CONTRACT REVIEW

THE POTENTIAL TO IMPROVE WOOL QUALITY AND ON-FARM PRODUCTIVITY

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The Australian wool industry has endured several years of low profitability and, despite the short-term recovery in prices in 1997, the longer-term prospects are presently not encouraging. There are two primary sources for the problem; one has been the low rate of on-farm productivity growth over several decades and the second has been the comparatively low prices paid for wool by the global textile industry.

On farm productivity

For the purpose of this contract, productivity is defined in terms of the total output relative to all inputs employed in its production. Since 1977/78, annual productivity growth on specialist sheep farms has been estimated at 1% per annum, compared to corresponding estimates of 4.6% for cropping farms and 3.2% for mixed crop/livestock farms (Knopke *et al.* 1995). Of even more importance, wool's productivity gains have been outstripped by technological improvements in cotton and man-made fibres contributing to an erosion of the terms of trade of wool producers. As one analyist put it "without a significant improvement in the terms of trade, a significant exodus of growers from the industry can be expected" (Swan Consultants, 1995 p.vii).

Textile demand

Spinners' demand for textile fibres generally has been significantly eroded during the 1990s by three important factors:

- A marked decline in the proportion of consumer expenditure allocated to apparel.
- Greater selectivity by consumers in choosing apparel has placed increased emphasis on innovative products.
- Downward pressure on retail prices has been caused by consumers increasingly deferring purchases until sales are conducted.

In the case of textile demand for wool, the situation has been aggravated by a consumer shift from formal wear to casual and leisure wear and by the weakness of synthetic fibre prices. There is not a lot the wool industry can do about changing consumer behaviour, but the industry can pursue two objectives:

- To reduce the costs of producing wool in order to earn profits at lower prices.
- To enhance wool's performance as a textile fibre.

Research programs conducted within the CRC for Premium Quality Wool have been designed to address these twin objectives. The three papers presented in this contract consider the following:

- Constraints which inhibit our ability to both raise productivity *and* enhance wool's processing performance.
- Nutritional factors that are limiting gains in on-farm productivity
- The potential role of molecular technologies in generating genetic improvement in Merino sheep.

MANAGING WOOL'S PROCESSING PERFORMANCE

The two most important fibre characteristics for a worsted spinner are average fibre diameter and fibre length (hauteur, H, in wool top). A challenge for wool growers is to be able to reduce fibre diameter and enhance those factors which, collectively, will increase H (within limits).

One difficulty is the sheer complexity of the interactions that determine H and the uncertainty that creates in determining the consequences of changes to wool traits. A second dimension to that problem for growers

is that changes to livestock and farm management practices in pursuit of specific fibre characteristics involve risk. For that reason, growers are often hesitant to introduce changes, preferring to stay with proven practices. If we could reduce that risk with simpler tools to manage hauteur, growers could more readily implement other changes, such as reducing fibre diameter or increasing stocking rates.

Growers are not alone in being conservative. Topmakers and spinners internationally require a lot of convincing to adopt new technologies, including revised fibre measurement parameters. For example, research has shown that worsted spinners can successfully spin beyond current upper limits for fibre length, but they continue to heavily discount wool that exceeds those limits. Again, successful technology transfer depends on taking the risk out of making changes.

NUTRITIONAL FACTORS

In such a dry continent as Australia, an ongoing concern is the inefficient use of available pasture by the livestock industries. The 'feast or famine' syndrome is an accepted norm for much of the Australian sheep industry. Worse still, the problems created for wool growers are often compounded by supplementary feeding regimens that are inefficient and not cost effective in terms of the net value of the wool produced.

In addressing these issues, potential opportunities for gains exist in the following areas :

- improved utilisation of pasture produced through grazing management and feed conservation
- development and testing of new and modified pasture species for wool production
- increased efficiency of conversion of supplementary feeds to wool through diet formulation, grain treatment and plant breeding
- selection of more efficient animal genotypes.

ROLE OF DNA TECHNOLOGIES

The genetic enhancement of sheep has been a long-term goal for the wool industry, but the rate of progress has been relatively slow. Techniques are now emerging that promise a much faster and more accurate way of achieving productivity gains, improving wool's performance as a textile fibre and eliminating/reducing less desirable inheritable characteristics. Some of those developments include:

- Assembly of ovine genetic maps and identification of specific genes as a basis for developing sheep breeding strategies
- The development of cost-effective DNA pedigreeing techniques to assign parentage as a strategy to identify likely carriers of particular genes
- Identification of candidate genes using partial sequence data, and measurement of their effects on traits associated with production of wool (eg follicle functions)
- Production of transgenic sheep and the development of more reliable and less costly methods of gene transfer

Much of the research described in this contract is approaching the stage where transfer of technologies to commercial application assumes increasing priority. This is a challenge in itself because conventional methods have not been highly successful. One solution could be to encourage an increasing number of breeders and growers to feel some ownership of the research.

Once a small core becomes committed, the demonstration effect prevails and others will follow. This would appear to be the way for research groups like the Wool CRC to approach technology transfer in the future.

CONSTRAINTS TO PRODUCTIVITY IMPOSED BY OUR CAPACITY TO MANAGE HAUTEUR

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To a spinner, the two most important characteristics of textile fibres are diameter and length. For wool fibres, the mean length of fibres in the top is called the hauteur (H). Because there is little fibre breakage during the latter stages of wool processing, the H reflects the fibre length for all subsequent textile purposes. Thus, the wool apparel industry can be described by a fibre diameter x H matrix (Stanton *et al.* 1997); for example, knitting yarns do not exceed 65 mm in H whereas high twist weaving (crepe) yarns require an H ≥ 70 mm. Moreover, the role of H may become more important as recent spinning trials have shown that, all other factors being constant, increasing H out to at least 95 mm improves yarn evenness, yarn strength and spinning performance (Lamb and Yang 1997). Hauteur can also be traded for fibre diameter to manage increased spinning efficiency; an increase in H of 10 mm was equal to a reduction in fibre diameter of one micron in terms of reduced ends-down. In addition, it is well established that, all other factors being constant, as the H of tops increases the amount of short fibre waste or 'noil' decreases. As margins continue to tighten over the next 5 to 10 years, wool processors will place even more emphasis on the characteristics of the raw wool that influence H.

Although H is a vital measurement for the spinner, it cannot be measured directly on the raw wool. The process of top-making (washing, carding and combing) breaks many raw wool fibres, reducing the average fibre length, creating noil, and increasing the variability of fibre length. The H thus depends on the initial fibre length, and the degree to which the wool fibres break during processing. Fibre breakage depends on a number of factors in the raw wool, and on the settings of the processing machinery. Characteristics of raw wool that affect H are summarised in the TEAM (Trials Evaluating Additional Measurement) Couchman *et al.* (1992) equation, which states:

$$H = 0.52SL + 0.47SS + 0.95\ FD - 0.19MPB - 0.45VM - 3.5,$$

where SL = staple length (mm), SS = staple strength (N/ktex), FD = fibre diameter (mm), MPB = midpoint breaks (%) and VM = vegetable matter (%). In addition, style factors such as crimp and dust penetration affect H in ways which are not yet fully quantified.

Current market analyses report premiums or discounts for the various components of raw wool that contribute to H, and although wool producers are not accustomed to thinking this way, these reflect the relative contribution to the overall predicted H. Indeed, the value of H predicted by the TEAM equation explained at least as much of the variance in price of objectively measured auction sale lots, as did the individual raw wool terms (SL, SS, FD, VM and PMB) in a multiple regression analysis (Stanton pers. comm.). The discounts in part reflect costs to processors and so indicate the direct loss to the wool industry.

Constraints on reduction of fibre diameter

In addition to the direct costs described above, raw wool factors affecting H and noil have major indirect effects on the productivity of the wool industry, by restricting the adoption of other technologies. For example, wool growers outside the traditional fine wool areas have been reluctant to meet the competition from new softer and finer synthetic fibres by breeding sheep that reduce the mean fibre diameter of their clip. A gross margin analysis favours finer wool sheep under most conditions (Atkins *et al.* 1995), but perceived risk factors have discounted the gross margins and dramatically slowed the rate at which breeding for finer wool has been adopted by industry. The two main risks are the greater volatility of price of finer wools, and the fact that price discounts for components that determine H (eg SS, SL, style) increase as FD decreases. The greater risk of dust penetration in cropping areas, for example, or the risk of incurring low SS in areas with a Mediterranean type climate, are important factors in determining the FD that producers aim for.

As a result, fine wool sheep are mostly limited to the relatively small area of Australia where the factors affecting H are easier to control, compared with the non-traditional areas. A greater ability to manage these

risk factors affecting H would encourage more widespread adoption of the powerful genetic tools that are available to reduce FD. To further encourage adoption, we must develop cost-effective packages to manage H to whatever value is required by spinners and we must demonstrate to early stage processors that these packages permit them to achieve the required H characteristics in fine wool tops without unacceptable processing costs or losses.

Constraints to increasing stocking rate and/or adopting more intensive grazing systems

Extension experts believe that farm profitability could be increased if farmers stocked heavier than at present and/or adopted more intensive grazing systems. However, these innovations also increase risk; risk of stock losses, risk of increased feeding costs, and risk of decreased wool quality. These risks must be quantified if extension messages are to be successful. Wool quality issues are commonly ignored in estimating the financial returns from increasing stocking rate or adopting more intensive grazing systems.

The point may be illustrated by examining the work of Doyle and Thompson (1993), who restricted feed intake of wethers by strip grazing during spring to reduce fibre diameter and increase staple strength, and as a result:

- decreased clean fleece weight per head and per ha
- decreased FD
- decreased the coefficient of variation of FD
- decreased SL
- increased SS
- changed the position of break

To illustrate the ramifications of their study in dollar terms, Oldham *et al.* (1997) assumed that the VM content (1%) was equal across treatments and that the shift in the position of break towards the mid point of the staple increases the proportion of mid breaks (C.M. Oldham, unpublished data). The sum of the changes listed in the variables listed above can then be expressed as changes in predicted H using the TEAM equation.

Table 1. Effects of strip grazing on the mean fibre diameter and predicted hauteur of adult Merino wethers stocked at 20/ha. Recalculated by Oldham *et al.* (1997) from Table 1 in Doyle and Thompson (1993)

Year	Set Stocked		Strip Grazed	
	Fibre diameter μ	Predicted hauteur mm	Fibre diameter μ	Predicted hauteur mm
1989	21.5	77	21.0	75
1990	21.0	75	18.5	66

With this information, Oldham *et al.* (1997) determined the relative value of the wool clips in each case from Figure 1 in Stanton *et al.* (1997), a fibre diameter x hauteur matrix of three years of objectively measured sale lots sold by auction in Fremantle. In both years the intensive grazing treatment increased the value of the wool, but the increase in value due to reduced FD was balanced to a varying extent by a decrease in value associated with reduced H. In addition, the total amount of clean wool per ha was reduced by strip grazing in both these studies, indicating the complexities that must be addressed when controlled grazing is utilised.

Clearly, managing wool growth and quality calls for more intensive and flexible management systems and a full understanding of all the factors in play. Effects of increased stocking rate at different times of the year, and the responses of different genotypes to stocking rate, need to be identified. Dunlop (1962) showed that there are genetic differences between sheep in the extent to which the FD responds to feed supply, indicating that genotypes differ in their potential to increase the variation in diameter along the fibre (and so reduce SS) as nutrition changes.

Further, reduced SS has been observed in sheep grazing paddocks that have been well-fertilised to enable increased stocking rate, possibly because the variation in pasture growth between seasons was increased and therefore the variation in FD along the staple also increased (Vizard pers. comm.). The benefits to farm

income of increased management inputs are normally clearly demonstrable, but such packages will be adopted more readily if they are also able to manage potential risk factors such as those that affect H.

Management of hauteur

Possible impacts of wool style on H have been widely discussed in recent years. Recent experiments conducted by the CRC for Premium Quality Wool suggest that there are other still unmeasured raw wool factors affecting H. In tops processed from spring-shorn wools, the increase in actual H in response to increased rates of feeding over autumn was curvilinear, with a greater response occurring at lower levels of supplementation. In contrast, both the response in SS and the increase in H predicted by TEAM increased linearly (C.M. Oldham unpublished data). Thus, the most economic response to supplementation was very poorly predicted by TEAM. These data indicate that inadequate prediction tools are a further constraint to the adoption of feeding to increase H.

There are tools to manage the individual components of H such as the SS or SL. However, these tools are not always cost-effective, and their practical on-farm applications are not yet fully worked out, so that better options are required. Furthermore, as yet there are no packages for the integrated management of H, despite the fact that integrated packages, which take into account all the components contributing to H, will be the most successful means of facilitating the management of H. Such packages will increase profitability directly, but will have their greatest impact by enabling wool growers to adopt other associated technologies to improve their productivity.

NUTRITIONAL CONSTRAINTS TO PRODUCTIVITY GAINS IN WOOL

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Sheep in Australia derive over 90% of their nutrients from pasture, and it is unlikely that this will change much in the future. The aim of the paper is to review some of the constraints to and opportunities for improving the efficiency of conversion of feed into wool. The major challenge is to capitalise on recent developments within the economic constraints of a farming operation.

Pasture constraints

Seasonal variation in the rate of pasture growth is usually the first factor limiting wool production. This may be during winter in temperate regions or summer and autumn in a Mediterranean environment. Selecting and/or breeding and introduction of novel or improved species that grow when rainfall and/or temperature are unfavourable for conventional species should improve productivity. For example new varieties of phalaris are likely to increase productivity of pasture in a range of environments for which the species have been specifically bred (Oram and Culvenor 1994).

Better utilisation of pasture grown and more efficient use of the nutrients ingested by the sheep will increase wool productivity per hectare. Abundant pasture growth in spring results in poor utilisation; for example only 30 to 50% of pasture grown in the south west of Western Australia is eaten by sheep, and the remainder disappears due to weathering and biological degradation (M. Grimm pers. comm.). In areas with > 500 mm rainfall, rotational grazing to a specified level of feed on offer creates opportunities for feed conservation in the ungrazed paddocks, thereby reducing pasture waste from weathering and increasing per hectare productivity (Hyder *et al.* 1996). Apart from hay making during late spring, pasture conservation is not widely practiced on Australian sheep farms, but if productivity per hectare is to increase substantially, then economic and technological barriers to feed conservation during early and mid spring will need to be overcome.

Even within current management practices the opportunity exists for most farmers to improve pasture productivity using existing technology. Highly productive enterprises in Western Australia have a higher stocking rate (10.7 vs 8.8 DSE/winter grazed ha) and higher wool cut (53.5 vs 36.1 kg greasy/winter grazed ha) than average producers (McFarland 1996). Likewise, in Victoria the Grassland Productivity Program

(GPP) has reported increases in gross margins of $62/ha (26%) for wool producing ewes lambing in spring and $33 (19%) for wethers by increasing pasture production through increased fertiliser inputs matched to higher stocking rates (GPP Autumn 1996, Update 1997).

Opportunities exist to improve per hectare wool productivity by application of selection, breeding and molecular genetic techniques to pasture species to improve digestibility and reduce protein degradability (Ulyatt 1997). Research, at varying stages of development, has demonstrated the likely potential of each of these approaches, the future challenge will be to successfully integrate new or modified species into our pastoral production systems. For example, decreasing the degradability of protein by feeding *Lotus corniculatus,* which contains condensed tannins, increased fleece weights (8%) and liveweight (25%) gains in lambs compared with lambs grazing a lucerne sward (Douglas *et al.* 1995). Breeding smooth bromegrass (Casler and Carpenter 1989) for increased *in vitro* dry matter digestibility, has reduced plant lignin levels and increased whole plant digestibility by three percent units although no animal trials have yet been undertaken. Increases in feed intake, digestibility and performance in animals fed 'brown midrib' mutants of several forage crop species (maize, sorghum and millet) were reviewed by Cherney *et al.* (1991). The brown midrib mutants had less lignin than non mutants resulting in up to a 30% increase in intake and 33% in digestibility, although increases do not always occur and the magnitude of the benefits tended to be correlated with the decrease in lignin content.

Supplementary feeding

Supplementary feeding for sheep survival during late autumn and early winter is a part of normal sheep husbandry in the Mediterranean regions of Australia and opportunities exist to increase the effectiveness of the supplementary feeds used for wool growth. It has been known for over 20 years that formaldehyde treatment of oil seed meals reduces protein solubility in the rumen and increases wool growth by up to 80% (Ferguson 1975). While oilseed meals are still too expensive to feed for wool production, canola seed production in Australia is forecast to increase to one million tonnes by 2000 and this increased supply, together with improved and cheaper methods of protection of protein may provide a more cost effective protein supplement. Little work has been done on more commonly available sources of protein. The protein in pulse grains such as lupins is highly degradable in the rumen and is used inefficiently for wool growth. For example, we have found that sheep fed lupins containing 32% protein grow only the same amount of wool as those fed oats of 10% protein at equal energy intakes. In addition, treatment of pulse grains, including lupins, with heat or formaldehyde either has no effect or depresses wool growth unless protected methionine is also included in the diet.

It is significant that 25% of the grains and oilseeds grown in Australia are used to feed animals (Grains Council of Australia 1997) yet the ability of these grains to provide the required nutrients has been considered of minor importance relative to crop yield. A greater emphasis on selecting for high grain quality to meet animal needs should result in higher efficiencies of wool production.

The development of knowledge-based computer programs, such as GrazFeed (Freer *et al*. 1997), are a breakthrough in decision support for development of feeding strategies and provide a basis for comparison of different types of supplements to pasture fed animals. However the models still need additional information on protein degradability and amino acid composition of various supplements to accurately predict wool growth.

Improving the amino acid balance of metabolisable protein

Under a wide range of circumstances, metabolisable protein may not contain the correct balance of amino acids for optimum wool growth. Provision of protected methionine to adult wethers fed to maintenance increased the efficiency of conversion of metabolisable protein to wool from 12.3% to 17.2%, and increased wool production from 9.6 to 13.5 g/d (derived from Mata *et al.* 1995). In field experiments carried out at Armidale in NSW, the delivery of 0.7g of methionine into the intestine of sheep resulted in increases in wool growth of 40% on native pasture and 18% on improved pasture (Langlands 1970). Economic benefits from providing protected methionine for four months to weaners grazing dry pastures in Western Australia was $7 at a protected methionine cost of about $10. This calculation took into account the reduced amount of lupins required by the methionine supplemented weaners for survival, together with the changes in wool growth, fibre diameter and staple strength (calculated from Mata *et al.* 1997). Thus, there is an incentive to reduce the cost of protected methionine by at least 30% to make it cost-effective as a supplement for wool growth.

Molecular engineers have incorporated a gene encoding for a sunflower protein rich in protected sulfur amino acids into clover and lupin (Tabe *et al.* 1993). In lupins the methionine content has been increased by 2.3 g/kgDM. In clover it has been increased by 0.23 g/kgDM, with potential to go to 2 g/kg (T.J. Higgins, pers. comm.). Likewise, a methionine-rich seed protein from the Brazil nut has been expressed in canola seed resulting in a doubling of methionine content (Altenbach *et al.* 1992). These advances have the potential to significantly increase wool production per hectare at little cost to the producer. The increase in fibre diameter that will result from increased methionine intake will need to be controlled through manipulation of genetics or stocking rate.

While methionine (as a precursor for cysteine production) is accepted as the primary limiting amino acid under most conditions, additional increases of 38% in wool growth may be obtained if other limiting amino acids are supplied (Reis *et al.* 1990). This means wool growth per head and per kg dry matter intake can be increased by over 70% under experimental conditions simply by balancing the amino acids in metabolisable protein.

Compared with rumen microbial protein, wool contains higher concentrations of serine and arginine, as well as cysteine. Serine and arginine are both classified as non-essential amino acids but the extent to which they can be synthesised *de novo* is uncertain. The response in wool growth to serine and arginine, either alone or in combinations with methionine or cysteine requires evaluation.

For the grazing sheep one option would be the use of small quantities of specific amino acids to improve efficiency of protein use and stimulate feed intake. This can be achieved by strategic supplementation and/or by improvements in herbage and grain quality through genetic enhancement. The benefits would include increased production and a reduced metabolic cost of detoxifying waste ammonia (Parker *et al.* 1995) with a simultaneous reduction in excretion of unused nitrogen which contributes to soil acidification and pollution.

Genotypes and nutrition

Numerous studies have shown that within Merino breeds, genotypes of large mature size eat more and produce more wool per head than those of small mature size, with no difference in efficiency of feed conversion to wool (Langlands and Hamilton 1969; Hogan *et al*. 1979; Thompson 1986; Lee *et al*. 1995a; Lee *et al*. 1995b). Since feed conversion efficiency for wool is the same for small and large sheep, and because pasture costs are on a per hectare basis whereas animal handling costs are per head, it is better financially to run large sheep than small sheep of equal fibre diameter. Large size is also favoured by the meat processing industry. An economic evaluation of the impact of sheep size using the computer program GrassGro (Donnelly 1998) predicts a 30% higher gross margin for a Merino ewe flock at Mt Barker in Western Australia comprising a large genotype (mature ewe 60 kg) compared with a small genotype (ewe of 48 kg). Unfortunately, the genetic relationship between diameter, wool cut per head and liveweight is such that for a producer starting with sheep of equal size, the main economic benefits come from breeding objectives that emphasise wool traits rather than liveweight (Ponzoni 1986).

Since feed costs constitute a major proportion of the cost of wool production, a potentially important way to improve the economic efficiency of wool production is also to select for efficiency of conversion of pasture to wool. The tools for this are now available through use of alkane technology.

The challenge for geneticists and wool growers is to produce large framed sheep with a high fleece weight, low fibre diameter and a high conversion efficiency of feed into wool.

HOW WILL DNA TECHNOLOGIES CONTRIBUTE TO GENETIC IMPROVEMENT OF MERINO SHEEP?

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Phenotypes or traits measured on individuals may be controlled by a single gene or by many genes, which may be moderated by environmental factors. Most traits of economic importance to the Merino industry are thought to be controlled by a large number of genes. It is difficult to estimate how many of the 70,000 to

100,000 genes in sheep influence traits of economic importance. However, we do know that some genes with large phenotypic effects exist for characters such as ovulation rate in sheep, eg the Booroola fecundity gene FecB (Piper and Bindon 1982), and Inverdale, the New Zealand major gene for fecundity. Genes with moderate effects on quantitative traits have been more difficult to identify but recent progress in the fields of molecular and quantitative genetics have led to the development of more sensitive methods that will assist in this search. Once genes, or markers for the genes, associated with quantitative traits have been identified their inheritance can be traced in pedigrees to give breeders the information needed to use them in marker-assisted selection (MAS). There is a range of molecular technologies at different stages of development. What impact are they likely to have on Merino breeding in Australia (recently reviewed by Mayo 1996a, 1996b)?

Ovine genetic maps

One method designed to better understand the genetic basis of quantitative traits is to assemble genetic maps which identify the location of important genes, or groups of genes, and allow us to predict how they might act and also interact. Physical maps provide the location and order of genes on chromosomes and recombination maps provide information about genetic linkage. Projects to map the genome are underway for most of the agriculturally important mammalian species; efforts in the human and mouse are significantly more advanced. As the function of genes is widely conserved between mammalian species, livestock genome researchers can utilise much of the information that is generated from the other species in addition to information on their own species (Hetzel 1996). The first sheep gene map was published in 1995 (Crawford *et al.* 1995). A number of other groups are presently creating more dense maps of the sheep genome in collaborative projects (eg the CSIRO sheep mapping project reviewed by Mayo 1996b). Sheep mapping information is regularly updated and available through the Internet via SheepBase (Sise *et al.* 1996) at the following addresses: http://dirk.invermay.cri.nz, http://tetra.gig.usda.gov:8400, or http://www.ri.bbsrc.ac.uk/sheepmap/.

Use of maps and markers in production systems

Genes or genomic regions that affect continuously variable traits are known as quantitative trait loci (QTL). Reports of QTL associated with production traits are rapidly accumulating for many species. For example, QTL associations for sheep are reviewed by Montgomery and Kinghorn (1997), and chromosome regions associated with large effects on growth, tenderness and lean meat yield in beef cattle are reported by Hetzel (1996). Opportunities for sheep breeders to utilise this molecular information lie in the development of the ovine map and identification of markers linked to QTL. In addition, non-genetic opportunities may also arise from a better understanding of the physiological basis of production differences. Markers are being developed that will be used directly to verify animal pedigrees and for genetic screening for QTL and disease genes. Markers for the genes are likely to be used in breeding programs, at least until the actual genes responsible for the trait can be identified and DNA tests developed. The real power of markers will be realised when they are integrated with conventional genetic evaluation and reproductive technologies such as juvenile embryo transfer which have the capability to reduce generation time and allow large scale production of genetically superior lines (Davis *et al.* 1997). Davis *et al.* (1997) speculated that oocytes could be collected from young animals and used to produce embryos *in vitro* which could then undergo genetic testing for sex, inherited disorders and gene markers for specific traits prior to transfer to a recipient dam thereby rapidly propagating a large number of progeny from parents of high genetic merit.

DNA pedigreeing

It is difficult and expensive to record pedigree information based on observations recorded in the field. Errors in pedigrees due to mis-mothering, a ram jumping the fence or a gate being left open, can substantially reduce the rate of genetic progress in breeding programs. These pedigree problems can readily be solved by DNA pedigreeing. Parentage can be assigned provided that a DNA sample can be obtained from the individual and its parents, and that informative genetic markers are available. Adoption by industry of a commercial test will depend on the cost of the whole procedure, which includes blood collection, DNA extraction and preparation, marker testing and analysis. This cost must be balanced against the cost of collecting the information using other methods and the genetic gain foregone by ignoring the pedigree information. Work is currently underway to develop better methods for collecting and extracting DNA, identifying and handling samples, interpreting gels and analysing the data. It is expected that this technology will be available to

industry in a cost-effective form in the near future. This technology will be useful for assigning parentage to lambs born following a syndicate mating, certifying parentage of stock prior to sale, controlling inbreeding, identifying animals carrying genetic defects, and more effective control of simply inherited defects. Having very accurate records of an animal's pedigree will also allow more accurate estimation of an animal's genetic merit for traits that the breeder wants to improve and genetic trends in these traits over time. Selecting animals with the benefit of knowing the full pedigree may offer improvements in rates of genetic gain in the order of 20% (Mayo 1996a).

Genetic markers

It is expected that QTL studies will identify chromosome regions containing genes that affect a wide range of traits, however, it will take considerably more time to then isolate the gene variant responsible for phenotypic differences. In the meantime it will be necessary to use genetic markers tagging the genes in breeding programs. Use of markers instead of the gene *per se* has the disadvantage that the association between the marker and the gene variant can be broken down over a number of generations because of the crossing-over of chromosomes that occurs during meiosis. For this reason flanking or linked markers will be more difficult to use in practical situations than the gene itself. The value of markers in selection programs will also depend on a number of other factors. Markers will be most useful for traits that are difficult or inefficient to select for, such as traits that are sex-limited traits, expressed late in life, difficult or expensive to measure, traits that can only be measured post mortem, and lowly heritable traits (Hetzel 1996).

Markers linked to QTL may be used directly in breeding programs as selection criteria. Where markers are linked to major genes with evidence of segregation and defined phenotypic effects, the markers would be used to increase the frequency of particular alleles (alternatives of the gene) in the population (Montgomery and Kinghorn 1997). MAS will be most useful once the genes and mutations responsible for trait differences have been identified. If the actual gene can be identified, DNA tests for particular variants can be developed. DNA tests are still relatively expensive, but the cost must be considered against the cost of conventional systems of measurement and/or progeny testing of rams. Advantages of the DNA test will include the ability to test for genes associated with particular production traits in animals as embryos or shortly after birth. This will enable selection and culling to occur much earlier than with current selection schemes. Tests could be developed for genes conferring disease resistance thereby negating the need to expose breeding stock to disease organisms. This would also be an advantage as selection based on challenging the animal can compromise their response in other traits, reduce the overall selection intensity and raise ethical questions. A related application of DNA testing may be to screen elite breeding animals for known genetic disorders to prevent spread of disease genes. This is particularly relevant for animals used in artificial insemination and embryo transfer programs where genetic material is widely distributed.

Candidate genes

Another approach to understanding the genetic basis of quantitative traits is to identify genetic variation in candidate genes and search for gene/trait associations. The candidate gene approach implicitly depends on some background biochemical knowledge which enables us to find genes that are likely to be associated with phenotypes.

As only a small proportion of sheep genes match up with previously characterised genes, predictions of the function of many genes is limited. Once a candidate has been identified, the effect of that gene on the trait can be measured. A number of candidate gene studies are currently underway in the Cooperative Research Centre for Premium Quality Wool. Candidate genes involved in follicle initiation and function are being identified via the literature, from partial sequence data (EST) and using a technique called differential display which 'displays' gene products on a gel so that differences between samples can be detected. Knowledge of genes expressed in wool follicles acquired from ESTs or differential display will provide further information pertaining to the regulation of wool biology and may provide the basis for DNA or physiological tests for factors controlling wool traits.

Transgenic animals

Despite an increasing acceptance of the use of recombinant DNA technologies in plants, it is unclear whether transgenic animals will ever have a major role in animal production. Transgenic plants conferring improved insect resistance, herbicide resistance, virus resistance, specialty oils, slower ripening and in-

creased pectin have been produced and delivered to industry. Gene transfer experiments in animals have met with comparatively limited success. This is primarily due to the low efficiency of production of transgenic animals. The best figures for transgenic sheep production to date is 1%, however, these were not necessarily expressing the gene (Walker 1995). The recent report of sheep cloned by nuclear transfer of cultured cells (Campbell *et al.* 1996) may have a major impact on this area of research and embryo transfer procedures. Nuclear transfer has the potential to markedly reduce the cost of producing transgenics as it will allow large numbers of cell fusions (cultured cells are fused with an enucleated oocyte) to be done which can be tested for incorporation of the transgene before being transferred to the recipient. Nuclear transfer may also enable specific genes to be removed or replaced with more favourable alleles. Adoption of this technology may assist current projects aimed at manipulating growth and introducing novel pathways into sheep via transgenesis. These include the introduction of bacterial pathways for cysteine synthesis in sheep to improve wool growth, secretion of chitinase from sweat glands in sheep as a means of controlling blowfly strike (Nancarrow *et al.* 1993), and modification of wool fibre properties by changing the abundance and/or the site of synthesis of keratin and matrix proteins (Rogers 1995, Ward *et al.* 1995). One successful application of gene transfer in livestock is the use of transgenic animals to produce valuable proteins in their milk eg alpha 1 antitrypsin in sheep (Wright *et al.* 1991) and human haemoglobin in pigs (Sharma *et al.* 1994). In the medium term this may well be the major use of transgenesis in livestock populations.

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