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WOOL METROLOGY RESEARCH GAPS AND INNOVATION

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SUMMARY

This paper summarises an extensive review of research and development in wool metrology to date, in which the research undertaken on wool properties is analysed to identify gaps that might be exploited through the application of new or novel use of technologies by the next generation of wool metrologists. The analysis indicates that although the main fibre/fleece characteristics which currently affect the pricing and trading of Merino wool are able to be readily and accurately measured, there remains considerable work to be done in linking wool measurements to the prediction of performance both in processing and in the final product.

INTRODUCTION

If raw material producers create a commodity with a specific customer in mind they are more likely to stay in business (Galbreath and Rogers, 1999; Chakravarty, 2014; Dessi *et al.,* 2014). Information technology and wool metrology can provide the language for accurate and relevant communication between producers and processors. Growers who make use of this technology are more likely to produce wool which is 'fit for purpose' and hence in demand by the textile trade.

The physical qualities of wool affect the processing route and processing efficiencies, the quality and potential uses of end products, and thus the commercial price of both raw wool and wool textiles (Cottle and Fleming, 2015; Fleming and Cottle, 2015). There are many attributes used for the assessment of wool quality (AWEX, 2015; Teasdale, 1988; Cottle, 2013).

This report is an edited abstract of a part of a recent extensive review published in the *Textile Progress* journal (Cottle and Baxter, 2015), which focussed on work published at the 3 main wool R&D centres in Australia and NZ on the metrology of attributes affecting the processing and textile quality of wool, in particular Merino wool. Whilst much of the raw wool research carried out in the dominant producer countries of the Southern Hemisphere has been presented at IWTO, it should be noted that one of the primary aims of this organisation has been standardisation of sampling and testing to facilitate trade, and therefore most of the work presented at IWTO conferences has been directed towards this aim, rather than pure research *per se*.

Previously, two key South African reviews have been conducted covering developments in wool metrology research and development (R&D). Hunter (1980) examined the effects of wool fibre properties on processing performance and yarn and fabric properties. Botha and Hunter (2010) then reviewed R&D involved with the standardisation of technologies, instruments and important test methods for the global marketing and trading of raw wool. They noted that while metrology R&D is ongoing, it has slowed significantly this century.

An updated ranking of the importance of raw wool characteristics and the availability of relevant test methods is given in Table 1. A higher star rating attracts a greater premium in price because of the respective importance of the effect on processing and/or end product quality creating higher demand for the wool.

Table 1. Ranking of Merino raw wool characteristics and current availability of IWTO test methods *(methods in italics apply only to semi-processed or processed wool)*

Characteristic	**Importance**		**IWTO test methods**
	Worsted	**Woollen**	
Fibre Diameter	*****	*****	*8-2011 (PM)*, 12-2012 (Laserscan), 28-2013 (Airflow), 47-2013 (OFDA) *62-2010 (OFDA4000)*
Yield	*****	*****	19-2012 (wool base)
Vegetable Matter	***	***	19-2012
Staple Length	***	**	30-2007
Staple Strength	***	**	30-2007
Fibre diameter CV	**	*	8-2011 (PM), 12-2012 (Laserscan), 47-2013 (OFDA), *62-2010 (OFDA4000)*
Colour	**	**	*35-2014 (sliver, tops)*, 56-2014 (raw)
Dark Fibres	**	*	*55-1999 (Optalizer, tops)* *DTM-13-1997 (tops), DTM-64-2012 (sliver)*
Style	**	*	
Handle	*	*	*DTM-67-2014 (lightweight knitted fabric)* *ASTM D1388-14 and D4032-08* *(ASTM fabric stiffness – not IWTO)*
Resistance to compression	*	**	AS 3535 (not IWTO)

OBJECTIVE MEASUREMENT

It could be argued that the 5 mm improvement in the difference between achieved and calculated hauteur results, from the TEAM 1 and the TEAM 2 and TEAM 3 studies (Harrowfield, 1996; TEAM-3 Steering Committee, 2003, 2004), was directly attributable to the use of objective measurement. Historically, the developed intuition of very experienced operators has maintained an understanding of the relationship between fibre, processing and product. As processing machinery becomes more sophisticated and consumers more discerning, highly stable and accurate predictions of final products quality are required. Objective measurements provide the language for communication between supplier and consumer, although correlations between some properties may cloud judgments, especially when only a few measurements are specified and their independent implications are not completely understood.

The improved descriptions of Australian wool should help to reduce the historical extremely variable returns that woolgrowers have obtained for their wool clips (Cottle, 2013). One reason for this variability is that wool itself is variable, especially fibre diameter profiles (FDP) along the fibre that are dependent on sheep nutrition (Hansford, 1996) and health, which differ from one season to the next (Litherland *et al.* 1990).

Specification of wool for processing through the objective measurement of fibre properties is required to:

1. Provide the tools for many farm management decisions.

2. Improve sheep breeding programmes
3. Clearly describe the fibre as a sound basis for international trade.
4. Assist or even replace subjective assessment, which is prone to human error, to quantify wool characteristics for gaining a better understanding of their interactions with processing operations, leading to improved process control.
5. Predict processing performance, to improve yields, which allows cost minimisation.
6. Identify potential products.
7. Predict product performance.
8. Put wool on a comparable footing with competing fibres.
9. Allow discrimination between competing fibres
10. Assist with quality control in marketing and manufacture.
11. Encourage new initiatives in wool production, marketing, processing and end product use.

The combined effects of the widespread use of fibre objective measurement of wool sale lots, the desire amongst woolgrowers for more relevant wool quality information for breeding, and the push for higher efficiency and cost effectiveness in textile mills have driven the need to find ways of predicting manufacturing performance from raw wool fibre characteristics. Eleven raw wool characteristics (Table 1) contribute to the prediction of variations in processing performance and end product quality (Cottle, 2013; Lamb and Yang, 1998; Hunter *et al.*, 1982).

While direct measurement is desirable, many methods can provide indirect measures of fibre properties and some give measures of the performance of a subset of fibres. The Projection Microscope (PM), Optical Fibre Diameter Analyser (OFDA) and Laserscan directly measure mean fibre diameter (MFD) in a sample of wool, while Airflow (AF) and Near Infra-Red (NIR) methods measure it indirectly. Measurements which are characteristic of a group of fibres (e.g. staple characteristics, contamination, and crimp/curvature/bulk/resistance to compression) may also be measured directly or indirectly. An important aspect of wool metrology is that all measurements require some sort of checking/calibration process to maintain both measurement precision (scatter or confidence interval) and accuracy (deviation from true value); a process that requires international coordination at IWTO and Interwoollabs.

Experienced wool buyers determine which wools will receive a price premium, and in the past they have relied on intermittent and often vague feedback from those engaged in processing to check or calibrate their performance. However, with objective measurements of known accuracy and precision being made on scoured wool parcels, the emphasis has changed and the measurements themselves are often predicted from greasy wool properties. If the objective properties of a processing parcel are predicted by combining estimates from the blend components made by experienced wool appraisers, the result can be more accurate than a single objective measurement of those properties on the final blend (D. Maddever, unpub. data). Unfortunately, this change to prediction often results in loss of feedback from processing. Considerable work is required to maintain and improve understanding of the relationship between measured fibre properties and processing and product performance, particularly now that fabric properties are increasingly being assessed objectively (Preston et al., 2016; Sanad and Cassidy, 2015)

Accuracy and precision in wool measurement is highly-dependent on sampling. If the sample is not truly representative of the parcel concerned, measurement results, no matter how precise, are useless. However it is also important that the precision used is appropriate for the application. For example, Russell and Cottle (1995) found that when estimating within-bale variance, the confidence interval for MFD for the international bale-sampling standards was larger than the price point intervals traded on by wool buyers. They emphasised that specifying different confidence limits at five micron (micrometre) intervals would provide traders with more information which would enable better discrimination than a single confidence limit for the entire wool MFD range. In another study, Russell *et al.,* (1995) showed that acceptable wool base precision could be achieved with 9-10 cores per lot rather than the prevailing 20 cores per lot, a suggestion which was not implemented, although it should have provided a more economical sampling regimen.

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Changes within the Australian wool industry since the demise of the reserve price scheme allow the following analysis to be put into context.

- In general terms, the size of the Australian wool industry today is less than half of its 1992/3 size (AWTA, 2015).
- In the last 25 years, the rise of China has taken it to the position of dominant buyer and processor accounting for over 70% of auction sales in Australia (AWEX, 2015).
- Broking, warehousing and exporting services have been consolidated.
- The change from the Australian Wool Research and Promotion Organisation (AWRAP) to Australian Wool Innovation (AWI) with a more market- and project-driven approach to the funding of research on a contestable basis (AWI, 2015).
- The reduction in the woolclip volume and value leading to a substantial reduction in wool testing volumes in the major grower countries.
- The contraction of the industry which has led to the decline or demise of specialist instrument builders with significant wool metrology instrument knowledge.

The ranking of the key characteristics of raw wool, given above in Table 1, has targeted the objective specifications that account for more than 80% of the variation in price at auction (Botha and Hunter, 2010). In short, the most important characteristics are now measured (or can be measured) and those that remain untested add proportionally less value to the industry. However, some characteristics can still only be measured on processed or semi-processed wool.

Although much research has been conducted in wool metrology, which is reviewed in detail in Cottle and Baxter (2015), there are, in summary, still several areas where further research could provide some benefit to the wool industry and fill the research gaps, viz;

- Use of spectral-based systems such as NIR or image-analysis processes for yield estimation.
- Determination of the effects of optimising a wider range of parameters on processing performance and yarn properties such as FDPs and fibre curvature. Staple length and strength measurement and their wider application could be further developed with the addition of the crimp meter and perhaps other parameters from ATLAS measurements, such as Decrimped Staple Length, Ratio and Energy at Break, etc.
- The addition of crimp and curvature measurements should help the effects of diameter and length to be more-fully understood.
- Modern high-speed and high-resolution image processing capabilities should enable the development of faster and more-practical methods for a monitoring a range of contaminations in both raw wool and tops.
- There needs to be a test method for soil content of wool
- The pesticide residue test needs to be upgraded to a full test method.
- There is room for improvement in colour metrology by
    - the development of genetic improvements to prevent wool yellowing (Hatcher et al., 2010),
    - helping to create systems for bleaching without reducing photostability and
    - the establishment of a standardised test for photostability.
- Objective fabric handle testing is a relatively new area, and the Wool HandleMeter's capability needs to be expanded to include more fabric types (for instance woven and nonwoven fabrics) rather than just single-jersey knitted fabrics.
- Fabric comfort testing needs to be further explored together with the planned development of yarn testing. Work in this area has already begun, but a robust relationship between the yarn and fabric Wool ComfortMeter results needs to be established to allow the industry to routinely produce high-quality soft yarns.

Examination of the trends in the numbers of papers presented to IWTO since 1945 for the four main parameters describing raw wool (Figures 1-4) are illuminating:

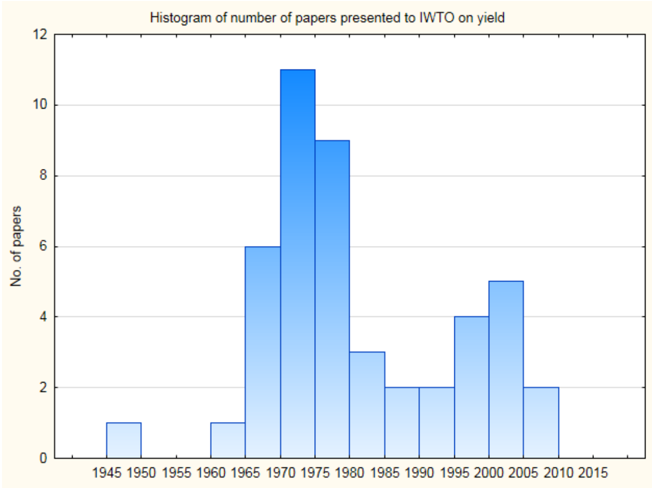

Figure 1. Number of papers presented at IWTO on yield since 1945.

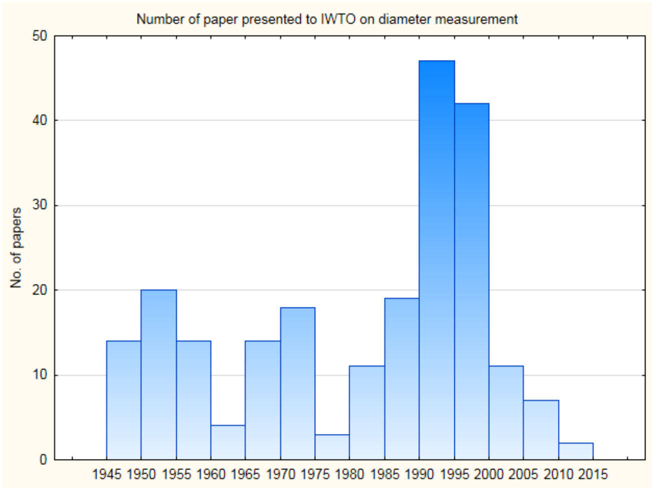

Figure 2. Number of papers presented at IWTO on diameter measurement since 1945.

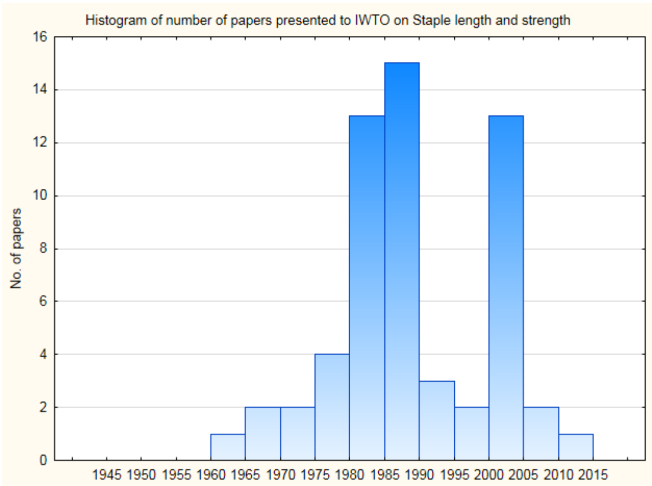

Figure 3. Number of papers presented at IWTO on staple length and strength since 1945.

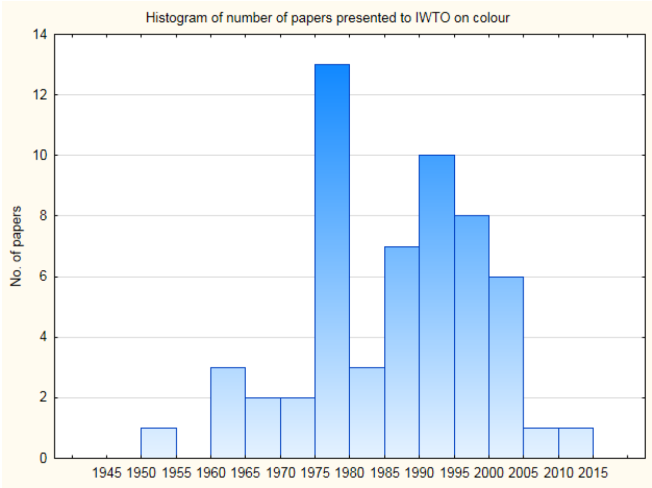

Figure 4. Number of papers presented at IWTO on colour since 1945.

In each case there are two development periods, one connected with the original technology which became written into the test methods, and a second when new technologies became available and attempts were made to improve the methods – some successful, others less so. The original developments were usually undertaken under the aegis of government or industry-funded independent R&D bodies such as WIRA, CSIRO, CSIR or WRONZ or in Universities such as UNSW. As a generalization, the next phase of development was often undertaken by commercial laboratories, seeking to improve their processes. A more critical observation is that since 2005 there has been significantly less published activity and this raises the question as to whether this is because we have reached the limits of development in these measurements, or whether it is related to the new structures and funding mechanisms that have evolved more recently.

Hence, wool metrology R&D cannot be examined in isolation from wider industry developments but rather reflects these changes (Rowe, 2010). The gap analysis clearly identifies areas for further research so it is our opinion that the industry has not reached the limits of development in these measurements. However it is likely that advancement will continue at a slower pace because many of the higher value developments in measurements have already been resolved.

In relation to the impact that changing structures and funding mechanisms in Australia and New Zealand may have on published research activity the following points can be made:

- The number of researchers involved in the wool metrology R&D community is now very small in comparison to the early 1990's.
- The contestability of funding coupled with the move towards private company investment has resulted in a reduction of research being published.
- The funding strategies of the primary wool industry bodies now have a greater emphasis on marketing.

A vast and often confusing economics literature relates competition to investment in innovation (Gilbert, 2006), so it is difficult to assess the impact of this industry structure on the rate of innovation in wool metrology. Following Schumpeter (1976), one view is that monopoly and largeness in scale promote investment in research and development by allowing a firm to capture a larger fraction of its benefits and by providing a more-stable platform for a firm to invest in R&D. Others argue that competition promotes innovation by increasing the cost to a firm that fails to innovate. Key determinants of investment in R&D are the extent of competition in product markets and in R&D, the degree of protection from imitators, and the dynamics of R&D competition. Competition in the product market using existing technologies increases the incentive to invest in R&D for inventions that are protected from imitators (e.g., by strong patent rights). Competition in R&D can speed the arrival of innovations. Without exclusive rights to an innovation, competition in the product market can reduce incentives to invest in R&D by reducing each innovator's payoff. There are many complications. Under some circumstances, a firm with market power has an incentive and the ability to pre-empt rivals, and the dynamics of innovation and competition can make it unprofitable for others to catch up to a firm that is ahead in an innovation race. Interestingly, Bullinger *et al*. (2010) found that a very high, as well as a very low degree of cooperation between competitors resulted in a high degree of innovativeness, while a medium degree of cooperative orientation results in a low degree of innovativeness.

Although it is difficult to draw parallels with other industries whose structures are often quite different, two examples, in which the raw materials are also very variable, and where there is significant testing undertaken to assist trading, are minerals, and other agricultural products. In both cases, it would seem that improvements in testing have resulted largely from the availability of better analytical instruments, more-automated sampling and blending/reduction technology, plus of course, the wider availability of computer networks and information systems. The minerals and other agricultural products industries have the advantage that the raw materials can be blended, homogenized, and reduced by random sampling. The wool industry has also spent considerable time and effort in the area of blending and sampling from the bulk. It has, however, been more difficult for wool compared to minerals and other agricultural products such as grains. The raw material is not easily blended or homogenized, and must retain some of its structural characteristics for a number of the tests to have meaning. It is noteworthy than in both these examples, test methods tend to be developed through either national or international standards bodies, such as ASTM, BSI, DIN, ISO, etc. Additionally, laboratories often have some freedom in the choice of analytical tools, as long as they can show equivalence with a standard method, and finally, there are hundreds, if not more than a thousand laboratories undertaking such tests and thus featuring as "stakeholders". In contrast, the wool industry has test methods that are highly prescribed by an industry body that now depends on its participating laboratories, of which there are only a handful, to maintain or develop these methods. Whilst national standards organizations in Australia and New Zealand played a significant role in the original development of a number of raw wool test methods, due to structural and funding changes this is no longer the case and because of the small market for such standards, they have either been declared obsolete or are being archived.

There is another factor that seems relevant. In both the mining and agricultural trading systems, product specifications have become more comprehensive over time, driven by user needs. For example, power plants need to optimize the performance and environmental consequences of their fuels, and supermarkets need to outperform their rivals and respond rapidly to the changing demands of their customers. In both cases there tends to be increasing demand-driven needs for better specification, which can be transmitted through the system because there are fewer traders in the chain. By contrast, in the wool industry there seems to be inertia in the intervening trading mechanisms, that usually rely on third parties that source their raw materials at various points in the still-lengthy processing chain, and who must each make margins on uncertainty. We have seen, on a number of occasions at IWTO, resistance to new measurement technology, often coming from the trading sector. However, there are two sides to this story. Where there is very wide variation in the properties of raw wool lots, and wide fluctuations in availability through the seasons, tighter or more comprehensive specification makes it much harder to source wools to fit those specifications – thus driving up the price to the end-user without necessarily benefiting the producer. Except for vertically-integrated businesses, it is easy to see why there remains some apparent resistance to change in a wool industry which still, by and large, trades the product separately at several stages in the processing chain.

In the view of Sneddon *et al.,* (2009a) there have been many aspects that have influenced the uptake of innovation in the raw wool industry, including vested interests and politics, that have manifest themselves via "*conflict, coercion, compliance and concensus amongst industry actors*". It has also been suggested, again in respect to the Australian wool industry and considering the impact of '*faddish and fashionable*' technologies, that "*the adoption of inefficient innovations and the rejection of efficient innovations can be driven by the adopter's social context, powerful external influences, and imitation within the adopter group and that these drivers change over time*" (Sneddon *et al.,* 2011). There have been several different socio-economic and political factors (Massy, 2007) at different times that impacted the way in which wool testing innovation has been taken up – some of which might not be regarded as technically logical when divorced from the politics of the day. However, both Sneddon and Massy suggest that such issues are not confined to the wool industry, but have also been found in other agricultural business areas such as pasture utilisation, rice growing, and the adoption of non-traditional crops. The same authors also noted, from an analysis of the uptake of additional measurements by growers, that researchers, policy-makers and technology-developers often lose sight of the fact that in order to maintain momentum with the uptake of new technology, they must not just initially, but continually engage with the users (Sneddon *et al.,* 2009a, 2009b, 2011).

Whilst this report is not about wider issues in the wool industry, improvements in wool metrology can still add benefit to the Merino wool industry. Pattinson *et al.* (2015) commented that it remains critical that the whole supply chain remains focussed on the right product for their chosen market. This has not always been the situation in the past, and it remains the case that producers are often ignorant of the raw materials' specifications required for the end use to which their wool will be put (Champion and Fearne, 2001, 2002; Fleming and Cottle, 2015). It is clear that this needs to change and that the supply chain would then become more transparent. Whilst, as discussed above, there remain areas where the metrology can be improved, it is our view that we now have the capability of providing sufficient measurements on the raw materials to satisfy the vast majority of processor requirements. What is perhaps still missing are the tools required to utilise all of the available measurements in predicting the relevant outcomes from the various processing routes, and, more importantly, to optimise the choice of available lots for specific end-uses. There could be benefits in encouraging more measurement on-farm (Holman and Malau-Aduli, 2012), but observations suggest that the uptake of new measurement technology by most growers has been impeded by their reactions to the simplest of market signals – the direct costs of such services and their current financial returns from wool. There has been some progress in outcome-prediction, with tools such as TEAM 3 (Steering Committee, 2004) and CSIRO's YarnSpec (Yang and Humphries, 2002) but these will need updating, especially for the greater volumes of superfine wool now available (Pattinson *et al.,* 2015; Powell, 2013) and, more importantly, the trading environment needs to change to encourage their use. Performance prediction may also need to look further downstream to the fabrics (Preston *et al.*, 2016). As the pressures in Australia to consolidate wool selling arrangements increase, greater use will have to be made of "sale by description", and hence the measurement or visual recording of style will need to be revisited. Some of these issues are being considered in depth during AWI's contracted review of the wool selling system, which was due for release towards the end of 2015 (AWI, 2015b).

There are a relatively small number of active researchers remaining in the wool metrology field, from its heyday when the three southern hemisphere organisations, UNSW, CSIRO and WRONZ had around 1000 staff in total involved in wool-related research activities. Our report has analysed gaps in research for all wool properties that might be exploited by new technology or novel use of existing technologies by the next generation of wool metrologists. Whilst not explicitly referred to in the review, the industry as a whole needs to consider how common-good R&D is going to be directed and funded, since this appears to be becoming a significant stumbling block to better utilisation of the enormous amount of good work that has already been done.

Readers are referred to the full review in Textile Progress, Volume 47(3), pages 163-315, for more detail of past and current R&D.

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