD (mean $22.1cm^3/g$), all results fall within the range of bulk measurements suggested earlier for apparel type wools.

2.5.8 Yield (YLD)

For XBD wool, a highly significant difference was apparent between the yields in R1 and R2 ($p<0.0001$) and between R2 and R3 ($p<0.0042$). For fine wool, significant differences were shown between R3 and those of R1 and R2 ($p<0.0001$ and $p<0.0001$ respectively), R3 being 10% higher yielding. A possible explanation is that the grazing land in R2 could be cleaner than that of

R1 and R3 and/or that the breed types within the XBD lines of R2 have more open type fleeces than those of R1 and R3.

Within R3 there was no significant difference between the breed types, perhaps indicating that the higher rainfall experienced in the Waikato has a 'washing' effect. There was little difference between the mean yields of R1 and R2. In R3 the FINE wools were higher yielding than XBD wools.

2.5.9 Colour (COL)

Mean colour values of fine and crossbred breed types by region are shown in Table 7. Other breed types were not common to all regions.

A comparison of the standard errors is noteworthy. The small number of samples available for R3 FINE Medium and R3 FINE Dark limits the value of the results for these wools. Overall, the variation of colour within lines prepared by the Waikato Pool is less than that in Manawatu and South Island pools for each breed-type colour.

Tristimulus XYZ Scale Results:

As expected, for all four colours (light, medium, dark, moorit) there were significant differences ($p<0.0001$) between X, Y and Z values.

Table 7: **Mean colour values (standard error) of fine and crossbred samples by region and breed (p<0.0001)**
(Figures printed in the same colour in each breed/colour combination indicate no significant difference between regions)

COLOUR	REGION	X	Y	Z	Y-Z	L*	a*	b*	
Fine Wools									
Light	1	21.6(14.0)	21.8(14.4)	23.3(14.0)	-1.5	51.0(14.1)	1.6(0.8)	3.5(3.0)	n = 15
Light	2	41.3(9.6)	41.9(9.9)	44.2(9.8)	-2.3	70.3(7.1)	0.9(0.6)	5.4(1.7)	n = 10
Medium	2	16.1(7.1)	16.0(7.1)	16.9(6.0)	-0.8	45.9(8.8)	2.4(0.8)	3.4(3.8)	n = 10
Medium	3	12.0(0.4)	11.9(0.4)	13.2(0.4)	-1.3	41.0(0.6)	2.8(0.2)	2.0(0.3)	n = 3
Dark	2	7.7(2.7)	7.7(2.8)	9.4(3.7)	-1.7	32.4(7.6)	1.7(0.5)	-0.5	n = 10
Dark	3	9.3(0.4)	9.3(0.3)	11.3(0.5)	-2.0	36.5(0.7)	1.9(0.1)	-0.9	n = 3
Crossbred Wools									
Light	1	34.0(11.1)	34.5(11.5)	34.9(11.5)	-0.4	64.3(9.9)	1.2(1.1)	6.8(2.6)	n = 14
Light	2	35.6(11.6)	40.2(6.1)	40.0(5.0)	0.2	69.4(4.4)	1.4(2.1)	8.1(2.6)	n = 10
Light	3	24.7(5.8)	24.7(6.0)	25.0(5.9)	-0.3	56.4(5.9)	2.1(0.9)	6.2(1.5)	n = 10
Medium	1	15.7(8.0)	15.7(8.2)	17.3(8.1)	-1.6	45.3(9.0)	2.1(0.9)	3.7(3.6)	n = 15
Medium	2	21.2(4.7)	21.3(4.8)	23.2(4.9)	-1.9	53.0(5.2)	1.4(0.5)	3.1(1.8)	n = 10
Medium	3	12.0(1.6)	11.9(1.6)	13.7(1.3)	-1.8	41.0(2.5)	2.3(0.4)	3.1(3.0)	n = 10
Dark	1	8.3(2.4)	8.2(2.4)	9.8(3.1)	-1.6	33.8(6.4)	2.0(0.7)	0.0	n = 15
Dark	2	11.3(4.7)	11.3(4.8)	13.4(5.1)	-2.1	39.3(6.3)	1.8(0.4)	-0.3	n = 10
Dark	3	9.7(0.6)	9.7(0.6)	11.7(0.3)	-2.1	37.2(1.0)	1.8(0.4)	-0.9	n = 10
Moorit	1	31.7(11.0)	31.8(11.5)	30.7(11.4)	1.1	62.2(8.7)	3.2 (2.8)	8.9(2.2)	n = 15
Moorit	3	14.4(1.3)	14.0(1.3)	14.1(0.8)	-0.1	44.2(1.9)	3.8(0.5)	5.4(1.6)	n = 10

Regions: 1 = Manawatu, 2 = South Island, 3 = Waikato

Breeds: FINE = Fine; XBD = Crossbred

Interestingly, the actual colour classifications differed between regions. By contrast, breed type colour classifications were uniform across all regions.

There is a similarity here with white wool. Regnault *et al.*(1995) identified colour differences between New Zealand regions and breed types which are considered to be caused by a combination of environmental and genetic factors. Such differences cause problems for dyers using white/cream wool and the Y-Z measure has been shown to be a useful indicator of the propensity of New Zealand wool to fading.

There was a significant ($p<0.001$) difference in X, Y, and Z values as one would expect, however the standard error for R3 results was noticeably lower in most instances than for R1 and R2 wools. This indicates lesser variation in the colours which are placed in any one R3 breed-type colour line. The allocation of wools into particular lines was based on the assessment of colour by the sorters. For Light XBD wools, R1 and R2 lines were of similar colour but R3 was a darker line. The XBD Medium lines of R1 and R3 were similar but were significantly different ($p<0.001$) from R2. The XBD Dark lines were similar across the three regions.

Moorit (Colour 4) presented a significant ($p<0.0001$) difference between that of R1 and R3, the latter being much darker.

FINE Medium and FINE Dark wools were similar in R2 and R3 but FINE Light wools differed significantly ($p<0.001$) between R1 and R2.

Significant Y-Z values ($p<0.0001$) were shown between R1 and R2.

CIELAB Scale Results:

For Light and Moorit XBD wools, L* and a* values were significantly different ($p<0.0001$) between R3 and those of R1 and R2 with the standard error being noticeably lower in R3. There was no significant difference between R1 and R2. R3 Moorit XBD wools were significantly darker ($p<0.001$) than the same wool types in R1.

The only significant ($p<0.001$) breed-type differences for L* and a* were between R1 and R2 FINE Light wools but significant differences ($p<0.0001$) were observed between XBD and FINE wools in the range of b* values.

All four colours (Light, Medium, Dark, Moorit) had significant differences ($p<0.0001$) in their respective L*, a*, and b* values although R3 XBD Moorit values were not too dissimilar from R1 XBD Medium.
As all colour lines were determined by human eye, the likelihood of lines form different regions being dissimilar is not unexpected.

2.6 Comparison of XYZ and CIELAB1976 Colour Scale Results

Both the XYZ and CIELAB1976 scales identified differences between light, medium and dark colours in terms of lightness/brightness, with decreasing values from light to dark.

Results for yellowness differed between the two scales, Y-Z tending to differentiate between R1 and R2 while b* identified a difference between R1 and R3. Both scales identified an overall difference in yellowness between FINE and XBD wools.

The XYZ scale provides an indication of the 'lightness' of colour present but it does not make such a clear distinction between the red, green or blue content of any one colour as the measurement value between X, Y and Z measures in the test results is generally less than 2. As naturally-coloured wool ranges from white to grey to black, light to dark brown, light to dark grey, reddish colours in overseas breed types, and mixtures of two or more colours, a more definitive result would assist in identifying colours within the three main categories of light, medium and dark. For moorit, a medium, yellow-brown colour, the results fit this colour between light and medium and indicate a higher yellow content than shown in the light, medium and dark wool tested.

By contrast, the CIELAB1976 scale, based on Munsell's concept of 'colour solid', measures the lightness of a colour together with the concentration (saturation) of that colour and its composition (Judd, 1950; Kelly and Judd, 1955). The results clearly indicate a reduction in lightness (L*) from light to medium to dark (white to grey to black) but more noticeable are the distinctive differences in the red, green, yellow and blue measures. In moorit wool, for example, the results show not only a distinct reduction from light to medium to dark, but an appreciable yellow content. As the lines were originally sorted and colour-labelled by eye, the yellowness of the medium colour moorit wool must have been obvious to the sorters and worthy of a separate colour classification.

The clearer differentiation of colour components within each measure suggest the CIELAB1976 scale to be more appropriate for measuring non-white wool.

2.7 SUMMARY

The analysis of data indicates that significant regional variations exist within breed-type wool lines for MFD, CVD, YLD, BULK, HDL and to a lesser extent for PF. STL and SS measurements were similar within breed-types for all three regions. While these results are consistent with studies of white wools by Regnault *et al.* (1985), this thesis provides the first known recorded analysis of data relating to regional differences in naturally pigmented wools grown in New Zealand.

The CIELAB1976 scale, due to its ability to distinguish more clearly between the saturation (concentration) of red, green, blue and yellow content in each wool colour, appears to be a favourable measure of colour in naturally pigmented wools.

The small quantities of wool produced on individual farms in each colour category means aggregation of wool lots from different sources is necessary as wool processors tend to purchase wool in commercial lots (>500kg). It is desirable for there to be an industry measurement scale which can clearly differentiate not only the degree of lightness but also the colour content of each sale line.

In an attempt to standardise the lines of naturally pigmented wool in New Zealand, wool growers and in particular sheep breeders, need to develop breeding objectives in line with processor requirements of colour and other characteristics (MFD, STL, etc). By so doing, and striving for the recommended parameters outlined earlier in this paper, which hopefully will increase grower returns, a greater quantity of wool meeting processor specifications will be available for further development of commercial niche market products.

SECTION 3:

3.0 THE OBJECTIVE MEASUREMENT OF COLOUR IN BLACK AND COLOURED WOOL

3.1 INTRODUCTION

Wools naturally vary from white to cream to deep yellow, to shades of light to dark brown, light to dark grey, and black.

The colour of wool is determined by the presence of melanin-containing pigment granules in the wool follicle bulb. Melanin is a protein that requires considerable amounts of the amino acid tyrosine. Two forms exist, eumelanin and phaeomelanin. Eumelanin results in black and brown wool, while phaeomelanin results in a range of colours from white to yellow, and red-colour wool, often referred to as 'tan'.

Colour measurement is vital in setting standards for amalgamating raw materials from different sources. A complicated multi-coloured item often requires specifications for each of several colours. Colour tolerances are no less important to the final sale than the length and fineness tolerances that ensure the appearance of the knitted or woven fabric (Judd, 1950).

Currently, objective measurements are not used routinely by growers or users of black and coloured wool. There is no standard measure by which the colour of black and coloured wool can be identified. The development of such a measure is an essential step in the sale of black and coloured wool to wool processors. Such a test would assist:

- the accurate standardisation and description of colours
- growers to supply wool within specified colour readings
- the purchase of desired colours from test readings
- a reduction in or elimination of re-sorting of fleeces by the processor, thus reducing labour costs
- the identification of sheep producing wool of particular colours for breeding purposes

In the meantime, for sale purposes, whether to the hand-craft or commercial market, lots are sorted into general colour lines - dark, medium and light - within breed types or fineness ranges. However, as interest in natural-coloured wool seems to be increasing in the commercial sector at present (late 1990s), it is an opportune time to develop clear specifications for these wools.

3.2 THE OBJECTIVE MEASUREMENT OF NON-WHITE WOOL COLOUR

The attraction of 'natural' products, unbleached and free of chemical dyes, represents an opportunity for black and coloured wools to fill a market niche. While the variation in colour is used to advantage by hand-craft users, commercial manufacturers require assurance of the regularity of the colour they are using. The variation in colour between and within black and coloured fleeces is a major reason why such wools have attracted lower prices than white wools. Naturally-coloured wool are difficult to dye into an even colour as the varying colours dye differently, often resulting in a streaky effect in the woven or knitted fabric. While this may be an intended result for some products, it is not constant enough for colour matching either in a blend or when utilising contrasting colours.

Since the late 1940s, researchers have attempted to differentiate the fleece colours of particular breeds of non-white sheep (Pereira & Serra, 1950; Serra, 1965; Sumner *et al.*, 1999) by assessing the amount of black, grey or brown colour and ranking the degrees of colour in a scale.

Despite the presence of two scales for objective measurement of white wool (CIE tristimulus values X,Y, Z and the CIELAB1976 scale), wool processors in the 1990's do not use a standard or colour scale to distinguish the colours of pigmented wool. Sumner *et al.* (1994) utilised the function (X-Z)/Y to provide a base from which to discriminate between black-grey and brown wool. Lemmon

(1997) suggested a combination of both visual differentiation of colour and CIELAB1976 measurements.

The colour content of naturally pigmented wool is complex and contributes to the difficulty in establishing a colour measurement scale. Unlike the measurements for white wool, variation in yellowness measurements in black and coloured wool may be contributed by two separate pathways. One path is the genetic colour of the fleece and the other non-scourable yellow due to the interaction of environmental factors and a susceptibility to yellow discolouration. In near-white wool, yellow discolouration is considered a fault due to the limited number of light and/or bright colours which can be generated through dyeing. With naturally-coloured wool, the differentiation of colours is complicated by the composition of particular colours. For example, the colour brown may include any of the following combinations:

Red + Blue + Yellow (i.e. Red + Green)

Red + Green + Yellow

Red + Green + Blue

Similarly, the colour grey is a combination of black + white, either as a mixture of black and white fibres or fibres with the black pigment diluted with white colour. In addition, wool classified as being grey may also contain brown/yellow colour fibres. The paint colour cards shown in Figure 3 illustrate lightness, hue and saturation effects with brown and grey colours.

Figure 3: **Paint colour charts showing variation in lightness, hue and saturation**
(Benjamin Moore & Co., Montvale, NJ, USA)

The fading of the tips of naturally pigmented wool fibres is a regular observation by people farming coloured sheep. Further colour variation can occur along the length of wool fibres. This is in addition to colour changes thought to be associated with ageing.

A German weathering trial (Kurt, 1999) of naturally-coloured wool fibres from the fleeces of Rough-coated Pomeranian Landrace sheep indicated that fading varies between colours and fibre types. In this instance, while black kempy fibres showed signs of tip-fading before the 68^{th} day of the trial, the middle section of the staple did not fade as much. By contrast, brown fibres faded by the 68^{th} day and continued to change colour up to the 96th day. The black kemp fibres (apart from the tips) were considered to be fast to light while the opposite was true among the brown fibres. These results add to current New Zealand knowledge of white wool (Regnault, *et al.,*1995), that different breed types produce wool with and without a propensity to fading. Research into the propensity to fading of New Zealand's naturally pigmented wool colours may identify the same colour indicator or combination of indicators, as that used for classifying the fading potential of white/cream wool (Y-Z).

Wools which are stained (*e.g.* pen-stain) are subject to a condition known as photofading. Natural yellow-green pigments of the stain material (*e.g.* chlorophyll) fade under exposure to light, particularly sunlight (Antrim *et al.,*1992). For this reason, it would be advantageous for processors to be able to more accurately assess the propensity of wool to photofading prior to any dyeing process.

The more that is known about the colour of fibres and their colour pigments, the more processors and manufacturers will be able to anticipate the likely long-term effects of exposure to light on the colour of yarns and fabrics manufactured from natural colour wool.

3.3 MATERIALS AND METHODS

A total of 277 random samples of black and coloured wool types were evaluated in the wool laboratory at Massey University. These samples were taken from fleece lines compiled by coloured wool pools and farms throughout New Zealand. The lines had been sorted by colour (light, medium, dark, moorit and grey) within breed-types (Fine, Half-bred, Fine Crossbred, Crossbred and Coarse Crossbred, Long Crossbred and Gotland).

Two 4gm (±0.2gm) scoured, dried, conditioned, carded sub-samples of each sample were measured using a HunterLab ColorQuest spectrophotometer. The spectrophotometer results were expressed in the CIE tristimulus values X, Y, Z.

CIELAB1976 values were calculated according to the following equations (Hunter Associates Ltd, Reston, VA 20190, USA):

$$L^* = 116 \left\{ \frac{Y}{Yn^3} \right\} - 16$$

$$a^* = 500 \left\{ \frac{X}{Xn^3} - \frac{Y}{Yn^3} \right\}$$

$$b^* = 200 \left\{ \frac{Y}{Yn^3} - \frac{Z}{Zn^3} \right\}$$

where Yn = 100.000; Xn = 98.041; Zn = 118.103

[Xn, Yn and Zn are tristimulus values of the standard illuminant]

3.4 STATISTICAL ANALYSIS

Statistical analyses were performed using the SAS General Linear Models procedure (SAS).

<u>Model 1:</u>

Colour = Region + Breed + X + Y + Z + Y-Z + X^3 +Y^3 + Z^3 (r^2=0.50)

[X3, Y3 and Z3 were included in the equation because CIELAB1976 values are derived from XYZ tristimulus values]

Model 2:

Colour = Region + Breed + L* + a* + b* (r^2=0.39)

In an attempt to find a specific set of measurements for each of the four designated colours light, medium, dark and moorit, regression analysis was undertaken with two models using both the XYZ and CIELAB colour scales:

Model 3:

Colour = Intercept + Region + Breed + $b_1X + b_2Y + b_3Z + b_4YZ + b_5X^3 + b_6Y^3 + b_7Z^3$

where *b* is the regression on the individual colour components

Model 4:

Colour = Intercept + Region + Breed + $b_1L^* + b_2a^* + b_3b^*$

where *b* is the regression on the individual colour components

3.5 RESULTS AND DISCUSSION

The measurement results for both XYZ tristimulus values and CIELAB1976 are shown in Appendix 1 and Appendix 2.

The mean values of each colour are shown in Tables 8 and 9:

Table 8: Mean Colour Values of Test Samples (standard error)

Measure	Light n=89	Medium n=70	Dark n=78	Moorit n=25
X	32.7 ±12.2	15.9 ±6.2	9.4 ±2.5	24.8 ±12.1
Y	33.0 ±12.6	15.8 ±6.2	9.4 ±2.5	24.7 ±12.5
Z	33.8 ±12.2	17.2 ±6.0	11.3 ±2.9	24.1 ±12.0
Y-Z	-0.8 ± 1.4	-1.4 ±1.1	-1.9 ±0.6	0.6 ± 1.8
L*	62.6 ±11.5	45.8 ±7.8	36.3 ±5.1	55.1 ±11.2
a*	1.2 ± 0.9	2.2 ±0.8	1.9 ±0.5	2.9 ±1.3
b*	6.0 ± 2.9	2.6 ±2.7	-0.4 ±1.6	7.5 ±2.6

Of the tested samples in Table 8, none were of a distinct grey colour, any wool with a grey colouring having a mix of both brown and grey fibres. For this reason, 15 samples of Gotland wool were obtained - 5 samples each of light, medium and dark grey, as defined by the breeder. The XYZ and CIELAB measurements are recorded in Appendix 2 and the mean values in Table 9.

Table 9: Mean Colour Values of Grey Wool Samples (standard error)

Measure	Light Grey n=5	Medium Grey n=5	Dark Grey n=5
X	25.1 ±2.7	12.8 ±0.7	4.4 ±0.4
Y	25.7 ±2.8	13.0 ±0.7	4.4 ±0.4
Z	26.9 ±2.9	14.4 ±0.7	5.1 ±0.5
Y-Z	-1.3	-1.4	-0.6
L*	57.6 ±2.7	42.7 ±1.0	25.0 ±1.4
a*	-0.3 ±0.8	0.2 ±0.1	0.3 ±0.1
b*	4.9 ±0.4	2.2 ±0.2	0.8 ±0.1

Using regression analysis (Table 10), the colour of XBD wools from Region 1 was calculated. The results, as shown in Table 11, indicated that 'perfect' colour would be very difficult to quantify. None of the results were exact numbers, but instead were in a range, *e.g.* between 2.0 and 3.0 but not exactly 2 or exactly 3. In other words, measurements illustrated that within each colour designation or subjective grouping (Colour 1 [light], Colour 2 [medium], Colour 3 [dark] or Colour 4 [moorit]) there are varying degrees of colour.

Table 10: Regression of colour by region and breed

Regions: 1 = Manawatu; 2 = South Island; 3 = Waikato
Breeds: 1 = FINE; 2 = Halfbred; 3 = Fine Crossbred; 4 = Crossbred; 5 = Coarse Crossbred

XYZ Colour Scale

Level	Intercept	Region	Breed	X	Y	Z	Y-Z	X^3	Y^3	Z^3
1	3.0056	0.1632	-0.5547	2.2644	2.1901	-4.536	-4.612	0.0001	0.0000	0.0000
2		0.3631	-0.3974							
3		0.0000	-0.4233							
4			0.2379							
5			0.0000							

CIELAB1976 Colour Scale

Level	Intercept	Region	Breed	L*	a*	b*
1	2.9163	0.1671	-0.3869	-0.029	0.2652	0.0000
2		0.2548	-0.1146			
3		0.0000	-0.2492			
4			0.2968			
5			0.0000			

Table 11: **The classification of hypothetical XYZ and CIELAB1976 colour values into Light, Medium and Dark colour categories (*i.e.* Colour 1, Colour 2, Colour 3) for crossbred wools in Region 1**

Example	X	Y	Z	Y-Z	= Colour
a)	10	10	10	0	2.5
b)	15	15	15	0	2.2
c)	20	20	20	0	1.9
d)	25	25	25	0	1.8
e)	25	25	24	1	1.8
f)	30	30	30	0	1.9
g)	30	30	29	1	1.8

Example	L*	a*	b*	= Colour
h)	35	2	0	2.9
i)	40	2	0	2.7
j)	45	2	2	2.6
k)	50	3	7	2.7
l)	60	2	6	2.2

XYZ results place Samples (a) and (b) in Colour 2 and could be interpreted as being a 'medium' and 'light' Medium colour respectively. The colour measurements shown in Section 2 of this thesis however, place XYZ values of less than 20 in the Dark category, *i.e.* Colour 3, which the results in Table 11 do not quite reach (2.5 and 2.2 respectively).

The CIELAB1976 results, also based upon a variation in the base colour scores of hypothetical samples, indicate that a range of L* values, varying by 10-20 points in some instances, would be required to nearly match the descriptive colour designated by human eye as being light, medium or dark. Clearly, the L* value alone is insufficient to categorise colours, as discussed earlier, and must be considered in conjunction with a* and b* values.

These examples clearly show that 'perfect' colour, identified by specific values of XYZ or L*a*b*, does not exist. Instead, a range of values for XYZ and L*,a*,b* would be a better indicator of colour.

As there were more readily recognisable differences between CIELAB1976 values than between tristimulus XYZ values for all the samples tested, the two measures were compared to ascertain whether the CIELAB1976 scale would be a suitable substitute for XYZ (Table 9). The correlations between the descriptive colour measurements for each scale were such that the CIELAB1976 scale is suggested as suitable for measuring colour in black and coloured wools. The CIELAB1976 colour scale is considered to more closely represent human sensitivity to colour and colour differences.

Table 12: Correlations between colour results in the XYZ tristimulus and CIELAB1976 colour scales

CIELAB1976 COLOUR	DESCRIPTIVE COLOUR	XYZ TRISTIMULUS COLOUR	CORRELATION BETWEEN SCALES
L*	Lightness	Y	r = .99
a* positive	Red	X	r = .92
a* negative	Green	Y	r = .92
b* positive	Yellow	Y - Z	r = .91
b* negative	Blue	Z	r = .91

The samples of brown and grey wools (Figures 4 & 5) illustrate the value of the L*, a* and b* results in the distinction between different brown and grey colours. Within the grey range, Sample 8 is near 'neutral grey' as the readings for a* and b* are almost zero.

A flock of light, medium and dark-grey woolled sheep has been developed through selection by the Gotland breeder. The difference between the intensity levels of the colours is used for contrast effects in yarn and fabric products. The dark grey colour is close to neutral grey as defined in the CIELAB colour space (*i.e.* a*=0, b*=0) and moving towards a blue-grey desired by the breeder. The declining value of b*, as lightness reduces to darkness, may assist in reducing the propensity of these wools to fading if the findings of Regnault, *et.al.* (1995) and Kuhn (1999) are applicable to this breed-type.

Figure 4: CIELAB1976 values of brown wool samples

Sample 1: L*= 80.3

a*= -0.4

b*= 10.2

Sample 2: L* = 57.3

a* = 2.7

b* = 12.2

Sample 3: L* = 52.7

a* = 4.0

b* = 9.0

Sample 4: L* = 46.1

a* = 4.0

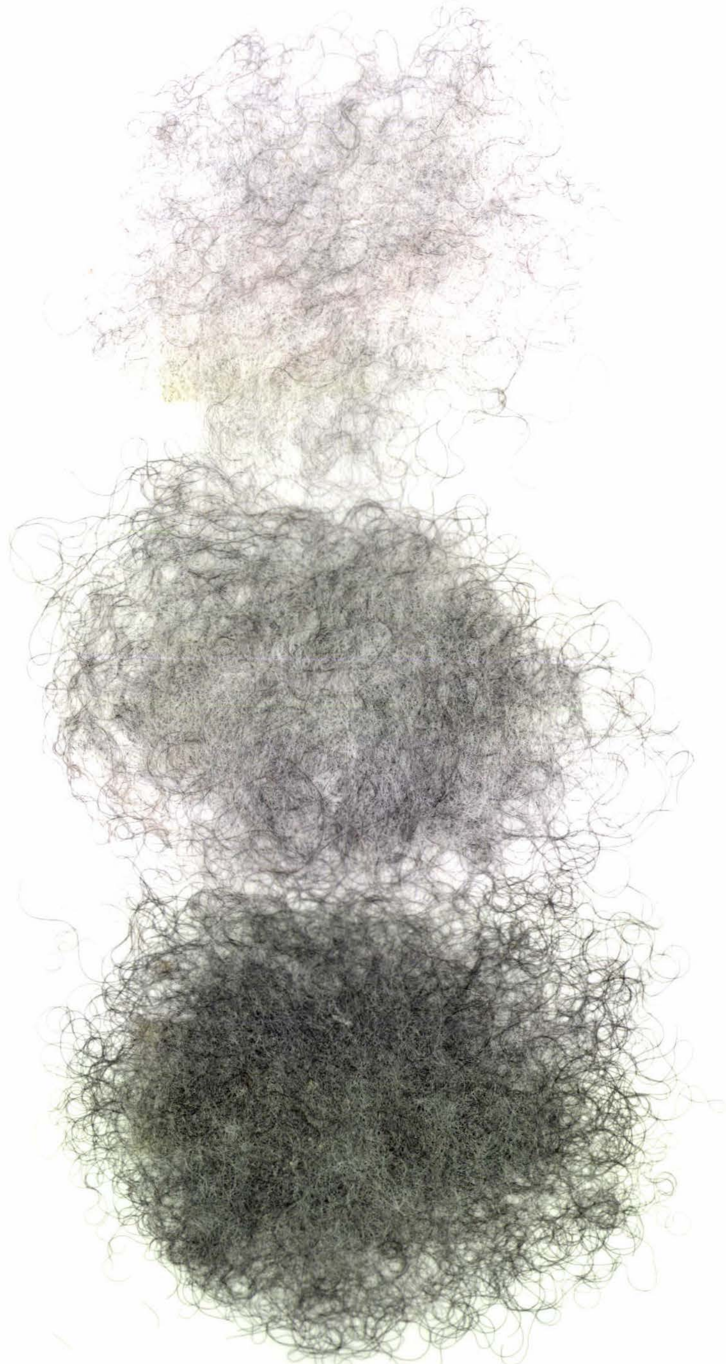
b* = 6.5

Sample 5: L* = 17.8

a* = 2.7

b* = 4.2

Figure 5: **CIELAB1976 values of grey wool samples**



Sample 6: L* = 61.2

a* = -0.3

b* = 5.2

Sample 7: L* = 42.2

a* = 0.2

b* = 1.9

Sample 8: L* = 26.4

a* = 0.2

b* = 0.8

3.6 SUMMARY

For white wool, New Zealand's wool test houses measure the CIE tristimulus values X,Y and Z, representing the red, green and blue areas of the colour spectrum. Each is measured on an open-ended scale with most values between zero and 100. Bright, white wools have an X, Y and Z reading in the mid to high 60s with a Y-Z reading for yellow of zero to -2.0. These wools attract a price premium as processors have come to value their ability to absorb dyes from dark to pale colours. Processors have come to appreciate the cost of dyeing fibres of inferior colour and the limitations so imposed.

From both this study of colour measurements made on black and coloured wools and that of Lemmon (1997), it is apparent that the XYZ scale does not provide clear definitions of colour, *per se*. In particular, the combination of colours which comprise grey, brown and moorit, for example, are difficult to distinguish and may be a combination of several colours in themselves. The three measures (X, Y and Z) differ ever so slightly with the result that one is frequently faced with a measurement value difference of less than 2 points on the scale.

While the lightness (Y value) of the three main colours (light, medium, dark) is apparent, the numbers are too large to show any noticeable distinction between a dark brown with a reddish hue and one with a yellow or blue hue. For matching or blending purposes, both for hand-craft and commercial use, this indistinction is a serious measuring fault.

Early studies in colorimetry (Judd, 1950; Kelly & Judd, 1955) have shown that it is not possible to amalgamate every colour into a simple 0-100 scale. Instead, each colour, such as brown or grey, must have a scale of its own to identify its lightness and intensity as well as the base colour. This is achieved using the CIELAB1976 scale. L^* is the lightness factor while a^* and b^* are the chromaticity coordinates.

In the hand-craft market, a demand exists for sample colour charts from which purchasers may choose fleeces (greasy or scoured), carded sliver, top or yarn. In many instances, the purchasers may live overseas. A simple sample card, as proposed by Dunn (1999), would serve the purpose but a problem arises when insufficient fibre has been purchased in the first instance and a colour match is required. Unless there was an objective measure with which to compare the original fibre purchased with that of the fibre currently available, there would be no guarantee that the intensity and lightness of the colour of the two orders were the same.

As greasy wools are known to change colour with time, and particularly naturally coloured wool, the only sure means of obtaining an almost identical match is to measure both lots objectively. An exact match would be almost impossible, but as long as the two lots had very similar measures then the chances are they would blend sufficiently well to be almost impossible to tell apart. As fleeces in each colour group may originate from different breed-types, colour would not be the only characteristic to be matched.

From the results of this study, the approximate CIELAB1976 measurement ranges for the colours present in the New Zealand population of black and coloured wools may be grouped as shown in Table 13:

Table 13: Measurement Values for Distinguishing Colour Variations in Naturally Pigmented Wools

	L* Lightness	a* Red +/Green-	b* Yellow +/Blue -
Black	0 - 20	0	0
Brown:			
Dark	20 - 40	0 - 2	< 1
Medium	40 - 50	0 - 3	1 - 3
Light	50 - 60	0 - 3	4 - 7
Moorit	60 - 70	3 - 4	8 +
Grey:			
Dark	25 - 30	< 1	< 1
Medium	40 - 45	< 1	1- 3
Light	55 - 60	< 1	4 +
White	80 +		

SECTION 4:

WOOL PRODUCTION OBJECTIVES FOR BLACK AND COLOURED SHEEP BREEDERS IN NEW ZEALAND

4.1 INTRODUCTION

Information which enables farmers to set wool production objectives is available from several sources. Analyses of prices paid at auction or other selling venues, buyers' comments, and a knowledge of processing and end-uses assist in the setting of objectives.

There are various ways of achieving objectives and genetic improvement (mainly through selection) is one option. General sheep management is another. There is a well-established literature pool on the definition of selection objectives.

In this section, an outline of processing methods illustrates the importance of particular traits to each process and the related consumer acceptance or otherwise of the end product. Comfort and handle (softness) are major considerations for the buying public.

Most black and coloured wool grown in New Zealand is produced by small flocks of sheep [less than 100 animals] (BCSBA, 1999), frequently of different colours within the flock. Consequently, the quantity of wool produced in any particular colour is erratic and often variable in terms of processing quality.

A further complication is the small genetic pool of coloured sheep in New Zealand. Frequently, flocks comprise animals from several sources, often with little attention having been paid to traits other than colour. As a result, wool type within a particular flock may be highly variable and the clip unlikely to produce adequate line volumes for sale purposes.

The development of objective measures for wool characteristics has enabled processors to more accurately specify the wools they require. Their ability to predict how a particular wool lot will perform during processing increases the likelihood of higher returns to those farmers growing wool to specification.

Growers interested in supplying processors should aim to produce wool of consistent colour/s and quality according to the purchasers' specifications.

4.2 THE PROCESSING OF WOOL FOR MANUFACTURING

Wool is a variable raw material which is difficult to process because of the number of stages required to convert the raw material to an end-product. In addition, it is not easy to state specifications for a particular finished product. By contrast, synthetic fibres can be specified simply by type, fineness, and length parameters. Tenderness, contamination, excessive length variation or mean diameter do not concern synthetic fibre purchasers. Cotton, a natural fibre, is a little more complicated, but objective measurements have been developed to meet the demands of users (Ainsworth, 1988).

In an effort to improve the demand for wool products and to maximise profits, processors aim to process wool at a competitive price with minimum cost. Results depend upon the efficiency of the wool purchase, the standard of specification, and the efficiency of processing. Inefficiencies in any of these areas cause loss of profit. Increased productivity and improved efficiency can also result directly from the use of optimum machine settings for the raw material, thereby minimising fault rates.

The characteristics of one batch of processed wool will not necessarily be the same as another batch, because of the variety of wools which are used. Similarly, processing conditions may differ between plants, (*i.e.* different machine settings, speed of processing).

In wool processing, many characteristics affect the properties of the resultant fabric, including yarn and fabric structure, finishing, and in particular, wool quality. In addition, different end-uses require different handling characteristics and these are determined significantly by such factors as fibre diameter and crimp frequency.

The systems upon which apparel-type white wool is processed, and the significance of raw wool characteristics to both processors and users, provide an insight to the importance of objective measurements and the influence of on-farm production and breeding objectives.

4.2.1 Wool Processes Used in the Apparel Industry

Greasy wool characteristics vary from lot to lot, both in terms of the types of wool involved and the range of each characteristic. The suitability of any line of wool will depend upon the end-product required and the processing system used.

The textile industry uses its fibres to produce yarns and then converts these yarns into consumer products.

The three main categories of processing systems used in the manufacture of yarns are the worsted, semi-worsted and woollen systems. For the production of yarn for either knitted or woven end-products, each system requires wools of particular specification. In identifying the factors which negatively affect each process, researchers encourage acceptance and use of objective measurements of raw wool as reliable performance indicators (Downes, 1975a; Mooy *et al.*, 1988; Ross, 1991).

4.2.1.1 The Woollen System

The woollen system is the simplest of the three methods. The process accommodates a wide range of wools varying in mean fibre diameter, mean fibre length, tensile strength, bulk, medullation, crimp and colour. Poor-styled wools and short, tender wools are frequently used. Yarns of coarse count are usually spun with a low twist to make them bulky and soft (for their diameter), but they tend to be hairy, less-even and have lower tenacity. Low fibre strength is not a serious processing problem because of the coarse yarn count and the ability of the system to cope with short, broken fibres. The presence of vegetable matter (VM) is undesirable but a proportion can be removed. High-VM wools affect the worsted system least. Higher-bulk wools are often preferred for producing knitting yarns on the woollen system (Ross, 1991).

Woollen yarns are used for both light and heavy woven and knitted apparel items, including tweeds.

4.2.1.2. The Semi-Worsted System

Sound wools of reasonable length (75-125mm) are required for the rapid semi-worsted process. With no fine comb to remove short fibres or VM contamination, only VM-free or nearly-free wool are suitable. The semi-worsted process cannot produce such fine, even yarns as the worsted system, hence its limited use for apparel yarns, other than those for medium to heavy knitwear (Ross, 1991).

Semi-worsted yarns are intermediate in properties between woollen and worsted yarns. They have greater strength than woollen yarns but still retain some short fibres. Semi-worsted yarns are less bulky than woollen yarns, because of greater fibre length, and the fact that fibres are straightened and aligned by gilling during processing. The surface of semi-worsted (and worsted) yarns is characterised by the almost complete absence of loops, whereas woollen spun yarns have many looped fibres (Elliott, 1984).

4.2.1.3 The Worsted System

The worsted system is expensive in that it involves carding, gilling, combing and drawing. It is used mainly for apparel wools, especially fine wools.

The raw wool must be long in relation to fibre diameter, and of sufficient tensile strength to withstand carding and combing without undue breakage; in other words, the better-styled, long, sound, fine and medium wools (Bow, 1979; Ross, 1991). At least 40 fibres per cross-section are spun into fine, even, firm yarns of sufficient strength to withstand the rigours of knitting and weaving. By contrast, the woollen system, in which a high proportion of short fibres lie at random throughout the yarn, necessitates closer to 200 fibres per cross-section to give the yarn sufficient strength (Elliott, 1984).

Fibre length is highly important in worsted processing as the combing process removes short fibres. Too many short fibres result in a reduced quantity of top (low tear). Crossbred wools need to be a minimum of 100mm in length but fine Merino wool may be as short as 50mm.

The worsted process provides more opportunity for VM removal than either the semi-worsted or woollen systems. The amount of vegetable matter and its type (*e.g.* hooked burrs) is important in determining the likely yield of top that will be produced from a given weight of raw wool.

Hunter (1980) considered the importance of fibre properties for worsted spinners as:

Fibre diameter	80%
Staple length	15-20%
Staple strength	0 - 5%
Other Properties	Only important when abnormal, including crimp

In other words, fibre diameter is thought to be responsible for 80% of the quality of the finished top.

For later manufacturing into apparel wear, worsted yarns must be free of neps, slubs, vegetable matter and fibres protruding from the yarn (hairiness).

4.2.2 Black and Coloured Wool Processing

There are no statistics of end-products manufactured in New Zealand from naturally pigmented wools. As with white wools, there is a variety of end-uses - from carpets to apparel wear, furnishing fabrics to felt products, wall hangings to toys. In other words, any item that can be made from wool.

Black and coloured wools grown in New Zealand are processed on all three of the above systems, *i.e.* woollen, semi-worsted and worsted.

As discussed in Section 1, the characteristics of available wool determine the end-product and processing system used to convert the raw wool into yarn.

Processors purchase wools which meet particular specifications in accordance with the requirements of the chosen processing system. The specified characteristics form the base of most on-farm wool production objectives as many may be achieved through careful husbandry and selective breeding.

The traits and methods of changing them will now be discussed.

4.3 METHODOLOGY

4.3.1 Establishing a Selection Programme

Selection has two types of effect. A temporary effect is caused through the culling of sheep which adversely affect the profitability of the flock because of, for example, one or more undesirable wool characteristics. A more permanent effect is the result of genetic changes in the level of production of sheep born in the flock (Rae, 1982).

The purpose of a selection programme is to increase the financial and biological efficiency of livestock production, *i.e.* output per unit input. Efficiency requires an appreciation of both the inheritance of particular traits and the genetic and phenotypic correlations among traits.

The final choice of traits to be included in a selection programme will reflect the amount of economic improvement that can be made relative to the cost of making that improvement (Smith, 1983).

Breeders' selection objectives need to relate to future consumer needs, with the relative importance of traits varying with the time of expression. One of the difficulties in breeding lines of sheep growing particular wool colours is changing fashion colour trends and trying to predict them. In any production system, the rate of genetic improvement relates to the intensity of selection, the accuracy of selection, the generation interval and the genetic variability in the present flock. Knowing trait correlations (positive or negative), the breeder is in a better position to choose lines of stock which accommodate not only present but hopefully future changes in market and management conditions.

The economic importance of genetic change in a performance trait is measured by:

- its direct effect on efficiency when the genetic level of other components is unchanged

- the cost of any required increases in feed intake or management

- price recognition of genetic improvement in terms of value per product unit

Some aspects of production environments are inflexible (*e.g.* climate) but strategic changes in management may permit use of more efficient genotypes and minimise unfavourable genetic interactions (Dickerson, 1982).

Genetic improvement by selection is a long-term, cumulative process and if efficiency was measured on short-term gains there would be fewer long-term benefits. A programme of long-term, permanent improvements requires a stable set of objectives.

In summary, the choice of traits in a selection programme depends upon a combination of:

- the economic importance of each trait
- the degree of heritability for each trait
- the genetic inter-relationship between traits
- the cost of measurement (labour, facilities, generation interval - ideally the trait could be easily assessed in young animals)

There are three steps involved in setting up a breeding programme based on genetic improvement:

- Selection Objectives
- Selection Criteria
- Selection Methods

4.3.1.1 Selection Objectives

Selection objectives are identified as the traits targeted for improvement of wool (or any other product) by selection. They take into account:

- Processor/Manufacturer requirements
- The financial reward for change in a particular wool trait
- The heritability of the trait
- The cost of changing a trait

To be included in a breeding objective, the character must be of economic importance and be able to respond to selection (Harris, 1970: Morris, *et al.*, 1982; Ponzoni, 1988).

4.3.1.2 Selection Criteria

Selection criteria are determined, *i.e.* the traits which will be measured in order to achieve the selection objectives. A selection criterion is either a single measurement or the average of repeated measurements for any selection objective taken from an animal or one of its relatives. The measurements may be taken from characteristics which are correlated with the selection objective also.

As long as there is a positive genetic correlation between selection criteria and selection objectives, or they are one and the same, the measurement of the criteria will be useful. If any selection involving more than one criterion occurs, the relative importance of each criterion must also be determined

4.3.1.3 Selection Methods

The most common selection methods, largely based on objectively measured criteria, are tandem selection, independent culling and use of a selection index.

Tandem selection involves culling on the basis of one trait at a time until it has been improved to the required level.

Independent culling requires a base level to be chosen for each trait. All animals which fall below the minimum level required in any trait are culled. This method tends to result in the most inferior animals being culled in each trait grouping regardless of their genetic merit for other traits. For example, severe footrot may be cause for automatic culling over desirable fibre diameter.

With a selection index, the breeder establishes a total score (or breeding value) for each of the traits selected for improvement, the total of which represents the merit of the animal, *i.e.* its selection index. For this system to be effective, the breeder must he aware of an animal's contribution to both income and expenses to obtain an indication of the economic importance of particular traits. If one trait, or a few, dominate an index then the efficiency of selection will be very sensitive to changes in that trait. As a result, there can be significant losses in terms of efficiency when important traits are omitted, unimportant traits are given too much importance, and when the direction of selection is reversed for an important trait (Smith, 1983). For example, if fleece weight is given prominence in a selection index and mean fibre diameter omitted, the result is most likely to be an increase in fleece weight at the expense of increased fibre diameter, which in turn may need to be reversed.

For each of these three methods, records must be kept of an may characteristics as possible and particularly of rams.

Subjective selection, based solely on a combination of visual characteristics, is not considered a very efficient method of selecting more productive animals as the aesthetic effects are often not stable and are difficult to quantify.

4.4 DISCUSSION

4.4.1 Selection Objectives for Improvement of Wool Quality

While some farmers prefer to rear pure-bred stock, traits selected for improvement may be introduced by using either pure-breds or crossbred stock. The choice will depend upon the degree of change required, notwithstanding the fact that commercial production may be from crossbreds. Breeding considerations have evolved from objectives based on appearance ("form determines function") to those based on commercial performance (Harris & Newman, 1994).

In a wool-producing programme, one or more of the following traits may be considered worthy of inclusion (Harris, *et al.*, 1970; Wickham, 1993):

mean fibre diameter

fibre/staple length

fibre/staple strength

colour

bulk

crimp frequency

medullation

Wool characteristics which respond rapidly to direct selection through high heritability are shown in Table 11.

Table 14: **Heritability of Wool Characteristics**
(Rae, 1982; Whiteley & Jackson, 1982)

Mean Fibre Diameter	0.5
Staple Length	0.4
Bulk	0.5
Yield	0.5
Greasy Fleece Weight	0.4
Greasy Colour	0.3
Scoured Colour	0.1

The major wool characteristics of importance to apparel processes will now be discussed in terms of selection objectives and the selection criteria with which to affect a change.

4.4.2 Major Wool Characteristics for Consideration in Selection Programmes

As some characteristics are breed-related, a summary of New Zealand black and coloured sheep breed-types and their main wool characteristics are outlined in Table 12.

Table 15: Major Wool Characteristics of New Zealand Coloured Sheep Breeds (New Zealand Wool Board, 1989)

Breed	Fibre Diameter (μ)	Staple Length	Fleece Weight	Apparel Wool Products
Border Leicester	37 - 40	150-200mm	4.5-6.00kg	Outerwear Knitting Yarns
Corriedale	28 - 33	75 - 125mm	4.5 - 6.00kg	Outerwear Worsteds Light Tweeds
Drysdale	40 +	200 - 300mm	5.00 - 7.00kg	Coarse wovens
English Leicester	37 - 40	150 - 200mm	5.00 - 6.00kg	Outerwear
Lincoln	39 - 41	175 - 250mm	5.00 - 7.00kg	Blended with mohair for apparel wear
Merino	15 - 24	65 - 100mm	3.5 - 5.0kg	Woollen & Worsted apparel wear
NZ Halfbred	25 31	75 - 110mm	4.00 - 5.00	Apparel wear
NZ Romney	33 - 3	125 - 175mm	4.5 - 6.00kg	Outerwear
Perendale	31 - 35	100 - 150mm	3.5 - 5.00k	Knitwear (High bulk wool
Polwarth	23 - 26	75 - 110mm	4.00 - 5.00kg	Worsted fabrics, apparel, knitting yarns

4.4.2.1 Mean Fibre Diameter

The effect of mean fibre diameter (MFD), or fineness, on the handle of end-products cannot be ignored. Processors choose wools that will allow the manufacture of products that have a handle acceptable to purchasers.

Fibre diameter is the prime determinant of the processing method used for particular wools because of its effect on the ease with which fibres can be drawn and spun into yarn (spinnability). In worsted processing, the measurements required to predict top parameters are mean fibre diameter, staple length, staple strength (position of break), colour and bulk. Mean fibre diameter can be the sole selection criterion as deficiencies in length and strength characteristics are frequently governed by flock management practices, leaving mean fibre diameter as a more definitive genetic measurement for improvement (Bastawisy, *et al.*, 1961).

Excessive variability in fibre diameter is only a minor disadvantage but it does reduce spinning performance when wools of markedly different mean fibre diameter are blended, *e.g.* a 5 micron difference in a blend of medium Merino wool. In such instances, fibre diameter is sufficient as a selection objective alone.

Recent Australian studies with Merino flocks (Cloete *et al.* 1997; Greeff, 1999) have indicated that CVD is likely to increase as staple strength deteriorates, and when selecting for higher clean fleece weights while maintaining mean fibre diameter. While these tendencies require further research, the scientists suggest that CVD be included in selection criteria for Merino flocks, particularly with regard to staple strength.

The measure of the percentage of fibres over 30 microns mean fibre diameter (%>30μ), or prickle factor (PF), is now being used by at least one New Zealand breeder of black and coloured Merino sheep to assist in ram selection. Interestingly, the region of the fleece from which the sample is taken is between the pelvic bones, not the mid-side. The reason for selecting this location is that the coarsest part of any fleece is considered to be the back end of the sheep and if that area has an acceptable 'prickle factor' then the rest of the fleece should be acceptable also. In the previous sections, a figure of 6% has been postulated as the maximum tolerable content of medullated or coarse fibres in an apparel garment worn next to the skin.

The easiest way for a grower to reduce 'prickle' is to reduce the mean fibre diameter of the flock as this characteristic has an overwhelming effect on the percentage of fibres >30μ (Turk, 1993).

4.4.2.2 Fibre/Staple Length

The length of fibre grown over a 12-month period varies from breed to breed, fine wool tending to be shorter than coarse wool. The interval between shearings is the on-farm determinant of fibre/staple length and can be adjusted according to market requirements.

Staple length is genetically correlated with fleece weight. The heritability of staple length is 0.4 and the genetic correlation with fleece weight is 0.5. Similarly, greasy fleece weight is positively genetically correlated with both staple length and fibre diameter.

With this knowledge, a breeder could cull on the basis of staple length prior to shearing, *i.e.* indirect selection for fleece weight, but it will result in an increase in mean fibre diameter in most instances.

4.4.2.3 Fibre/Staple Strength

Modern high-speed wool processing machinery demands yarns with high tensile strength. The strength of yarn is primarily determined by the fibre length in the yarn - the longer the mean fibre length in the yarn, the greater the tensile strength of that yarn.

Tender wools break more easily during processing than sound wool and increase the number of 'ends-down' for the processor. A maximum of 15 ends-down per 50 spindle hours is considerable acceptable by commercial processors but the cost of these interruptions in processing is of concern. Fibre diameter varies along the length of fibres and a fibre tends to break in regions of fine diameter. Fibre diameter is not constant along the length of wool fibres due to the fluctuating nature of the wool growth cycle over the course of a year. In the first instance, a farmer's aim should be to reduce the incidence of tender wool and to manage shearing times in such a way as to have any breaks near the butt- or tip-end of the staple.

Wools shorn in winter have the area of minimum fibre diameter at or near the butt end while those shorn in summer are likely to have a break or tender region in the middle of the staple.

Ewe hoggets tend to have a lower incidence of fleece tenderness than older ewes, while differential feeding levels in mid-pregnancy have been observed to have a greater effect on fleece tenderness than differential feeding levels during late pregnancy (Bigham, *et al.*, 1983). Reproduction need not be a barrier to the production of sound wool if it is shorn at an appropriate time. The longer a fibre within a staple, the greater the chance of a weak point being present.

Wool growers have two basic management options to improve the strength of their wool, apart from breeding - shearing close to the position of break, and strategic management to better match feed demand with nutrient supply and elimination of disease. Short-term management or environmental stress may materially affect fibre strength, *e.g.* sudden substantial feed changes, unseasonal adverse weather (Coop, 1953; Butler, 1994).

The seasonal nature of wool growth is well understood by New Zealand farmers. Growth peaks during summer and is lowest in winter, a pattern reflecting not only a genetic influence in Romney-cross breeds but also the quality and quantity of available pasture at different times of the year.

Studies with sheep reared indoors (Geenty *et al.*, 1984) have identified minimum strength also occurs during the period of low wool growth (July). A positive association between staple strength and clean wool growth was particularly noticeable in housed sheep where staple strength was estimated to increase by around 12 N/ktex for each additional one gram of clean wool growth per day. On the basis of the results with housed sheep, selection for staple strength and wool growth would be advantageous in terms of genetic improvement, despite findings that the expression of additional strength was not so apparent in ewes reared outdoors. Selection for a lower CVD may also have an effect.

In summary, length and strength measurements present benefits to growers - they can manage shearing times to change the position of break and feed supplements if sheep are under nutritional, health or lactational stress. Changes in environment, nutrition and health affect the strength and position of break in the staple. Sheep subjected to a relatively harsh or alternatively lush environment throughout the growing cycle of the wool will produce much stronger wool in terms of tensile strength than feast-to-famine conditions.

4.4.2.4 Bulk

Bulk is breed-related, being higher in fine and Down breeds than in coarse wool breeds. Cross-breeding, changing breeds, or selection of high-bulk stock are the options available to farmers wishing to improve bulk measurements in their clips.

The most bulky wools tend to be highly crimped for their diameter, although in ignoring crimp effects, bulk tends to be associated with coarse diameter.

Breed differences in bulk may be exploited but as bulk can be introduced through blends it is not always necessary to select for bulk, apart from high-bulk Perendales. With the Perendale wool, bulk influences wool preparation, sheep breeding and marketing (Carnaby *et.al.*, 1980).

Within a breed, the correlation between crimp and fibre diameter is not particularly high so selection for high crimp frequency is not a particularly effective way of achieving finer diameter.

4.4.2.5 Crimp Frequency

Crimp frequency and bulk are both highly heritable and have genetic correlations with fibre diameter. High crimp frequency and bulk tend to equate with fine wool, and low crimp frequency and bulk with coarse wool although in the Romney breed, there is a positive correlation between bulk and MFD, high bulk being present with coarse MFD. If fibre diameter and bulk were held constant, the likelihood of greasy fleece weight being increased is considerably reduced as crimp frequency and bulk have a negative (-0.23) genetic correlation with clean fleece weight (Whiteley & Jackson, 1982).

The number of crimps in a wool staple is breed-related however the regularity of crimps may be adversely affected by nutritional stress and mineral deficiencies.

4.4.2.6 Yield

The yield of individual fleeces and fleece lines is largely breed-related but can be improved through farm management. Yield tests reveal wool loss through contamination [particularly that caused by vegetable matter (VM) and stains (*e.g.* pen-stain, non-scourable markers] can be addressed in two ways (Lunney, 1988):

a) by improved efficiency of removal
b) by better description of types of VM present in the lot

Coloured wools are thought to be of lower yield than white wools because of the observed propensity of the darker colours to retain more grease and suint, coloured sheep to be more susceptible to fly-strike and the tips to be sunbleached. Research into these factors is very limited but can be assumed to be at least as important as for white sheep and possibly more important for the reasons outlined.

The total weight and value of wool produced prior to breeding age as well as the annual wool production of ewes in later life are an important consideration when determining selection objectives for wool-producing sheep. It is expected, but not always true, that sheep which produce the heaviest fleece weights are the most efficient biologically and that the best sheep may be described as the one which grows the heaviest clean weight of wool fibre of a specified average fibre diameter, but other factors will invariably influence this simple objective (Whiteley & Jackson, 1982). Within breeds and mobs of sheep, some will be higher yielding than others and may be used in breeding programmes to improve the yield measurement of the line.

A New Zealand study (Geenty *et.al.,*1984) of two mobs of sheep, reared indoors and outdoors, had interesting results concerning wool yield. The yield for the two groups of ewe-wool at different times of the year were the same during winter, spring and summer (72%, 73% and 78% respectively) but during autumn the fleeces grown by outdoor ewes had a yield of 82% compared with only 73% for the indoor group. In addition, the period of highest growth for the outdoor sheep was late spring (November) while the indoor sheep grew most wool in summer (January). These results indicate that covering or housing sheep in order to obtain better yields needs careful consideration and attention to shearing management.

4.4.2.7 Medullation

The presence of coarse fibres limits the end-use of yarns and fabrics in apparel ranges due to the 'scratchy' sensation such fibres create when worn next to the skin.

As natural-coloured wool remain undyed in many products, the lack of dye uptake in medullated fibres is not the problem it is with white wool. If dyeing takes place, medullated fibres are not able to absorb dye colour to the degree of non-medullated fibres and create a streaky effect in the dyed yarn and fabric.

Selection against medullation and hairiness is aided indirectly through selection for reduced MFD and CVD. In most circumstances, there would be no need to consider medullation in the objective but it may become an issue in some flocks. In such situations, there could be visual culling of a few sheep with hairy britches.

4.4.2.8 Colour

Melanin pigment is produced in small granules within specialised cells in the skin (melanocytes) which are transferred to cells which form the wool fibres and outer skin. The presence of melanin, and its form, is considered to be controlled primarily at the A (*agouti*) and B loci. At the A locus, eumelanin production is inhibited by a dominant allele, A^{wht}, in which case white or tan wool colour results (phaeomelanin). The non-agouti (*a*) allele is recessive to all other alleles at the A locus in sheep. Animals with the *aa* genotype have an entirely coloured fleece. There are two alleles at the B locus, *B* (black) and *b* (brown or moorit), the latter being recessive. A third locus, S, is responsible for sheep having white spotted fleeces, the spotting allele, *s*, being recessive (Brooker & Dolling, 1965). It is only in sheep in which the A^{wht} gene is not present that other alleles are expressed. The inheritance of sheep colour is reviewed by Roberts & White (1930), Brooker & Dolling (1965), Ryder (1980), Lauvergne (1984), Nicholas (1987) and Sumner *et al.* (1994).

Farmers have observed that the naturally dark coloured (black or brown) fleeces of some sheep frequently have 'yellow' or faded tips. This is often attributed to a copper deficiency. Wool colour is determined by the presence of the melanin protein, and the copper-containing enzyme tyrosinase is required for the synthesis of melanin. It is of significance that the wool of black and coloured sheep contains a higher level of copper (x2) than white woolled sheep. Much of New Zealand's pasture is copper marginal and the degree of deficiency is affected detrimentally by a high molybdenum/sulphur ratio and the prevailing iron content. There are also seasonal fluctuations so that adequate copper is a very important factor in the farm production of black and coloured wool (Lee, 1956; Ryder & Stephenson, 1968; Bruere & West, 1993).

Scientists in Europe, New Zealand, and Australia have studied the inheritance of colour patterns in sheep (Adalsteinsson, 1970; Adalsteinsson, 1984a;

Adalsteinsson, 1984b; Adalsteinsson & Ryder, 1984; Lundie, 1984; Dolling, 1984; Aliev & Rachkovsky, 1989).

Lauvergne (1984) suggested that the use of a tristimilus-colorimeter-type colour scale was insufficient to distinguish wool colours for breeding purposes because of the wide variation within colour ranges. Sumner *et al.* (1984) suggested that quantitative analysis of pigment types and the biochemical processes responsible for pigmentation may be effective in distinguishing colour for sheep breeding purposes. However, for selling wool of different natural colours the use of the CIELAB1976 scale colour ranges, as outlined in Section 3I, would effectively distinguish colours one from another, be they black, dark brown, shades of grey or fawn.

The colours required by processors vary from season to season according to consumer demands. The difficulty for black and coloured sheep farmers is that the time taken to change the colour of one's flock can involve several generations. Ideally, farmers should breed lines of sheep producing commercial quantities of solid fleece colours. While spotted sheep of various colour combinations may be attractive as pets, their fleeces are of little interest to processors requiring specified colours in the first instance.

The colours available from current New Zealand flocks are dark brown/black, medium brown, light brown, moorit, dark grey, medium grey, light grey, and grey/brown combinations in addition to white.

Any colour preferences by processors should be considered in colour objectives. However, how to breed for particular wool colours in New Zealand breed-types is not well-documented. As there has been no definitive colour scale with which to measure the colours from particular matings, any data available has been assessed by eye and related to pattern markings. Breeders have indicated that moorit-colour rams mated to moorit-colour ewes will produce moorit-colour progeny if the sire and dam are homozygous moorit.

Adalsteinsson (1984a) conducted a selection programme aimed at producing dark grey homozygotes. The first step was to select heterozygous animals for breeding which were as dark-grey as possible. These were mated to black or grey- badgerface animals to produce dark-grey badgerfaces. In turn, these progeny were interbred to produce homozygous grey sheep. Selection of dark colour types then took place among the offspring.

While the genetics of New Zealand's coloured sheep population is under review by Lundie (1999) in particular, overseas experiences with several breeds have been documented and reviewed in Iceland (Adalsteinsson, 1979), Europe (Lauvergne *et. al,* 1979), the United Kingdom (Roberts & White, 1930; Alderson, 1979) and Australia (Smart, 1979; Welke, 1979; Tyquin, 1979; Michell & Michell, 1979).

4.5 SUMMARY

The first task in the establishment of an improvement programme for wool production is to define current base performance levels as well as the production and marketing systems under which genetic improvement is desired.

In order to at least maintain but, hopefully, improve wool's share of the fibre market, the grower needs to be mindful of the properties of the wool grown and make soundly based decisions regarding husbandry and breeding.

For centuries markets have existed world-wide for home-based spinners, weavers and knitters, but today, commercial apparel manufacturers are requiring naturally coloured wool in increasing tonnages and in a wide range of colours. It is an opportune time for those farming coloured sheep to apply commercial test methods to their coloured wool with a view to entering the commercial market by more closely meeting processor requirements. It is important that farmers familiarise themselves with down-stream processes and their respective requirements (Drummond, 1993).

The more wool growers know about the wool they are producing the more likely they are to respond to possible deficiencies. Differences between lines, between flocks, between strains and between seasons identify opportunities for management/breeding changes which enable production of preferred wool types to be targeted. This may involve the introduction of a fine wool gene, more frequent shearing to obtain premiums for shorter, stronger wool, or the farming of a greater number of wethers to increase wool strength in regions where ewe flocks show weaker fibre strength due to pregnancy/lactation nutritional effects (Teasdale, 1985).

The objective measurement of wool characteristics may be new to the majority of black and coloured wool producers. However, the loss and/or retirement of many experienced wool industry personnel, whose knowledge of factors such as fabric handle and tailorability was accumulated over many years, and the subsequent replacement of these craftsmen with conventionally trained engineers, highlights the importance of objectively measured characteristics for wool fabric and garments (Postle, 1986). Data from garment manufacturers indicates that wool and wool-rich fabrics are more easily tailored into garments of good appearance than polyester-rich fabrics. Being able to assess likely handle and tailoring performance is an important development in the drive for an increased market share for wool fabrics and garments.

Management practices influence some parameters but breed also determines likely parameter measurements and can reduce the need for additional objective measurements.

Pigmented wools (black, grey and brown) occur in many breeds and their inheritance is a subject of particular interest to breeders of sheep producing these wool colours. For the apparel industry, Merino wools have a major role to play. In Australia only 6% of Merinos are thought to have a colour gene

(Fleet, 1995). The New Zealand Merino is likely to have a similar occurrence due to the importation of Australian rams by some white studs. Observations indicate that the majority of black and coloured sheep in New Zealand are based currently on the Romney breed with much cross-breeding to achieve soft-handling wool for the hand-craft market.

In establishing breeding objectives, traits with high economic and heritability values will tend to dominate the equation, other traits being of less importance individually. However, there is a need to consider all traits when setting breeding goals affecting economic production as a group of traits with low economic values, and possibly low heritability, may have appreciable cumulative effects. (Smith, 1983).

Specifications, identified by wool processors as best meeting their requirements, are important in encouraging wool growers to identify market preferences and produce wool for those markets. Wool measurements should provide value for money in terms of the monetary return for meeting the specifications. Mean fibre diameter, mean fibre/staple length, mean fibre/staple strength, bulk, colour and yield are primary components for the grower to take cognisance of in selecting stock for breeding purposes.

Breeders will be motivated to develop breeding stock that improve the performance of the customer's production system if income from breeding stock sales is in proportion to the expected added profitability for the commercial farm customer (Harris & Newman, 1994). It is important that breeders converse with wool buyers, wool processors and other breeders to ascertain the long-term direction the market is taking.

In the marketing of many commodities, objective measurement has augmented or superseded subjective assessment. In the past, the primary technical problems with the auction method of selling wool were the errors which resulted from the subjective appraisal of the bales on show (Lunney & Andrews, 1979). Recommended selection criteria have been suggested by Wickham (1972) for the improvement of wools in New Zealand sheep breeds and are shown in Table 16.

Table 16: Recommendations regarding selection criteria for wool improvement by sheep breeding
(Adapted from Wickham, 1972)

	Soft Apparel Wear	Resilient Apparel Wear	General Purpose
Breeds	Merino, Polwarth, Halfbred, Corriedale	Fine Perendale	Romney, Border Leicester Coarse Perendale
Eliminated during preliminary screening	Hairy britch Kemp	Hairy britch Kemp	Hairy britch Kemp
Major selection characteristics	Colour Fleece weight Fineness	Colour Fleece weight Fineness	Colour Fleece weight Fineness
Likely future criteria	Staple length Softness Staple strength Colour	Staple length Bulk Staple strength Colour	Staple strength Colour
Minor points	Blocky tip	Crimp frequency	Crimp frequency Freedom from medullation

SECTION 5: SUGGESTED SYSTEM FOR PROVIDING LINKAGES BETWEEN PRODUCERS AND PROCESSORS WITH MORE ACCURATE SPECIFICATION OF THE WOOLS REQUIRED

5.1 INTRODUCTION

The black and coloured wool sector of New Zealand's wool industry is small both in terms of the total number of sheep farmed and the associated quantity of wool produced (BCSBANZ, 1999).

The BCSBANZ, formed in 1976 by a group of enthusiastic farmers in the lower North Island, is the body responsible for promoting excellence in farm husbandry and wool production among its members. It is unknown how many black and coloured sheep are farmed by non-members of the Association.

For the handcraft market, sales of black and coloured wool are conducted privately primarily. By contrast, buyers requiring commercial quantities (>500kg) of any particular colour/s may purchase privately or through wool pools, brokers or auction houses.

For the commercial buyer, access to economic processing quantities is essential.

Almost 25 years after the founding of the BCSBANZ, there is no national co-ordination or business programme providing a two-way link between producers and processors. Other small-scale agriculture-based industries have been developed in New Zealand in recent years. Their approaches to marketing, product specification, and stock improvement may provide an incentive for the establishment of a suitable structure with which to assist the development of additional markets for naturally pigmented wool and better relate raw material requirements to consumer demands.

The experiences of overseas black and coloured grower-based co-operatives are of interest also.

5.2 RECENTLY ESTABLISHED AGRICULTURE-BASED ENTERPRISES IN NEW ZEALAND

5.2.1 Sheep Dairying

This niche market had its beginnings in the late 1970s and by 1997 sheep milk from a small number of flocks was being used in commercial quantities for cheese production.

Emphasis from the outset was based on quality stock and economic quantities of the raw material, in this instance, sheep milk.

A vertically integrated industry has since developed in which farmers supply the required quantity and quality of milk to processors who then market sheep milk products to consumers.

Due to the diligence and persistence of the farmers and processors involved in the early stages, guidelines for new entrants to the industry have been established and quality standards demanded.

In short, the sector, through its own Sheep Dairy Association of New Zealand, has established clear guidelines covering breeds and breeding programmes, farm management and husbandry, dairy shed design, marketing opportunities, product specifications and consultancy services (SDANZ, 1997).

5.2.2 Dairy Goats

The number of dairy goat herds in New Zealand numbered approximately 187 in 1997, an average herd consisting of 180 animals (Singireddy *et al.* 1997) .

The New Zealand Dairy Goat Co-operative is responsible for the manufacture of dairy goat milk in to such products as wholemilk powder.

The identification of superior milk-producing does continues to be an industry objective along with identification of high yielding breed-types. The Co-operative continues to explore new market opportunities and product development.

5.2.3 Alpaca Farming

Alpacas produce fibre in a range of colours, similar to those found in sheep flocks, *i.e.* from white to shades of brown and jet black.

The New Zealand alpaca fibre market has parallels with the coloured wool market in that the primary objective is to produce quality fibre and breeding stock. In their South American homelands, multi-coloured alpacas are seen on the majority of farms which is not conducive to providing a consistent quality and quantity of any one colour.

As with sheep (Sumner, *et al.,* 1999) the fibres in each colour patch on a multi-coloured animal tend to have different characteristics from the fibres of other colour patches. It is not uncommon for there to be three different colours in one fleece as well as three different grades of wool (Nelson, 1991). One breeding objective, therefore is to produce single colour fleeces.

In New Zealand alpaca fibre is marketed to hand-spinners/weavers and to commercial spinners but the number of alpacas (approximately 2000) is the limiting factor in upgrading the breed. A herd of 10000 breeding stock has been suggested (Nelson, 1991) as a desirable base from which to improve the breed and, subsequently, the volume of alpaca fibre available for commercial processing.

5.3 EXAMPLES OF COLOURED WOOL ENTERPRISES IN AUSTRALIA & EUROPE

In Australia, the coloured wool growers' groups in some states play an active marketing role on behalf of their members. For over 20 years members of the Melanian Sheep Breeders' Society of Australia (MSBSA), based in Western Australia, have worked voluntarily to 'add value' to their coloured wool clip.

The Society produces its own naturally coloured yarns under the label 'Western Dream Yarns'. Yarns, wool tops and greasy and scoured fleeces are currently exported to the USA, Germany, New Zealand, Singapore, China and Japan (Lynn, 1999).

Some wool is sorted on-farm and forwarded to a wool broker/auction house which supports and encourages the objectives of MSBSA, primarily the sale of consistent and frequent consignments of coloured wool at a fair price. Wool destined for craft use is also marketed through one outlet. Strict control is exercised over wool quality and here vendors are expected to replace or refund any wool about which complaints are received (Smart, 1999)!

The South Australian Coloured Sheep Owners' Society Inc. (SACSOS) also produces a range of mill-spun yarns and fabrics from members' wools. These are marketed under the name 'Sable Wool'. Strict specifications are stipulated by SACSOS with regard to colour, mean fibre diameter, length and oddments. SACSOS acts as its own wholesaler, selling to retailers throughout Australia (SACSOS, 1979).

In Europe, a recent study (Kurt, 1999) has noted an increase in popularity of wool garments made from mixed-wool breeds such as East-Prussian Skudden and Rough-Coated Pomeranian Landrace sheep. The wool from these naturally-coloured sheep is not soft-handling and had become a waste product. However, the sheep were considered worthy of preservation in their pure-bred form as they are a genotype which could easily be lost through repeated cross-breeding. As a means of providing an economic incentive for small landowners to continue farming these and other endangered breeds, knitting yarns and tweed fabrics have been manufactured and are now promoted in fashion collections.

5.4 METHODOLOGY

There are similarities between the sheep dairying, dairy goat, alpaca fibre and overseas-owned coloured sheep/wool enterprises in so far as each has had to:

a) identify the best producers for breeding purposes

b) match raw material supplies to processor specifications in terms of quality and quantity

c) market the products as niche items

Currently, the BCSBANZ is not involved in marketing or selling end-products. Instead, the emphasis is on the production of quality raw materials, *i.e.* sheep and wool.

From the time of the first 'National Congress on Breeding Coloured Sheep and Using Coloured Wool' held in Adelaide, South Australia in early 1979, breeders of coloured sheep throughout the world have had an opportunity to meet at what has become an international congress, every five years.

It is commendable that all five congresses to date have featured international speakers covering genetics, farming, marketing, processing and manufacturing of coloured wool (SACSOS, 1979; Blair, 1984; Erskine, 1989; Alderson, 1994; BCSBAA, 1999).

The free exchange of information and ideas provides a valuable resource with which to develop a suitable structure for New Zealand's coloured wool growers, marketers and buyers.

5.4.1 The Role of Wool Pools/Wool Brokers/Auction Houses/Processors

In New Zealand naturally-coloured wool is sold through three main outlets:

1. Private Sales
2. Wool Pools/Wool Brokers/Auction Houses
3. Direct to Wool Processors/Manufacturers

Discussions with wool pool operators, wool brokers/auction houses and processors identify one major factor inhibiting stronger demand from processors - a lack of quality wool in commercial quantities (> 500kgs).

The reason for this low supply is that many growers sell their 'best' wool to hand-craft buyers both in New Zealand and overseas. The result is that the processors see very little good wool in sale lots and therefore have no incentive to develop new product lines from the poorer quality naturally-coloured wool available.

If a processor is forced to purchase small quantities and hold that wool until more is available, the financial cost becomes prohibitive.

The quantity problem is exacerbated by the range of colours and fibre types in New Zealand's coloured sheep population. It would appear from discussions with members of the BCBANZ that many farms graze a mix of both sheep colours and breeds and that this practice will continue in order for the farmers to keep abreast of changing fashion colours and fibre-type demands.

5.4.2 The Role of the BCSBANZ

Soon after the formation of the BCSBANZ many small, privately-owned businesses emerged, specialising in hand knitting yarns, carded sliver, felt batts, greasy fleeces for hand-craft use, *etc.* Over the last 20 years, some of these businesses have disappeared while others continue to flourish. The advent of the internet enables New Zealand growers to promote their wool internationally with varying degrees of success.

The enthusiasm with which the BCBANZ was formed in 1976 appears to have waned as flocks are dispersed by retiring owners, wool prices fall and the demand for wool decreases.

What is the answer?

Wool industry representatives from farmers, to judges, to buyers, to manufacturers are in agreement that the quality of New Zealand's naturally coloured sheep and wool have improved significantly since the BCSBANZ was established, thereby achieving one of its primary objectives.

As members of the BCSBANZ have achieved this target, it seems an opportune time to introduce a 'brand' in recognition of their efforts. This is one method of identifying quality black and coloured wool and is along the lines of the Western Australia practice of identifying the wool grown by members of the Melanian Sheep Breeders' Society of Australia.

The aggregation of wool by pool operators and auction houses into sale lines has served to facilitate the presentation of coloured wool to the market place but the quantities and range of colours available through any one source is limited. As outlined in the research results of Section 2, fibre types and colour classifications differ from one region of the country to another. This lack of consistency is one of the major reasons why some New Zealand processors source naturally-coloured wool off-shore then process the imported fibres in New Zealand before exporting the end-products! This practice is not unique to coloured wool but highlights a problem in the supply chain which may be solved by innovative changes to existing arrangements, such as the use of a BCSBANZ stencil or label.

In tandem with the above scenario, is the price paid to the grower. My own observations and knowledge of the coloured wool market suggest that today's growers are 'price takers' not 'price makers'. This comes about for several reasons, one of which is that few farmers of coloured sheep rely on the income from this sector of their farming operations for their living. Aside from this is the fact that many growers do not know enough about their own wool to place a realistic value on it. As one wool buyer remarked, growers must be prepared to

accept poor prices for poor quality wool and create a demand for top quality, higher priced wool. If necessary, this could mean placing a reserve value on the sale lot. Wool sold by tender is an example of price taking also.
To achieve better prices, objective measurements need to be available for the buyers' inspection. Such measurements frequently prove too expensive for individual growers producing small quantities of wool but by appointing one broker/auction house to handle all wool sales each contributor to a sale line would benefit from the quality control data provided by that selling firm. In turn, the growers could be provided with a full sale report showing details of the measured characteristics of the pooled wool lot.

Additionally, the selling firm could be asked to seek feed-back from processors on all sold lines thereby assisting everyone involved in the wool chain to meet the requirements of each other.

Referring back to the dairy goat and sheep milking industries, and coloured wool co-operatives overseas, it is a co-ordinated and integrated approach that is required to increase returns for both grower and processor. Without an understanding of both upstream and downstream requirements, consistency of product, be it raw material or manufactured article, will neither result nor be rewarded. At the end of the day, the financial return will determine the success or failure of a naturally-coloured sheep farming enterprise.

5.5 SUMMARY

An important objective when the BCSBANZ was established was to promote production of quality naturally-coloured sheep and wool. This has been achieved according to wool industry personnel.

The next step is to promote the sale and purchase of both the raw wool and items manufactured from naturally-coloured fleeces.

Individual fleece sales for hand-craft purposes will continue to be made by private negotiation as that is the relationship between many hand-crafters and wool growers world-wide.

For larger wool quantities, the current practice of individual wool pools, brokering firms and auction houses presenting small lines of varying breed-types and colours for sale or tender is segmenting the exposure of naturally-coloured wool lots to potential processors and manufacturers. By identifying the growers (*i.e.* members of the BCSBANZ) through labelling or branding the quality wools now produced should create further demand. In practice this would require the establishment of one single sale location, at which objectively measured wool would be displayed. This would provide consistency of sorting, maximum availability, and provision of commercial lot sizes. In addition, farmers and processors would have the opportunity to co-operate and more fully understand and appreciate the parameters within which each must operate.

The medium- to long-term effect of such a structure for the farmer would be a reward for producing what the market wants in terms of quality (price making) and an acceptance that poor quality wools will only be sold at a price the buyer is prepared to pay (price taking).

Successful relationships encourage diversity and development, which in turn create further demand for raw material and new products.

CONCLUSIONS

Three groups of people must be considered in the production of wool yarns and fabrics - farmers, processors and consumers.

For the farmer, the justification for measuring greasy wool characteristics concerns the effects on both clip preparation and processing.

A processor's assessment of the value of a wool lot is determined by the costs involved in processing that wool.

The consumer is interested in the price and quality of the end-product.

Greasy wool buyers purchase objectively measured wool to meet the specifications required by processors. Both fleece and non-fleece lines (such as bellies, pieces, tender wool, *etc.*,) may be included in some blends (Drummond, 1993). The present 'pool' system of selling commercial lots of black and coloured wool reduces the quantity and quality of wools available through any one of a number of sale locations at any given point in time. The development of a marketing brand and 'one-stop-shop' for New Zealand's coloured wool clip would provide better exposure of the product to buyers.

While the use of objective measurements is not common among black and coloured wool growers, they do help determine the value of wool. Their widespread implementation will enable wool to compete with other fibres, especially synthetics, in terms of fibre specifications. Only through the availability of more fully specified wools will wool become more attractive to processors easily swayed by the specifications available for non-wool fibres.

The use of an objective measurement suitable for identifying colour in black and coloured wool would enhance the range of data available to processors. In addition, there would be better consistency in the matching and blending of wools purchased from different sources.

The successful acceptance of objective wool measurements by everyone in the wool market has resulted in non-measured wool causing risk and doubt (Ainsworth, 1988). For this reason, breeding programmes should incorporate wool characteristics important to processors and manufacturers.

FUTURE RESEARCH

This study has identified the following subjects for future research:

1. The propensity of naturally pigmented wool to fading.

2. Breeding specific colour phenotypes

3. The development of a measure for medullation in naturally pigmented wool.

ID	REG	BR	COL	HDL	STL	CRF	SS	YLD	BULK	MFD	SDD	CVD	PF %	%					COLOUR		
								%	cm^3/g			%		MED	X	Y	Z	Y-Z	L*	a*	b*
101	1	4	1	5	110	3.45	7.8	84	22.0	38.46	7.99	20.80	87.6	4.4	42.51	43.39	44.51	-1.13	71.82	-0.09	6.95
102	1	4	1	5	98	4.03	8	79	27.5	31.40	8.08	25.70	60.3	2.0	51.01	52.13	51.87	0.26	77.36	-0.26	8.94
103	1	4	1	5	108	4.40	6.2	76	25.5	30.28	8.46	27.90	47.1	6.0	25.99	26.04	25.96	0.07	58.07	1.91	7.01
104	1	4	1	5	148		5.2	77	29.0	34.15	7.48	21.90	72.3	16.4	19.33	19.27	20.38	-1.11	51.00	2.21	4.17
105	1	4	1	7	154	4.06	7.4	76	25.5	32.31	7.40	22.90	60.6	3.3	41.07	41.98	40.22	1.76	70.86	-0.27	10.09
106	1	4	1	4	130	3.35	6.4	75	28.5	34.71	9.90	28.50	67.3	11.5	20.90	20.75	20.87	-0.11	52.67	2.67	6.17
107	1	4	1	5	132	3.22	8.4	87	26.0	31.93	6.65	20.80	60.7	34.8	13.69	13.64	15.68	-2.04	43.71	2.02	0.92
108	1	4	1	5	140	3.18	7	82	23.0	37.05	9.17	24.70	79.5	3.1	39.74	40.38	39.62	0.75	69.74	0.47	8.86
109	1	4	1	4	132	3.33	7.6	75	21.5	36.94	7.01	19.00	87.0	10.6	29.05	29.38	31.99	-2.61	61.12	0.94	3.55
110	1	4	1	8	136	4.01	7.6	75	26.5	31.35	6.26	20.00	59.8	4.5	37.55	38.14	38.99	-0.85	68.12	0.51	6.81
111	1	4	1	6	154	4.55	8	80	24.5	32.67	6.96	21.30	66.0	9.1	28.39	28.64	28.35	0.29	60.46	1.21	7.54
112	1	4	1	6	140	5.39	8	79	22.5	32.55	6.02	18.50	70.1	2.3	45.25	46.15	46.80	-0.65	73.64	0.01	7.66
113	1	4	1	7	176	2.95	7.6	75	21.5	37.26	7.59	20.40	86.4	4.6	42.49	43.29	40.95	2.34	71.75	0.14	10.79
114	1	4	1	6	128	3.98	7.6	83	21.0	32.77	6.13	18.70	71.1	4.9	39.62	40.32	42.29	-1.97	69.70	0.28	5.73
116	1	4	2	2	108	3.24	5.4	83	30.0	32.59	6.55	20.10	67.6	34.4	12.27	12.16	13.58	-1.42	41.47	2.39	1.83
117	1	4	2	3	126	4.88	3.8	72	35.0	31.95	7.52	23.50	61.9	17.2	18.45	18.44	19.73	-1.29	50.03	1.93	3.69
118	1	4	2	3	76	4.67	8.2	89	29.0	36.86	6.20	16.80	90.0	34.3	14.48	14.54	16.65	-2.11	45.00	1.38	1.08
119	1	4	2	4	86	3.26	5.8	88	28.5	35.91	9.93	27.60	71.0	37.8	16.56	16.63	18.46	-1.83	47.79	1.43	2.25
120	1	4	2	4	118	4.62	7.6	71	29.0	33.03	6.96	21.10	68.9	39.8	12.87	12.84	14.88	-2.04	42.52	1.87	0.63
121	1	4	2	6	96	3.39	8.4	75	23.0	37.34	7.74	20.70	84.0	2.8	41.40	42.23	42.45	-0.22	71.03	-0.01	7.85
122	1	4	2	6	104	4.62	8.2	78	30.5	32.47	7.08	21.80	66.2	40.2	9.30	9.17	10.63	-1.46	36.31	2.56	0.56
123	1	4	2	6	120	2.21	8.2	83	22.5	38.82	9.22	23.70	85.3	53.3	18.39	18.53	21.12	-2.59	50.13	1.16	1.34
124	1	4	2	5	226	3.89	4.4	84	26.5	31.92	7.60	23.80	68.2	41.9	7.52	7.43	7.24	0.19	32.77	2.24	5.22
125	1	4	2	7	100	4.80	8.2	72	23.5	31.69	6.27	19.80	63.2	18.4	17.55	17.49	19.15	-1.66	48.87	2.17	2.79
126	1	4	2	4	84	5.83	5	71	26.5	28.39	8.85	31.20	39.8	17.3	14.77	14.64	16.21	-1.56	45.14	2.53	2.24
127	1	4	2	3	122	2.83	4	89	26.0	38.58	8.18	21.20	87.4	53.5	10.79	10.80	12.81	-2.01	39.24	1.50	-0.14
128	1	4	2	4	96	5.68	8	75	29.0	29.71	5.29	17.80	51.2	62.5	9.93	9.88	11.89	-2.01	37.63	1.92	-0.58
129	1	4	2	4	106	3.44	7.4	71	29.5	32.14	8.81	27.40	58.4	39.8	11.80	11.73	13.49	-1.76	40.78	2.11	0.86
130	1	4	2	5	128	4.45	6.8	76	27.5	34.92	6.92	19.80	79.1	34.8	19.40	19.43	21.63	-2.19	51.19	1.77	2.26
131	1	4	3	6	150	3.70	6.2	75	21.0	34.06	7.55	22.20	75.9	65.1	3.03	2.96	2.93	0.03	19.88	2.24	3.54
132	1	4	3	4	76	2.24	8.8	82	23.0	34.27	10.13	29.50	65.2	69.2	9.64	9.65	11.84	-2.19	37.21	1.44	-1.17
133	1	4	3	5	128	4.53	4	74	28.5	29.16	7.14	24.50	45.8	40.9	9.82	9.72	11.38	-1.66	37.34	2.31	0.27
134	1	4	3	6	122	2.25	8.2	79	20.5	35.16	9.77	27.80	69.7	76.2	8.63	8.66	10.97	-2.32	35.32	1.21	-2.09
135	1	4	3	2	112	6.21	7.2	64	29.0	31.39	7.39	23.50	56.0	90.7	7.88	7.91	10.10	-2.19	33.79	1.15	-2.26

136	1	4	3	8	146	5.10	5.2	76	21.5	23.43	6.03	25.80	15.2	77.6	8.06	8.05	10.16	-2.11	34.09	1.52	-1.93
137	1	4	3	5	122	5.29	3.8	75	26.0	31.34	6.09	19.40	60.3	58.4	8.91	8.84	10.63	-1.79	35.67	2.06	-0.54
138	1	4	3	8	118	3.64	7.8	81	23.5	33.13	6.46	19.50	72.7	64.6	9.64	9.61	11.58	-1.97	37.13	1.75	-0.62
139	1	4	3	5	104	4.47	8.2	78	26.5	39.37	10.26	26.10	81.5	64.5	9.23	9.16	10.85	-1.69	36.29	2.07	-0.09
140	1	4	3	6	126	4.21	6.6	74	25.0	33.06	5.86	17.70	73.1	54.3	9.74	9.64	11.28	-1.63	37.19	2.31	0.28
141	1	4	3	7	118	3.52	7.8	69	24.0	37.12	9.62	25.90	76.9	82.7	8.27	8.24	10.21	-1.97	34.48	1.71	-1.40
142	1	4	3	8	118	5.59	6.6	82	26.5	36.41	7.44	20.40	82.4	78.5	8.66	8.65	10.77	-2.13	35.30	1.55	-1.57
143	1	4	3	5	66	2.20	8.6	77	24.0	31.11	8.97	28.80	53.2	66.8	9.54	9.53	11.67	-2.13	36.99	1.59	-1.11
144	1	4	3	7	150	5.13	6.6	70	24.0	28.34	5.05	17.80	39.1	18.5	10.98	10.67	11.38	-0.71	39.02	3.86	3.17
145	1	4	3	5	104	4.90	7.8	80	25.5	36.42	7.76	21.30	81.80	64.6	2.38	2.27	2.01	0.26	16.84	3.20	5.18
146	1	4	4	5	102	6.52	7.2	68	29.5	27.53	6.58	23.90	37.1	9.3	25.27	25.27	26.47	-1.20	57.34	2.09	4.96
147	1	4	4	7	168	2.77	7.8	83	22.0	35.66	7.20	20.20	81.8	1.0	51.73	52.68	51.88	0.80	77.69	0.21	9.49
148	1	4	4	6	116	3.23	7.4	74	24.5	35.75	7.09	19.80	81.3	1.5	28.59	28.48	27.83	0.65	60.32	2.60	8.05
149	1	4	4	5	128	5.70	8.8	72	23.5	30.32	7.45	24.60	52.2	2.1	29.29	28.93	26.10	2.82	60.72	3.56	11.36
150	1	4	4	5	120	2.92	7.4	76	23.5	34.87	6.78	19.40	78.9	2.5	25.35	25.21	21.96	3.25	57.28	2.68	12.19
151	1	4	4	6	130	2.81	7.6	74	24.0	35.78	7.63	21.30	79.7	3.1	29.05	28.89	28.12	0.77	60.68	2.80	8.25
152	1	4	4	8	134	3.62	7	81	24.0	29.36	6.10	20.80	50.5	0.4	48.34	48.93	45.71	3.22	75.41	1.01	11.85
153	1	4	4	8	84	4.76	8.4	81	26.5	31.79	6.35	20.00	63.6	0.9	21.24	20.80	19.41	1.40	52.73	4.05	8.95
154	1	4	4	7	144	3.23	6	78	21.5	34.53	8.73	25.30	71.3	3.5	30.96	30.88	29.18	1.70	62.41	2.53	9.68
155	1	4	4	7	146	4.28	4.6	71	25.5	33.33	7.95	23.90	66.7	1.5	21.91	21.50	20.20	1.30	53.49	3.89	8.80
156	1	4	4	8	128	3.32	8	75	25.0	33.29	6.78	20.40	71.5	1.0	28.08	27.97	27.40	0.57	59.86	2.59	7.90
157	1	4	4	6	112	3.62	5	79	25.0	29.16	7.04	24.10	47.2	3.1	31.46	31.54	30.98	0.56	62.96	1.96	8.11
158	1	4	4	6	106	4.81	7.6	68	27.5	30.63	7.50	24.50	55.6	11.5	27.59	27.73	29.56	-1.83	59.64	1.60	4.38
159	1	4	4	6	166	4.01	7.6	85	22.0	36.85	7.36	20.00	85.3	2.3	55.88	57.15	55.78	1.36	80.26	-0.37	10.22
160	1	4	4	5	86	6.86	6.6	64	32.0	26.74	7.03	26.30	29.9	0.8	21.44	21.03	19.64	1.39	52.98	3.90	8.95
161	1	1	1	8	78	8.91	8.4	78	36.0	27.58	5.19	18.80	31.6	1.8	47.76	48.81	50.17	-1.35	75.33	-0.26	7.12
162	1	1	1	9	82	6.04	4.2	71	33.0	30.96	6.41	20.70	56.3	27.8	15.32	15.22	16.77	-1.56	45.93	2.35	2.44
163	1	1	1	8	80	6.38	9	68	25.5	24.91	4.63	18.60	12.9	4.8	37.34	37.81	40.41	-2.60	67.88	0.88	4.74
164	1	1	1	7	84	7.68	7.6	72	33.0	20.96	5.83	27.80	9.4	3.7	29.72	29.82	30.70	-0.88	61.50	1.83	5.98
165	1	1	1	8	80	6.75	7.2	75	34.0	27.33	5.26	19.20	33.4	29.6	13.64	13.60	15.49	-1.89	43.65	1.95	1.24
166	1	1	1	8	68	6.25	6.4	67	26.0	21.77	4.35	20.00	4.0	27.8	13.68	13.61	15.16	-1.55	43.67	2.14	1.99
167	1	1	1	7	84	7.44	7.4	82	31.0	25.01	6.32	25.30	20.3	16.1	11.21	11.00	12.03	-1.03	39.58	3.11	2.42
168	1	1	1	9	94	13.56	4.8	54	37.0	25.98	5.29	20.40	22.4	49.6	10.17	10.08	11.85	-1.78	37.99	2.23	0.14
169	1	1	1	9	90	6.83	6.8	76	30.0	27.16	5.40	19.90	29.7	28.1	17.76	17.82	20.22	-2.40	49.28	1.54	1.49
170	1	1	1	5	96	7.03	7.2	69	31.0	31.01	6.36	20.50	56.8	78.7	8.38	8.40	10.58	-2.18	34.80	1.27	-1.90
171	1	1	1	5	108	6.39	7	71	29.0	34.01	6.73	21.70	55.6	37.5	13.70	13.67	15.90	-2.23	43.76	1.89	0.52
172	1	1	1	9	86	7.67	8	80	28.5	29.67	5.60	18.90	49.2	53.2	12.44	12.45	14.70	-2.25	41.92	1.58	0.01
173	1	1	1	9	86	9.19	6	64	34.5	27.07	5.69	21.00	28.5	47.4	10.78	10.66	12.26	-1.60	39.00	2.46	0.84

174	1	1	1	6	90	7.33	7.8	74	30.0	25.90	5.52	21.30	22.0	2.2	33.82	34.02	34.35	-0.33	64.98	1.62	7.11
175	1	1	1	8	88	7.39	6	71	36.0	28.35	7.66	27.00	41.7	5.1	49.15	50.02	49.55	0.47	76.08	0.30	9.04
201	2	1	1	9	100	13.95	8.8	80	32.5	21.76	3.63	16.70	2.2	0.2	55.03	56.20	58.36	-2.16	79.73	-0.17	6.93
202	2	1	1	9	112	13.21	7.2	72	27.0	21.82	3.98	18.30	3.2	9.7	24.57	24.67	26.93	-2.26	56.75	1.65	3.25
203	2	1	1	9	102	12.94	7.6	76	29.0	20.94	4.13	19.70	1.9	1.2	53.38	54.48	57.70	-3.22	78.74	-0.08	5.83
204	2	1	1	9	86	12.33	7.4	77	34.0	22.13	4.22	19.10	4.6	0.4	47.47	48.13	49.51	-1.38	74.91	0.78	7.05
205	2	1	1	9	86	12.21	7.2	76	27.5	18.97	4.30	22.70	2.2	3.1	42.06	42.83	43.74	-0.92	71.44	0.21	7.13
206	2	1	1	9	80	12.44	8	74	27.0	18.80	4.27	22.70	2.3	2.9	38.23	38.54	40.17	-1.64	68.42	1.42	5.94
207	2	1	1	9	124	12.50	8.4	75	29.0	22.00	3.34	15.20	1.6	5.4	37.89	38.42	42.29	-3.87	68.33	0.71	3.37
208	2	1	1	8	72	10.49	8	80	33.5	23.98	4.69	19.50	9.5	2.6	46.03	46.72	48.11	-1.39	74.01	0.63	6.93
209	2	1	1	8	98	11.07	6.6	61	34.0	23.29	5.26	22.60	12.1	8.0	30.00	30.31	33.21	-2.90	61.92	1.07	3.32
210	2	1	1	9	118	11.99	8.6	74	30.5	22.09	3.57	16.20	2.1	3.2	38.67	39.17	42.15	-2.98	68.87	0.85	4.47
211	2	1	2	9	90	12.83	7.8	74	32.5	22.37	4.54	20.30	5.8	35.7	11.62	11.56	13.43	-1.87	40.51	2.04	0.53
212	2	1	2	9	110	14.45	4	67	30.5	19.73	4.42	22.40	3.0	36.3	14.60	14.61	16.93	-2.32	45.10	1.68	0.67
213	2	1	2	8	50	8.40	7.8	61	34.0	23.86	4.78	20.00	10.7	55.9	8.56	8.49	10.15	-1.66	34.98	2.06	-0.36
214	2	1	2	9	82	12.01	9	79	25.5	22.31	5.32	23.80	8.3	5.8	20.43	20.15	19.76	0.38	52.01	3.30	7.05
215	2	1	2	7	114	15.39	3.6	71	30.0	23.49	4.65	19.80	8.7	44.3	9.53	9.46	11.07	-1.61	36.86	2.07	0.28
216	2	1	2	8	110	10.32	7.8	70	29.0	21.65	5.93	27.40	6.8	2.0	31.81	31.84	29.44	2.40	63.21	2.15	10.70
217	2	1	2	9	112	8.75	8.2	62	27.5	22.36	4.87	21.80	8.9	2.0	15.03	14.67	14.36	0.31	45.18	3.90	6.40
218	2	1	2	9	92	10.87	8.6	70	26.0	21.71	4.97	22.90	5.5	3.9	19.59	19.32	19.00	0.32	51.06	3.26	6.85
219	2	1	2	9	92	10.60	6.6	75	25.0	20.37	4.83	23.70	4.1	11.9	20.24	20.27	22.36	-2.09	52.14	1.80	2.64
220	2	1	2	8	80	13.50	7.6	73	32.0	20.81	4.30	20.70	2.5	51.4	10.10	10.06	12.16	-2.10	37.95	1.85	-0.72
221	2	1	3	8	106	10.38	6.4	70	29.0	20.03	4.43	22.10	3.5	53.9	9.52	9.50	11.62	-2.12	36.93	1.67	-1.07
222	2	1	3	7	88	9.26	7.6	65	34.0	22.87	4.99	21.80	9.6	59.9	9.05	8.98	10.88	-1.90	35.95	2.07	-0.77
223	2	1	3	9	94	10.43	8	72	30.5	22.04	4.70	21.30	6.6	82.8	8.19	8.21	10.37	-2.16	34.42	1.26	-1.97
224	2	1	3	6	90	9.06	7.2	77	30.0	26.80	6.82	25.50	30.6	82.5	8.42	8.47	10.73	-2.26	34.94	1.02	-2.08
225	2	1	3	8	90	7.89	8.6	83	22.5	26.58	6.96	26.20	30.7	75.9	8.83	8.87	11.15	-2.29	35.73	1.14	-1.87
226	2	1	3	9	102	14.95	2	68	31.0	17.33	4.66	26.90	1.5	60.8	2.56	2.47	2.33	0.14	17.78	2.72	4.20
227	2	1	3	8	94	11.22	7	67	29.5	22.08	5.36	24.30	9.6	80.7	8.55	8.59	10.89	-2.30	35.18	1.11	-2.11
228	2	1	3	8	92	10.49	7.6	79	28.0	21.10	4.96	23.50	4.4	0.4	2.70	2.65	2.70	-0.05	18.58	1.92	2.86
229	2	1	3	9	134	11.90	7.2	71	27.5	19.23	3.33	17.30	0.4	61.8	9.11	9.06	11.04	-1.98	36.10	1.90	-0.94
230	2	1	3	8	106	10.71	5.8	69	26.0	19.87	4.15	20.90	2.5	52.8	10.39	10.35	12.58	-2.22	38.46	1.86	-0.90
231	2	2	1	7	86	4.83	8.8	73	29.5	31.56	6.16	19.50	62.5	0.7	49.67	50.51	50.40	0.10	76.38	0.40	8.70
232	2	2	1	6	88	5.06	8.4	80	20.5	31.94	6.77	21.20	63.1	2.2	41.10	41.61	41.53	0.08	70.60	0.93	8.15
233	2	2	1	7	92	4.89	8	70	27.5	33.00	6.87	20.80	69.9	3.3	41.74	42.24	43.47	-1.24	71.04	0.99	6.73
234	2	2	1	5	102	5.39	7.8	81	28.5	30.67	6.61	21.50	56.6	4.4	39.37	39.75	38.24	1.51	69.29	1.25	9.72
235	2	2	1	8	88	4.43	8.6	79	24.5	32.40	7.41	22.90	62.4	3.4	47.00	47.78	47.95	-0.17	74.69	0.43	8.26
236	2	2	1	8	102	4.31	8.8	79	24.5	32.38	6.53	20.20	66.0	2.8	38.43	38.86	40.45	-1.59	68.65	1.05	6.02

237	2	2	1	7	106	5.57	8.6	81	25.0	30.65	6.12	20.00	59.0	1.2	41.78	42.19	42.83	-0.64	71.00	1.25	7.38
238	2	2	1	8	120	5.54	8.8	84	23.5	29.33	5.71	19.50	50.9	4.3	44.36	44.82	44.69	0.12	72.77	1.21	8.40
239	2	2	1	8	112	3.66	8.8	86	22.5	34.52	5.96	17.30	80.5	4.1	32.95	33.21	34.97	-1.75	64.33	1.38	5.20
240	2	2	1	7	134	4.37	8.4	83	24.5	31.95	6.26	19.60	69.5	3.4	43.55	43.96	43.05	0.91	72.20	1.32	9.20
241	2	2	2	7	102	7.01	6.6	72	27.5	26.78	5.64	21.00	30.7	42.5	11.19	11.10	12.76	-1.65	39.75	2.24	0.86
242	2	2	2	8	96	4.53	8.2	72	26.0	30.03	5.61	18.70	53.7	13.4	23.94	24.07	26.44	-2.37	56.16	1.49	2.97
243	2	2	2	5	80	5.75	8.6	69	30.5	28.75	6.78	23.60	44.0	54.6	10.73	10.72	13.00	-2.27	39.10	1.65	-0.84
245	2	2	2	7	82	5.00	8	66	32.5	29.77	7.49	25.20	49.2	24.7	17.89	17.90	20.03	-2.13	49.37	1.81	2.01
246	2	2	2	6	116	2.67	7.8	74	25.0	29.70	5.92	19.90	50.6	18.1	15.02	14.89	16.37	-1.49	45.48	2.53	2.50
247	2	2	2	6	112	3.79	8.2	77	25.0	31.82	7.57	23.80	62.3	34.0	19.48	19.53	21.96	-2.43	51.30	1.67	1.88
248	2	2	2	7	120	4.67	8.2	72	25.0	27.47	7.02	25.60	35.1	10.5	17.41	17.18	17.66	-0.48	48.49	3.08	5.03
249	2	2	2	6	98	6.43	8.6	69	30.5	29.41	7.14	24.30	46.8	20.6	14.03	13.93	15.10	-1.17	44.13	2.34	2.92
250	2	2	2	7	88	4.66	7.2	76	25.0	36.39	8.72	24.00	78.0	57.4	15.94	15.90	17.80	-1.90	46.84	2.02	1.92
251	2	2	3	4	130	6.88	4.6	70	29.0	28.58	6.80	23.80	43.1	71.5	8.67	8.68	10.90	-2.22	35.36	1.38	-1.83
252	2	2	3	5	134	7.09	3.4	70	28.0	27.82	7.31	26.30	35.5	64.3	9.18	9.16	11.22	-2.06	36.29	1.66	-1.10
253	2	2	3	8	130	5.08	8.8	81	24.0	31.72	6.57	20.70	62.2	41.9	11.14	10.99	12.36	-1.37	39.56	2.68	1.55
254	2	2	3	5	108	3.47	3.6	73	28.0	33.06	9.77	29.60	62.8	31.1	11.88	11.75	13.07	-1.33	40.82	2.53	1.94
255	2	2	3	7	78	6.60	6.2	71	32.5	26.33	5.58	21.20	26.2	29.0	11.18	11.05	12.63	-1.58	39.66	2.53	1.04
256	2	2	3	8	110	5.68	7.4	72	26.5	32.29	8.75	27.10	60.1	64.4	8.99	8.98	11.03	-2.05	35.95	1.57	-1.18
257	2	2	3	7	120	4.92	7.6	73	29.0	28.68	6.70	23.40	43.9	29.6	11.60	11.44	12.94	-1.50	40.31	2.74	1.39
258	2	2	3	7	74	5.95	6.4	67	33.0	27.03	6.43	23.80	32.4	33.5	12.53	12.41	13.80	-1.39	41.86	2.46	1.98
259	2	2	3	5	88	7.84	9	78	27.5	30.47	7.21	23.70	52.3	81.1	8.28	8.27	10.34	-2.07	34.54	1.53	-1.67
260	2	2	3	7	142	5.04	7.4	79	26.0	29.90	6.62	22.20	52.7	15.9	13.69	13.51	14.34	-0.83	43.52	2.84	3.59
261	2	3	1	7	120	3.25	4.6	82	21.0	30.88	7.08	22.90	59.2	3.3	33.86	34.01	34.14	-0.13	64.97	1.79	7.36
262	2	3	1	5	104	3.99	9	76	27.0	36.51	6.44	17.60	87.4	6.1	37.35	37.98	40.64	-2.66	68.01	0.37	4.69
263	2	3	1	8	112	4.15	8.4	80	22.5	35.72	7.72	21.60	79.3	2.3	41.38	41.92	42.89	-0.97	70.82	0.85	6.99
264	2	3	1	6	96	3.49	8.6	84	27.0	36.65	7.02	19.10	87.2	9.7	31.51	31.96	34.53	-2.56	63.31	0.64	4.00
265	2	3	1	6	130	3.88	7.6	81	30.0	34.21	9.70	28.40	63.4	4.3	47.65	48.66	48.52	0.15	75.24	-0.16	8.63
266	2	3	1	4	116	2.97	6.8	66	23.5	32.53	7.02	21.60	64.3	1.9	34.62	34.73	33.67	1.06	65.54	1.95	8.95
267	2	3	1	6	120	3.83	8.4	77	23.5	36.90	8.67	23.50	77.2	4.3	40.02	40.68	42.56	-1.88	69.95	0.42	5.87
268	2	3	1	7	130	3.42	7.8	79	23.0	37.44	7.49	20.00	84.5	6.3	29.62	29.82	31.40	-1.58	61.50	1.46	5.01
269	2	3	1	7	106	4.81	7.8	69	24.0	29.94	5.88	19.60	50.5	3.5	50.80	51.86	53.11	-1.25	77.20	-0.12	7.46
270	2	3	1	5	112	3.30	9	81	22.0	26.70	8.35	31.30	31.0	46.6	10.09	10.00	11.95	-1.95	37.84	2.23	-0.36
271	2	3	2	6	164	4.54	8	87	24.5	32.96	6.50	19.70	71.1	3.0	24.35	23.98	21.96	2.03	56.07	3.66	10.10
272	2	3	2	7	140	5.32	8	89	22.0	28.65	6.80	23.70	49.2	2.8	24.56	24.17	22.32	1.85	56.26	3.74	9.81
273	2	3	2	6	120	2.96	9	73	23.5	34.88	7.82	22.40	75.6	28.5	18.05	18.06	20.15	-2.08	49.57	1.82	2.12
274	2	3	2	8	120	6.04	9	76	25.5	31.45	6.87	21.80	61.8	30.0	13.80	13.72	15.62	-1.90	43.83	2.21	1.25
275	2	3	2	6	124	1.98	7	76	22.5	36.42	8.80	24.20	79.0	57.3	3.51	3.43	3.35	0.08	21.69	2.34	3.99

276	2	3	2	8	130	5.00	7	75	28.5	33.25	8.42	25.30	66.7	11.4	13.34	13.07	13.49	-0.42	42.87	3.43	4.46
277	2	3	2	6	86	5.99	8.6	64	28.0	29.53	6.29	21.30	49.9	16.7	14.73	14.55	15.78	-1.23	45.01	2.83	2.95
278	2	3	2	6	88	5.80	8.4	79	30.0	30.94	6.01	19.40	60.7	26.8	12.65	12.48	13.65	-1.17	41.97	2.79	2.53
279	2	3	2	6	128	5.59	7.6	68	26.5	29.22	6.41	21.90	47.6	32.2	10.88	10.72	12.15	-1.43	39.10	2.76	1.29
280	2	3	2	8	150	4.93	7.8	88	22.5	30.94	6.03	19.50	60.5	2.5	23.54	23.08	21.34	1.74	55.15	4.07	9.61
281	2	3	3	6	134	3.10	8.6	75	24.0	34.15	9.10	26.60	67.0	69.6	9.67	9.68	11.97	-2.29	37.26	1.44	-1.42
282	2	3	3	5	150	3.53	7.8	80	27.0	36.00	9.35	26.00	73.2	73.4	8.34	8.28	10.20	-1.92	34.56	1.97	-1.23
283	2	3	3	6	100	4.20	8.2	73	24.0	33.96	8.14	24.00	69.6	71.0	8.72	8.69	10.80	-2.11	35.38	1.72	-1.52
284	2	3	3	5	134	3.88	8.4	80	24.5	32.84	8.92	27.20	63.6	79.3	8.84	8.83	11.15	-2.33	35.65	1.56	-2.01
285	2	3	3	5	84	3.10	9	80	26.5	38.26	6.77	17.70	91.3	63.7	11.04	11.02	13.29	-2.27	39.61	1.73	-0.67
286	2	3	3	5	146	2.74	3.6	94	30.5	36.12	7.47	20.70	81.4	68.4	9.57	9.53	11.65	-2.11	36.99	1.83	-1.06
287	2	3	3	4	162	2.56	5.8	93	27.5	36.62	8.11	22.10	82.4	61.0	10.74	10.71	12.96	-2.25	39.09	1.79	-0.77
288	2	3	3	8	160	2.50	8.4	89	22.5	37.25	9.01	24.20	81.0	63.3	8.75	8.63	10.38	-1.75	35.26	2.49	-0.54
289	2	3	3	4	92	5.27	6.4	80	25.0	30.42	7.13	23.40	51.8	76.2	8.40	8.41	10.41	-2.00	34.82	1.36	-1.38
290	2	3	3	5	118	3.52	6	83	25.5	36.18	8.05	22.20	79.5	76.6	8.30	8.27	10.30	-2.03	34.54	1.71	-1.56
291	2	4	1	7	124	3.43	8.6	83	21.0	31.92	5.93	18.60	64.5	4.7	31.36	31.57	32.76	-1.19	62.99	1.49	5.75
292	2	4	1	3	110	1.59	9	79	18.0	36.73	9.41	25.60	77.2	3.7	43.70	44.59	46.67	-2.08	72.62	-0.05	6.03
293	2	4	1	4	134	2.54	9	79	21.5	38.72	8.17	21.10	87.0	1.4	39.18	39.55	38.50	1.05	69.15	1.27	9.16
294	2	4	1	6	122	4.26	7.8	81	24.5	33.43	5.40	16.10	76.8	2.9	37.02	37.42	37.02	0.40	67.59	1.09	8.26
295	2	4	1	5	98	1.79	8.8	80	20.0	37.85	8.85	23.40	83.6	7.6	36.02	36.68	38.45	-1.77	67.04	0.19	5.58
296	2	4	1	3	144	2.57	7.6	86	20.5	38.24	7.78	20.40	89.0	3.2	44.44	45.30	45.03	0.27	73.09	0.08	8.58
297	2	4	1	3	164	3.11	5	76	22.5	38.48	9.65	25.10	82.2	7.4	41.63	42.29	40.01	2.27	71.07	0.51	10.70
298	2	4	1	6	174	3.10	5.6	79	21.5	37.09	8.95	24.10	80.2	1.1	45.89	46.78	45.06	1.72	74.05	0.07	10.20
299	2	4	1	5	196	2.47	5.8	81	19.5	37.18	8.96	24.10	80.5	0.6	46.11	47.28	43.41	3.87	74.37	-0.68	12.54
300	2	4	1	3	13	1.81	5	82	17.5	36.49	10.28	28.20	72.6	6.7	30.24	30.54	32.74	-2.19	62.12	1.11	4.28
301	2	4	2	3	128	2.81	6.6	83	23.0	38.18	8.31	21.80	85.9	37.3	13.62	13.60	15.71	-2.11	43.65	1.83	0.76
302	2	4	2	3	118	3.22	8	81	25.5	36.01	8.66	24.00	76.0	24.3	18.05	18.13	20.67	-2.54	49.65	1.45	1.32
303	2	4	2	3	106	2.55	9	76	20.0	37.94	9.38	24.70	80.6	9.1	27.45	27.71	29.50	-1.78	59.63	1.13	4.43
304	2	4	2	4	124	2.34	7.6	86	22.0	31.83	9.77	30.70	57.0	12.8	19.65	19.58	20.37	-0.79	51.36	2.27	4.81
305	2	4	2	5	164	2.65	4.8	80	21.0	34.49	9.04	26.20	70.0	9.4	23.80	23.86	24.03	-0.17	55.95	1.79	6.41
306	2	4	2	4	160	2.38	4.2	87	21.0	38.95	8.38	21.50	87.3	19.8	20.89	20.92	22.56	-1.64	52.86	1.82	3.54
307	2	4	2	3	136	2.61	4	80	21.0	38.42	8.67	22.60	86.1	13.6	29.34	29.82	32.78	-2.96	61.50	0.40	3.16
308	2	4	2	2	106	2.55	8.4	85	21.0	33.68	11.36	33.70	59.8	25.5	19.22	19.28	20.97	-1.69	51.01	1.61	3.13
309	2	4	2	5	144	2.95	6.2	75	22.5	29.85	6.37	21.40	48.4	13.6	22.36	22.54	24.69	-2.15	54.60	1.20	3.02
310	2	4	2	5	116	2.59	7	80	21.0	36.02	8.86	24.60	77.2	35.1	17.95	18.13	21.04	-2.91	49.65	0.93	0.66
311	2	4	3	3	108	3.70	8.6	84	24.5	29.17	9.15	31.40	46.0	67.0	8.92	8.88	10.87	-1.99	35.75	1.81	-1.07
312	2	4	3	2	120	2.96	8	85	22.5	27.37	6.71	24.50	30.6	45.9	9.91	9.82	11.66	-1.83	37.52	2.23	-0.16
313	2	4	3	1	102	3.73	8.2	85	25.0	29.63	11.44	38.60	43.1	52.0	9.93	9.87	11.65	-1.79	37.61	2.00	0.02

314	2	4	3	4	144	3.99	4.6	79	22.0	34.29	8.47	24.70	69.9	60.6	10.16	10.11	12.29	-2.18	38.04	1.93	-0.90
315	2	4	3	3	140	2.50	6	87	21.5	28.88	10.86	37.60	40.2	44.7	9.72	9.63	11.46	-1.83	37.17	2.23	-0.23
316	2	4	3	1	148	2.57	8.2	93	26.0	29.50	10.63	36.00	42.8	59.9	9.56	9.53	11.70	-2.17	36.99	1.75	-1.19
317	2	4	3	3	122	3.73	4.4	95	22.0	36.64	6.49	17.70	88.0	12.8	24.54	24.85	27.87	-3.03	56.93	0.76	2.15
318	2	4	3	2	146	2.29	4.6	76	23.5	34.17	9.74	28.50	64.7	71.2	8.98	8.97	11.17	-2.19	35.93	1.56	-1.59
319	2	4	3	2	148	1.96	6.2	86	26.0	33.05	8.06	24.40	65.5	54.3	10.13	10.06	11.95	-1.89	37.95	2.08	-0.18
320	2	4	3	2	158	1.65	7	76	24.5	32.98	8.00	24.20	66.6	59.6	10.97	10.97	13.09	-2.12	39.53	1.58	-0.33
401	3	1	2	8	120	8.08	5.4	86	24.5	26.29	5.19	19.80	23.2	32.7	11.61	11.46	12.82	-1.36	40.34	2.67	1.74
402	3	1	2	6	114	8029	6.4	84	23.5	27.35	6.91	25.30	30.5	34.6	12.12	11.92	13.09	-1.17	41.09	3.01	2.36
403	3	1	2	9	104	7.31	6.2	86	24.0	26.70	5.44	20.40	26.1	24.4	12.43	12.26	13.63	-1.37	41.63	2.79	1.98
404	3	1	3	9	100	10.95	6.6	79	26.5	20.94	4.83	23.10	4.7	62.1	9.31	9.25	11.44	-2.19	36.46	1.99	-1.40
405	3	1	3	9	100	12.9	7.6	80	26.5	20.11	4.37	21.70	2.8	66.9	8.95	8.92	10.70	-1.78	35.83	1.73	-0.46
406	3	1	3	9	102	11.37	3	82	23.5	21.59	5.57	25.80	7.6	53.2	9.67	9.62	11.69	-2.07	37.15	1.91	-0.87
407	3	4	1	5	130	3.88	6	83	22.0	32.27	7.66	23.70	65.3	5.0	17.71	17.45	17.85	-0.41	48.82	3.24	5.23
408	3	4	1	3	118	3.47	6.4	79	22.5	32.35	7.38	22.80	63.1	14.4	20.97	20.97	22.59	-1.62	52.92	1.97	3.59
409	3	4	1	4	110	4.5	7.2	77	24.0	34.32	7.33	21.40	74.2	4.8	27.01	26.92	25.55	1.37	58.90	2.50	9.08
410	3	4	1	5	128	4.18	7.2	78	26.5	33.67	6.48	19.20	74.7	4.3	17.98	17.77	17.94	-0.17	49.22	2.97	5.73
411	3	4	1	4	142	3.8	8.6	77	23.5	33.34	7.95	23.90	67	11.0	22.90	22.98	24.12	-1.14	55.05	1.67	4.72
412	3	4	1	4	130	4.73	5.8	78	24.0	32.70	7.52	23.00	65.6	4.8	29.08	29.21	29.18	0.03	60.97	1.70	7.20
413	3	4	1	3	116	6.55	7.2	80	25.5	33.96	6.63	19.50	76.3	3.1	18.71	18.43	18.53	-0.10	50.01	3.33	5.95
414	3	4	1	3	112	3.26	8	78	22.0	37.47	8.61	23.00	81.9	10.9	28.08	28.27	28.43	-0.16	60.13	1.43	6.85
415	3	4	1	3	136	3.71	5.4	75	22.5	34.30	7.70	22.40	73.5	5.3	33.08	33.55	33.59	-0.04	64.60	0.66	7.45
416	3	4	1	4	128	3.79	6.8	82	25.0	34.30	7.19	21.00	74.6	4.2	31.53	31.81	32.58	-0.78	63.19	1.25	6.33
417	3	4	2	5	132	3.03	7.2	83	22.0	38.86	9.04	23.30	84	53.5	11.03	10.98	13.23	-2.25	39.55	1.95	-0.64
418	3	4	2	3	116	3.1	6.6	81	24.5	34.46	8.45	24.50	70.3	29.5	12.96	12.90	14.84	-1.94	42.61	2.07	0.88
419	3	4	2	4	146	3.63	6.4	78	23.5	34.18	7.37	21.60	72.2	30.1	12.20	12.05	13.67	-1.62	41.30	2.66	1.32
420	3	4	2	1	128	3.32	6	75	30.0	33.79	7.54	22.30	71.8	30.2	13.74	13.67	15.47	-1.80	43.76	2.15	1.46
421	3	4	2	3	98	3.57	9	87	21.0	33.73	8.83	26.20	69.6	16.5	15.16	14.91	15.87	-0.96	45.51	3.24	3.61
422	3	4	2	2	120	3.46	6.6	80	24.5	34.45	8.33	24.20	71.1	38.5	12.10	11.98	13.64	-1.65	41.18	2.46	1.20
423	3	4	2	2	104	3.94	7.2	82	27.5	35.59	8.84	24.80	74.7	32.0	12.11	11.99	13.31	-1.32	41.20	2.46	2.02
424	3	4	2	4	104	3.99	8	87	20.5	36.27	7.70	21.20	80.4	53.2	10.38	10.34	12.66	-2.33	38.45	1.86	-1.13
425	3	4	2	3	122	5.66	7.6	77	26.5	33.27	7.78	23.40	66.5	53.2	10.00	9.96	11.99	-2.03	37.77	1.85	-0.59
426	3	4	2	3	114	3.33	4.6	75	30.0	32.56	5.46	16.80	71.9	62.8	10.52	10.47	12.64	-2.16	38.67	1.94	-0.69
427	3	4	3	5	128	4.1	3	83	26.5	34.93	8.99	25.70	71.3	66.0	9.18	9.19	11.27	-2.08	36.35	1.41	-1.14
428	3	4	3	8	114	4.25	8.8	84	23.0	31.38	6.54	20.80	61.6	54.5	9.80	9.75	11.90	-2.15	37.39	1.92	-1.01
429	3	4	3	8	102	4.71	5.6	79	21.0	32.96	8.19	24.90	62.9	67.8	9.78	9.77	12.21	-2.43	37.43	1.60	-1.75
430	3	4	3	7	88	5.4	3.4	75	32.5	30.42	7.78	25.60	53.2	71.3	9.39	9.37	11.64	-2.27	36.69	1.67	-1.54
431	3	4	3	7	84	7.86	5.6	72	29.0	27.24	6.26	23.00	33.5	60.5	9.34	9.32	11.40	-2.08	36.59	1.66	-1.07

432	3	4	3	9	104	6.3	4.4	70	23.5	28.74	7.59	26.40	38.9	58.8	10.07	10.04	12.10	-2.06	37.91	1.77	-0.63
433	3	4	3	8	114	4.34	4.8	68	25.0	28.48	7.06	24.80	40.3	73.9	9.29	9.33	11.48	-2.15	36.61	1.17	-1.25
434	3	4	3	9	108	5.6	2	80	21.5	27.94	5.75	20.60	38.4	32.4	11.20	11.06	12.30	-1.24	39.68	2.60	1.90
435	3	4	3	6	116	2.72	5	79	24.0	33.66	8.99	26.70	65.4	73.7	9.45	9.37	11.58	-2.21	36.69	2.15	-1.38
436	3	4	3	8	152	3.09	7.4	84	23.0	35.67	8.63	24.20	76.4	67.3	9.51	9.45	11.69	-2.24	36.84	1.99	-1.42
437	3	4	4	5	114	5.39	7.2	77	27.0	32.74	5.93	18.10	68.7	42.6	10.96	10.82	12.17	-1.35	39.28	2.61	1.54
438	3	4	4	8	98	6.38	6	77	29.0	30.03	6.25	20.80	51.2	3.7	14.11	13.79	14.26	-0.48	43.93	3.71	4.48
439	3	4	4	6	92	4.95	8.8	80	23.5	31.63	6.34	20.00	65.4	3.5	14.79	14.43	14.37	0.06	44.84	3.91	5.80
440	3	4	4	6	134	4.96	8.6	82	24.5	33.64	6.11	18.10	76.1	4.1	15.48	15.14	15.02	0.12	45.83	3.76	6.02
441	3	4	4	5	98	6.33	5.4	71	28.5	33.54	7.03	21.00	70.8	6.2	13.98	13.65	14.00	-0.34	43.73	3.78	4.73
442	3	4	4	7	116	6.16	6.6	78	27.0	33.07	6.04	18.30	73.3	2.1	14.13	13.81	13.70	0.11	43.96	3.70	5.84
443	3	4	4	5	116	5.73	7.6	68	21.5	29.50	6.27	21.30	49.5	4.1	15.06	14.64	13.80	0.84	45.14	4.26	7.63
444	3	4	4	5	102	5.25	5.2	76	31.5	30.46	5.91	19.40	54.5	23.0	14.96	14.53	14.17	0.35	44.98	4.32	6.50
445	3	4	4	5	102	6.86	8.4	79	26.5	30.90	5.39	17.50	57.9	2.4	15.75	15.36	15.01	0.35	46.12	4.03	6.55
446	3	4	4	5	98	4.85	8.2	80	26.0	31.23	6.86	22.00	57.1	2.5	14.68	14.35	14.60	-0.26	44.73	3.74	5.08
447	3	6	3	5	146	5.51	7.4	79	25.0	34.19	6.13	17.90	79.3	75.2	9.27	9.21	11.44	-2.22	36.39	1.99	-1.53
448	3	6	3	5	108	6.57	4.2	72	28.0	30.95	5.95	19.20	57.2	77.1	9.33	9.25	11.34	-2.10	36.46	2.15	-1.13
449	3	6	3	8	128	4.34	8.8	81	23.5	30.51	6.59	21.60	54.4	49.6	9.61	9.54	11.63	-2.09	37.00	2.07	-0.97
450	3	6	3	7	150	4	8	82	22.5	34.52	6.53	18.90	78.4	54.7	9.48	9.39	11.16	-1.77	36.72	2.23	-0.19
451	3	6	3	5	136	5.26	5.2	77	26.0	33.74	6.82	20.20	71.8	60.4	9.59	9.53	11.42	-1.89	36.99	1.99	-0.44
452	3	6	3	7	126	5.79	5.8	83	28.5	29.50	5.64	19.10	47.7	40.4	10.28	10.16	12.00	-1.84	38.13	2.46	0.00
453	3	5	1	5	140	2.18	9	83	19.5	36.27	7.39	20.40	81.3	5.2	42.65	43.46	42.06	1.40	71.87	0.12	9.73
454	3	5	1	7	138	3.91	8.2	78	19.5	33.42	6.60	19.70	71.8	3.2	36.78	37.19	36.22	0.97	67.42	1.04	8.95
455	3	5	1	6	134	2.39	9	82	18.0	30.51	10.83	35.50	51.4	29.1	42.33	43.05	42.62	0.43	71.59	0.37	8.62
456	3	5	1	6	136	2.98	6.6	74	20.0	39.67	7.48	18.90	91.1	7.2	22.37	22.29	21.83	0.46	54.33	2.37	7.34
457	3	5	1	7	156	2.69	8.4	85	21.0	38.61	7.81	20.20	90	22.1	19.61	19.59	20.86	-1.26	51.37	2.02	3.94
458	3	5	1	5	122	3.28	6	85	24.5	38.20	7.04	18.40	89.8	30.3	16.91	16.96	18.78	-1.81	48.21	1.56	2.35
459	3	5	1	7	140	2.36	4.8	82	24.0	40.06	7.55	18.90	92.1	8.3	20.58	20.50	20.76	-0.26	52.40	2.34	5.89
460	3	5	1	7	130	3.73	7.8	82	23.0	35.47	7.25	20.50	80.2	37.3	13.23	13.14	14.95	-1.80	42.97	2.26	1.26
461	3	5	1	3	138	2.97	7.6	78	25.0	41.48	9.92	23.90	88.3	8.3	34.40	34.94	33.08	1.85	65.70	0.49	10.01
462	3	5	1	5	152	2.11	7.8	79	21.5	40.91	8.30	20.30	91.8	15.4	23.94	24.09	25.38	-1.29	56.18	1.41	4.65
463	3	5	2	6	82	3.41	9	85	21.0	33.51	8.34	24.90	65.7	43.7	14.54	14.61	16.86	-2.25	45.10	1.32	0.81
464	3	5	2	6	80	4.38	9	82	25.0	29.10	6.74	23.20	46.5	26.1	14.50	14.43	16.30	-1.88	44.84	2.16	1.55
465	3	5	2	5	106	3.02	7.6	80	23.5	38.06	10.00	26.30	78.3	30.9	13.01	12.94	14.64	-1.70	42.67	2.13	1.44
466	3	5	3	5	132	3.94	4.4	78	25.0	35.42	7.87	22.20	78	65.8	9.55	9.43	11.51	-2.08	36.80	2.47	-1.00
467	3	5	3	3	136	3.57	6.4	88	26.5	34.86	8.79	25.20	69.5	42.9	10.32	10.18	12.00	-1.82	38.16	2.62	0.06
468	3	5	3	3	146	2.67	7	87	23.0	37.10	8.28	22.30	80.7	55.6	10.08	9.98	12.03	-2.05	37.81	2.31	-0.63
469	3	5	3	6	82	4.02	8.6	82	25.5	34.48	7.45	21.60	73.8	61.0	9.75	9.75	11.91	-2.16	37.39	1.52	-1.04

470	3	5	3	5	120	5.71	4.6	81	27.0	34.57	7.35	21.30	76	55.4	9.84	9.77	11.96	-2.18	37.43	2.08	-1.11
471	3	5	3	3	114	4.61	6.8	76	26.5	39.60	8.88	22.40	86.6	66.8	9.67	9.64	11.69	-2.05	37.19	1.76	-0.81
472	3	5	3	5	132	3.41	7.2	79	24.0	38.44	9.43	24.50	81.2	54.6	9.75	9.72	11.83	-2.10	37.34	1.76	-0.93
473	3	5	3	5	148	3.78	4.4	79	24.0	35.50	7.39	20.80	77.6	66.1	9.06	9.07	11.09	-2.02	36.12	1.40	-1.04
474	3	5	3	8	136	4.26	7.6	80	24.0	34.76	7.81	22.50	74.2	64.4	9.61	9.56	11.52	-1.96	37.04	1.91	-0.62

	x	y	z	y-z	L*	a*	b*
601	-1.42	28.78	29.44	30.86	61.17	-0.32	5.19
602	-1.05	24.21	24.69	25.74	56.77	0.02	5.11
603	-1.48	27.08	27.7	29.17	59.62	-0.31	4.89
604	-1.05	23.6	24.05	25.11	56.14	0.09	5.01
605	-1.39	22.05	22.49	23.88	54.54	0.00	4.24
606	-1.33	13.2	13.43	14.76	43.40	0.21	2.43
607	-1.37	12.56	12.78	14.16	42.43	0.20	2.12
608	-1.45	13.7	13.94	15.39	44.15	0.21	2.30
609	-1.33	12.02	12.22	13.54	41.56	0.27	2.09
610	-1.43	12.44	12.65	14.08	42.23	0.25	1.96
611	-0.61	4.17	4.24	4.85	24.45	0.18	0.74
612	-0.57	3.88	3.93	4.49	23.44	0.40	0.75
613	-0.71	4.87	4.95	5.66	26.59	0.21	0.79
614	-0.68	4.8	4.87	5.56	26.36	0.32	0.82
615	-0.58	4.14	4.2	4.78	24.32	0.31	0.85

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