FINAL REPORT

(due within 3 months on completion of project)

Part 1 - Summary Details

Cotton CRC Project Number: 4.01.02

Project Title: **Support and extension of SiroMat (Generation I)**

Project Commencement Date: 1/7/2007 **Project Completion Date:** 30/6/2009

Cotton CRC Program: Value Chain

Part 2 – Contact Details

Administrator: Jo Cain

Organisation: CSIRO Plant Industry

Postal Address: Locked Bag 59, Narrabri NSW 2390

Ph: 02 6799 1513 **Fax:** 02 6793 1186 **E-mail:** jo.cain@csiro.au

Principal Researcher: Dr Stuart Gordon

Organisation: CSIRO Materials Science and Engineering

Postal Address: PO Box 21. Belmont VIC 3216

Ph: 03 5246 4000 **Fax:** 03 5246 4057 **E-mail:** stuart.gordon@csiro.au

Supervisor: Dr Geoff Naylor

Organisation: CSIRO Materials Science and Engineering

Postal Address: PO Box 21, Belmont VIC 3216

Ph: 03 5246 4000 **Fax:** 03 5246 4057 **E-mail:** geoff.naylor@csiro.au

Signature of Research Provider Representative: ______________________________

Part 3 – Final Report Guide (due within 3 months on completion of project)

Background

The aim of this project was to continue the technical support effort required to promote and demonstrate the SiroMat for research and commercial testing purposes. Promotion of the instrument was aimed towards potential licensees, i.e. future manufacturers and marketers of SiroMat, and end-users of SiroMat. Potential licensees were identified as Uster Technologies (USA), Premier Evolvics (India) and BSC Electronics (Australia). It was proposed that end-users of SiroMat could range from plant breeders at CPI to classing houses (in Australia and overseas) and spinning mills (overseas).

Licensees were sought early in the project. Meetings and presentations were given to Uster Technologies and Premier Evolvics in Germany during March 2008, following a year of communication with Uster Technologies on applications of SiroMat. No firm commitments emerged from these meetings and communications. In May 2008 the SiroMat was shown to BSC Electronics (Perth WA), who indicated a firm interest in SiroMat and the cotton test instrument market. BSC Electronics visited the Australian Cotton Conference in August 2008 in order to gauge the potential of SiroMat from Australian end-users, e.g. merchants and researchers. They showed their OFDA1000 (an instrument for measuring wool fibre diameter) alongside the SiroMat at the CRC Stand at the Conference Tradeshow (see Appendix 1).

Formal expressions of interest for SiroMat were sought from the three companies in September 2008 (see Appendix 2). The winning tender was submitted by BSC Electronics (see Appendix 3). Interviews with BSC Electronics around commercialisation commenced in November 2008. A Term Sheet detailing key terms for commercial agreement between BSC Electronics and CSIRO for the commercialisation of SiroMat was written and sent to BSC Electronics for response in late December 2008. Subsequent negotiations resulted in the licensing agreement being formalized and signed in June 2009. A CMSE built SiroMat instrument was loaned to BSC Electronics in July 2009.

At the time of writing this report BSC Electronics has successfully built a new SiroMat prototype (now called Cottonscope) that is faster (within 1 minute) and will likely include measurement of other fibre attributes such as ribbon width and linear density, as well as fibre maturity. Two replicate Cottonscopes are expected to be delivered to CMSE for testing in November 2009.

At the same time as commercial negotiations were being carried out a wide range of research was conducted to demonstrate the value of SiroMat data in various applications, from the study of fibre development to predicting dye uptake. Work on measuring and achieving good reproducibility between instruments was not completed, largely because of time constraints, although the reasons for inconsistent instrument results and solutions to them were identified.

Project Objectives

The stated objectives of the project and whether they were achieved are listed in Table I below.

Table I – Project objectives, milestones, performance indicators and achievement

Objective	No.	Milestone	Performance Indicator	Achieved
Complete business case for commercial assessment and development of technology	1.1	Business case completed	Business case submitted to CRDC	✓
Achieve acceptable inter-instrument & inter-laboratory variation between instruments	2.1	Check colour transmission of optical components	Optical components transmit same visible wavelengths	✓
	2.2	Inter-instrument variation remains acceptable	Inter-instrument means for all SiroMat measurements are within 95%CI	**Not tested**
	2.3	Prepare operation manual for SiroMat	Manual available to new users of SiroMat (see objectives 2 and 3)	**NA**
One instrument used to assess maturity of new (premium) breeding lines at ACRI	3.1	Locate one SiroMat instrument at ACRI	Locate one SiroMat instrument at ACRI for assessment of 2007 and demonstrated by 2008 breeding trials	✓ Instrument located at CPI for end of 2007 season. Currently assessing 40 2008 breeding lines at CMSE.
	3.2	Confidential report to CRDC/CCC CRC on SiroMat performance in assessing new breeding lines	SiroMat utility is defined by its ability to distinguish between breeding lines on basis of maturity, maturity distribution and fineness	**Not achieved** Breeding lines in Linking Farm Systems project are measured with SiroMat
One instrument used to assess mill contracts by merchant	4.1	Locate one SiroMat instrument in merchant classing room	Locate one SiroMat instrument with merchant for assessment of 2007 and 2008 grower cotton and mill contracts	**Not achieved** Chinese mill contracts for the CRC Cottonspec project are measured using SiroMat
	4.2	Confidential report to CRDC/CCC CRC/merchant (ACSA) on SiroMat performance in assessing grower cotton and mill contracts	SiroMat utility is demonstrated by its ability to distinguish varieties and mill contracts on basis of maturity, maturity distribution and fineness	**Not achieved** SiroMat ability is demonstrated but not applied widely as per the objective
Demonstrate ability of SiroMat data to predict and manage spinning mill quality, particularly with regards to avoiding barre in dyed knit fabric	5.1	Collect range of cottons (100 g per sample) with similar micronaire but with different fineness and maturity values	Set of cottons collected and described by micronaire, SiroMat, Cottonscan, AFIS PRO and FMT	✓
	5.2	Prepare and spin 20 tex knit yarns on miniature short-staple spinning plant	Yarns spun from each fibre sample and ready for knitting	✓
	5.3	Knit continuous fabric samples from yarn samples	Knit fabric samples ready for dye uptake trials	✓

	5.4	Dye knit fabric samples	Knit fabric samples dyed and ΔE (colour differences) calculated	✓
	5.5	Preparation of report	Trial demonstrates SiroMat ability to differentiate cotton fibre samples on basis of maturity and dye uptake (barre patterns in fabric)	✓
Use SiroMat to measure cotton fibre development from initiation at flowering to harvest	6.1	See objectives within project CRC130	See objectives within project CRC130	✓

Methods
A series of studies were conducted to demonstrate the value of SiroMat in understanding the management of fibre quality in terms of plant physiology, agronomic and crop physiology and in spinning mill management. Typically, each study was written up into a formal paper for presentation at a conference or publication in a peer review journal. Titles of relevant papers appear under each project objective heading (see below) in lieu of a detailed description of methods used to achieve each objective.

Methodologies for research into the source of instrument variation are described under the objective for this work.

Application of SiroMat to industry uses, e.g. its use in an Australian classing house samples was not undertaken because of time constraints, although the instrument was used to assess fibre bought for the Premium Cotton Initiative (PCI) and Cottonspec projects. Data from the Cottonspec project is described in this report.

The SiroMat was extended to CPI breeders and agronomists at the ACRI for a short time in 2007 but the slow test throughput of the instrument at that time limited its value for the proposed work.

Results and Outcomes
Where research has been published or reported the appropriate reference is listed under the particular objective heading with the full paper appended to this report.

A list of all publications including those 'in press' and 'in preparation for submission' appears at the end of the report.

Complete business case for commercial assessment and development of technology
SiroMat Business Case – Appendix 4

Achieve acceptable inter-instrument & inter-laboratory variation between instruments
Poor SiroMat inter-instrument and hence inter-laboratory variation was identified in the previous SiroMat project; CRC Project 4.04.02 'Commercial Preparation of SiroMat'. Variation between instruments is associated with differences arising from:

- Colour temperature differences and variation over time in the SiroMat light source;
- Absorbance differences between retardation plates used in polarized light microscopy to accent the interference colours and;
- Camera CCD responses.

In work towards characterising and rectifying these differences, snippet images and background were measured using a spectrometer with an optic fibre pointed to the SiroMat field of view (fov). By positioning the optic fibre at the primary image plane of the SiroMat (transmission light) microscope information on whole fov colour differences as a result of changing the above factors could be measured and assessed. Figure 1 shows a typical SiroMat fov.

Investigations showed small changes in colour temperature and/or absorbance change the order and intensity of interference colours viewed and captured by the instrument, which in turn affect the measured maturity result. These differences can be reduced by a combination of actions including:

- Choosing components, e.g. light bulbs and retardation plates, on the basis of consistent and constant transmission of spectra and;
- Normalizing the camera RGB response to the colour of each instrument's light source and mathematically adjusting the fibre image 'filtering' and 'colour to fibre maturity' algorithms so that measured fibre maturity results coincide with given standard results.

Work and current understanding around each of these points is discussed below.

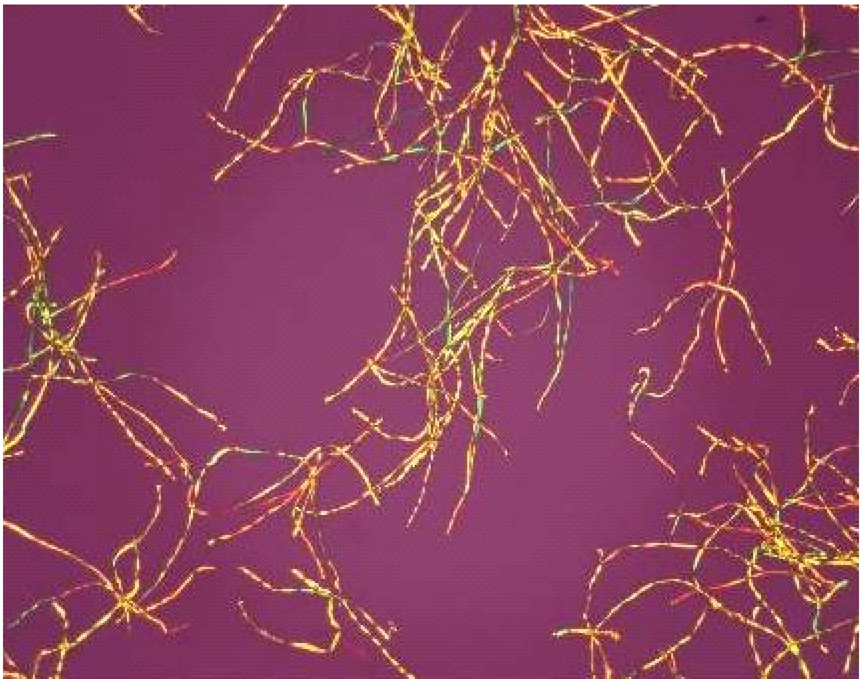


Figure 1 – Mature 1 mm fibre snippets in the SiroMat fov ~9 mm^2.

Choosing components on the basis of consistent and constant transmission of spectra

Figure 2 shows the effect of varying LED light intensity on the interference colour spectra. Previously we have noted significant movement in the colour temperature of halogen bulbs, which has affected instrument accuracy and precision over time. In 2008, the halogen light sources (dichroic bulbs) were replaced with a small LED lamp, which have proved more stable in colour temperature. The Figure shows that when the LED light intensity (amplitude) is decreased there is little or no movement in the spectral pattern or ratio of wavelengths. Work reported at the Beltwide Cotton Conferences in 2009 also showed the stability of this light source over time (see publication 6).

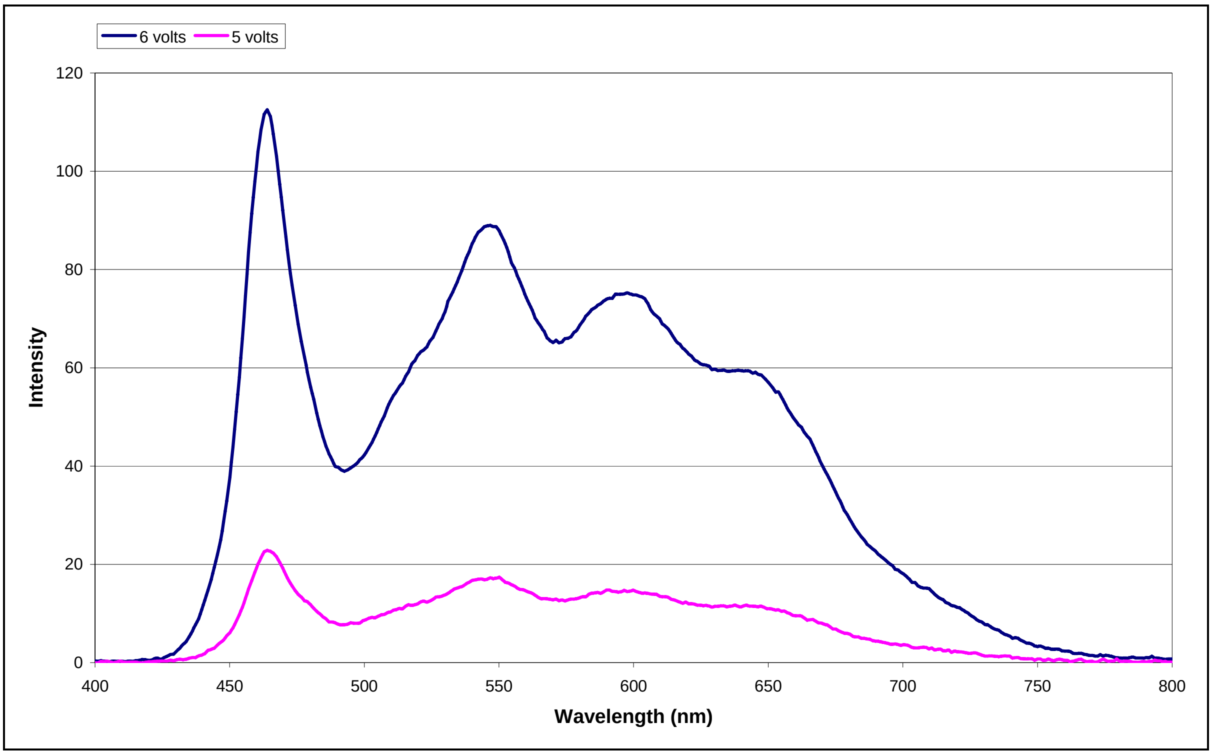


Figure 2 – LED spectra changes at two lamp intensities (5 V and 6V).

Figure 3 shows the spectra of retardation plates (RP) that are different in terms of their absorbance properties. The differences between RP3 and RP1 and 2 are significant enough to cause large variation in the hue of snippets and therefore in the reported maturity result. The differences in these plates are a result of their manufacture from different materials; RP3 is made from a polymer material that varies in its crystalline order across the area. RP1 and 2 are made from crystalline Selenite ($CaSO_4.2H_2O$) to tighter tolerances. The differences between RP1 and RP2 are small enough to make these plates inter-changeable between instruments without affecting the reported maturity result.

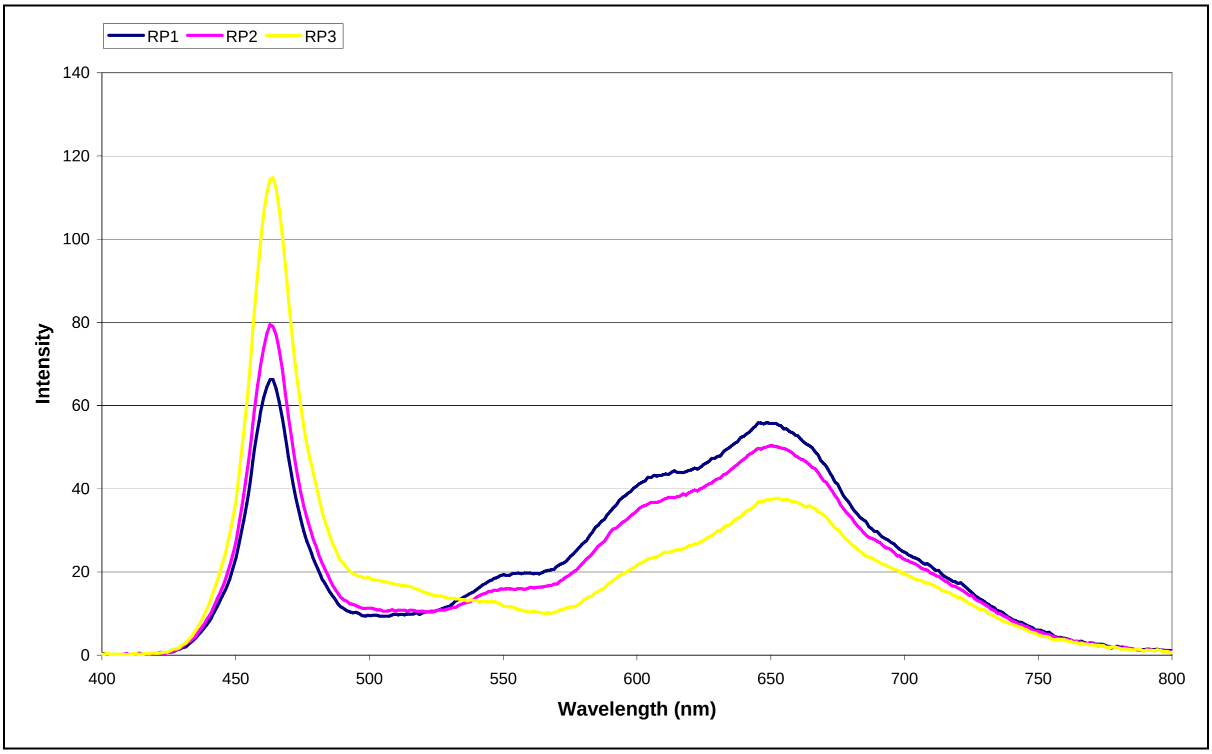


Figure 3 – Absorbance spectra of three retardation plates; RP1 and RP2 are crystalline plates of same specification; RP3 is a polymer plate

Figure 4 shows the effect on colour, this time measured in term of the camera's CCD response as RGB values, when the intensity of the halogen light (dichroic bulb) source is varied through two matched retardation plates. The plot shows large, disproportionate changes in RGB values 'seen' by the camera as light intensity is changed. This figure contrasts with Figure 2, which shows the LED light source maintains good proportionality at each wavelength as intensity is changed.

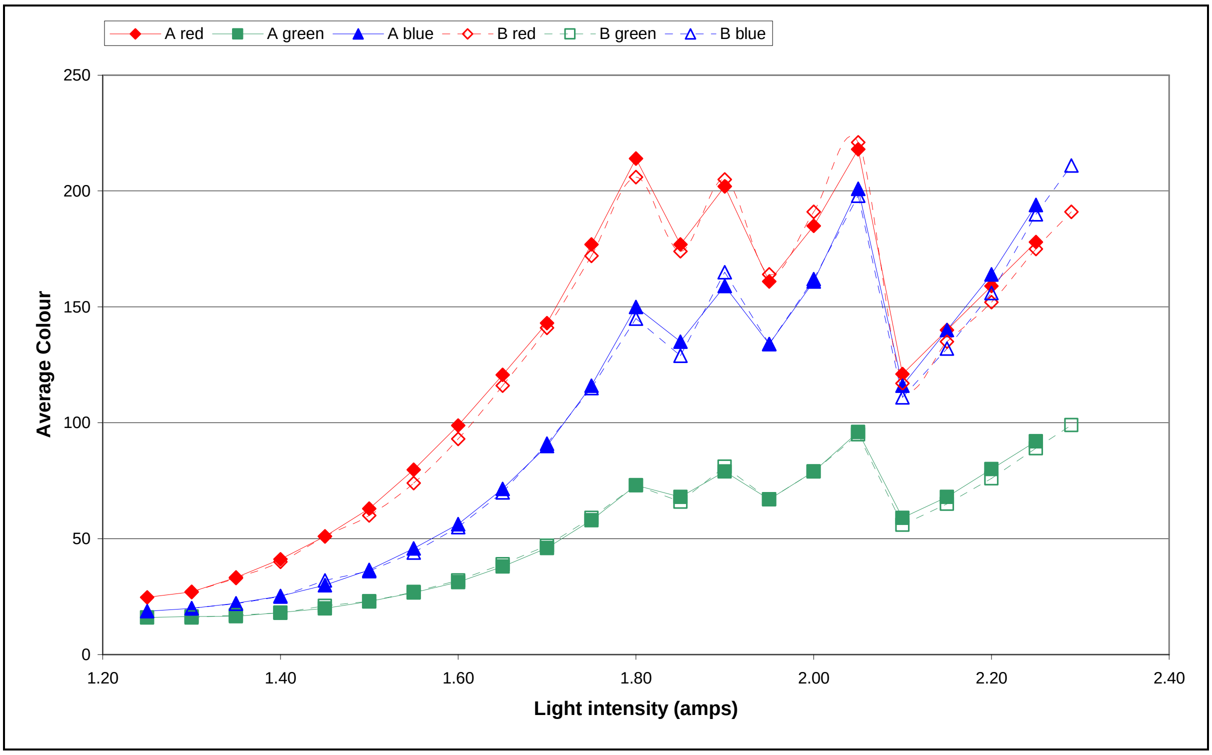


Figure 4 -

Normalizing the camera RGB response

Figure 5 shows hue values from 6 Wratten filters (yellow, deep red, magenta, cyan, blue and deep green) measured on two SiroMat instruments (SM1 and SM2) each without their bottom polarizer and retardation plate. The RGB camera values for the six Wratten filters were normalized to the light source of each microscope (rgb), which was used as the white reference. The rgb values were then converted to values within the hsv colour space to produce a hue value. The graph of hue values shows good agreement between each instrument.

Applying this treatment to the full SiroMat set-up, the camera CCD of each instrument is exposed to a standard background, which is obtained using the following protocol:

- Expose camera CCD to an instrument set-up whereby bottom polarizer is aligned parallel with top polarizer, i.e. light is polarized and able to be transmitted in one plane through system.
    - Camera shutter is adjusted to make each RGB response the same.
- Bottom polarizer is then returned towards the 90 degree crossed orientation until one of the RGB responses is maximized.
    - The camera U and V settings are then used to make the other RGB values the same. At this point the fov colour should be grey.
    - The camera shutter is opened until each RGB response is maximized.
    - An image of this background 'colour' is then saved.
- The camera CCD response is then normalized to the RGB values of the saved background to give rgb, before conversion to digital hsv values.

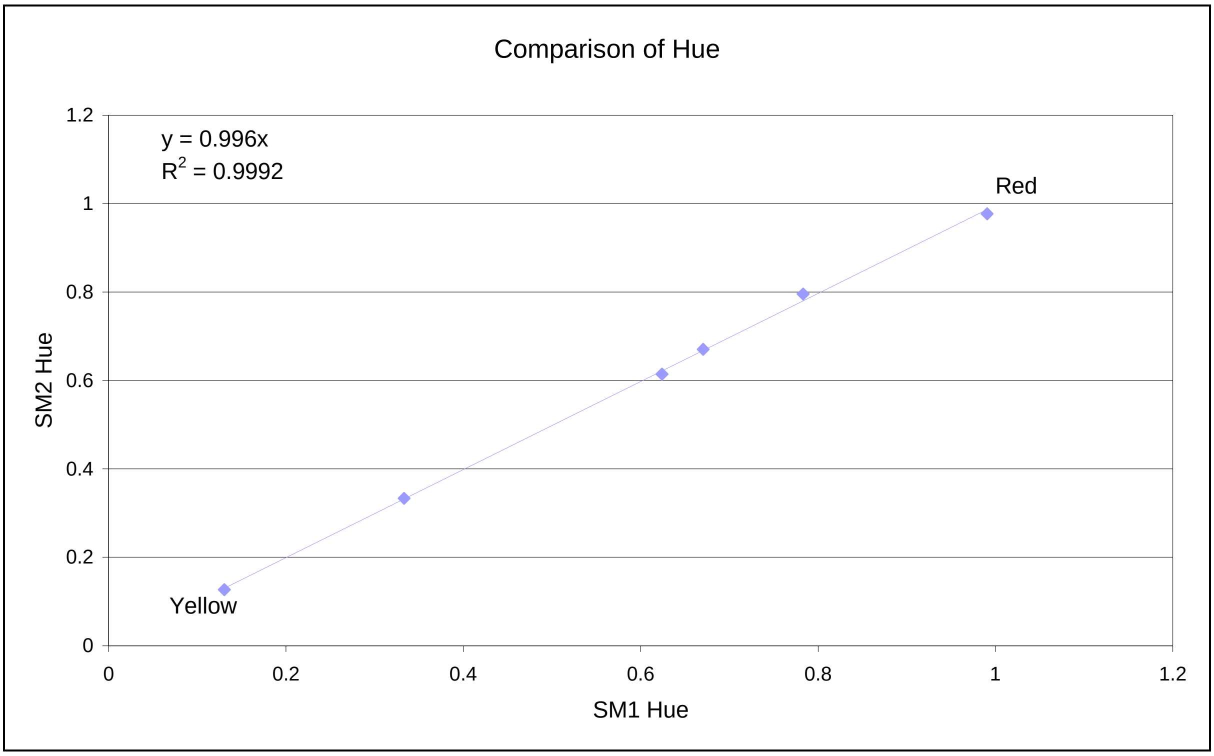


Figure 5 – Comparison of the hue perception of two digital cameras used by SiroMat after normalisation (white balance) to the microscope light source.

Mathematically adjusting the image 'filtering' and 'colour to fibre maturity' algorithms

It was noted that unfiltered yellow (and green) hsv colour test results of the same sub-set (12 samples representing a wide range of fibre maturity values) of ITC samples[1], on SM1 and SM2 normalized according to the protocol above, were well correlated and proportionally similar (see Figure 6). However, when the fibre image results were filtered on the basis of snippet size, i.e. snippet images these correlations disappeared (see Figure 7). The poor correlation is a result of images with aspect ratios (pixel length of major axis/pixel length of minor axis) less than 30 being rejected from the analysis. This was a condition applied to images of earlier versions of SiroMat, which used a higher light intensity to illuminate fibre snippets. Our interpretation of this affect is that using the normalized background protocol means the light intensity used to illuminate the specimen is now reduced. This affects the boundary recognition algorithms and results in greater fragmentation of images, which in turn produces more snippet images with aspect ratios less than 30.

The lower light intensity and background protocol also affects the percent green (%G) area measured in SiroMat images and consequently the influence of %G area as a co-predictor of fibre maturity. Previously, when lamp intensity was set higher %G values ranged from 4% to 7% for 'immature' samples to 3% to 4% for 'mature' samples. Whilst this is not a wide range, and therefore the %G value does not have a strong influence on maturity prediction, the %G value enforces a selection criterion for fibres that have an average maturity. This is on the basis that immature fibres transmit can transmit some yellow colour but no green interference colour. Equation 1 represents the standard conversion algorithm for earlier versions of SiroMat.

$$\text{Maturity Ratio} = 2.4543\%Y - 1.078\%G - 0.3323 \qquad (1)$$

Currently, with the revised colour normalizing protocol and dampened light intensity the %G has been removed from the conversion algorithm. After this change %G values fell from

[1] ITC are the 104 International Textile Center cotton fibre maturity reference samples

between 3% to 7% to 0.1% to 1.4%. In comparison, %Y fell from between 38% to 65%, to 23% to 50% a change in the average %Y but not the range (see also Figure 6). Equation 2 is now used to convert %Y values to maturity ratio values.

Maturity Ratio = 2.593%Y - 0.274 (2)

Percent colour values are still equated with maturity ratio values obtained using the ACRI and USDA Shirley Fineness and Maturity Testers in the previous SiroMat project; CRC Project 4.04.02 'Commercial Preparation of SiroMat'. However, the conversion equation values of maturity and %Y appear to correlate reasonably well with maturity ratio values from the ITC set of cotton maturity reference samples. Analysis of the correlations with ITC reference data appears in the Beltwide Cotton Conference paper entitled 'The Accuracy and Precision of the SiroMat' presented in January 2009 (see Appendix 5).

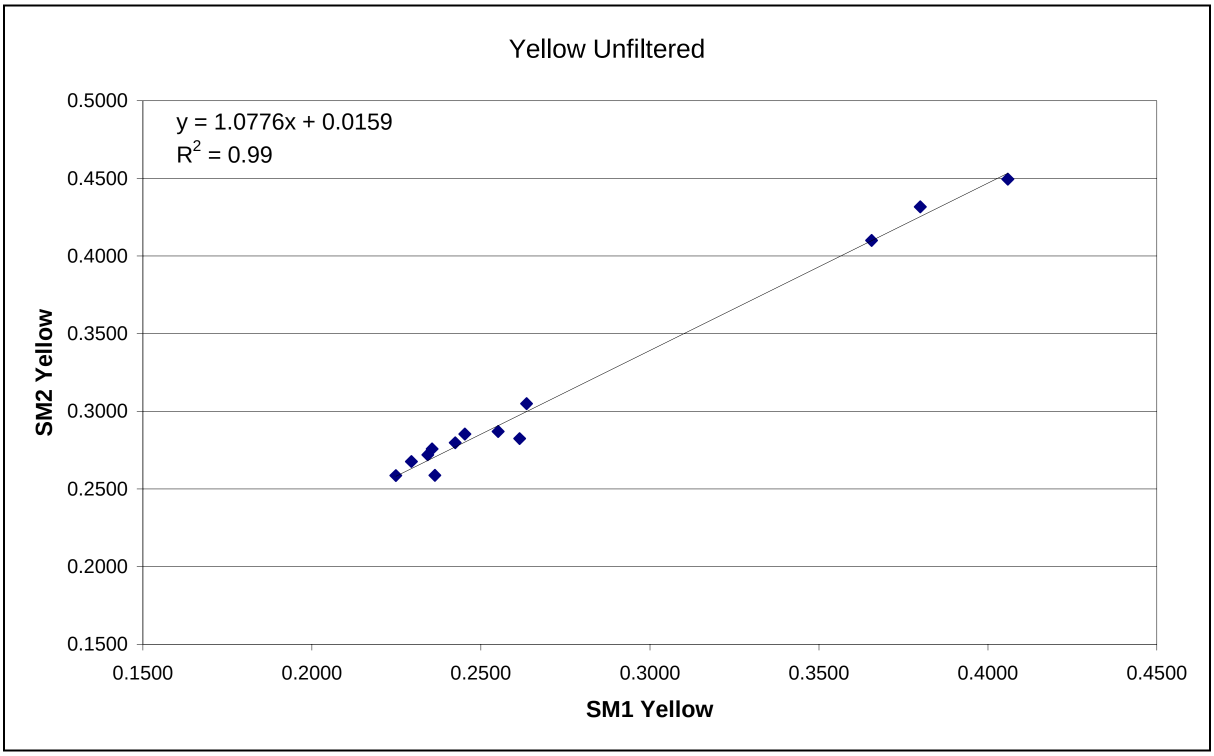


Figure 6 – Unfiltered yellow values by SM1 and SM2 for 12 of the 104 ITC fibre maturity reference samples

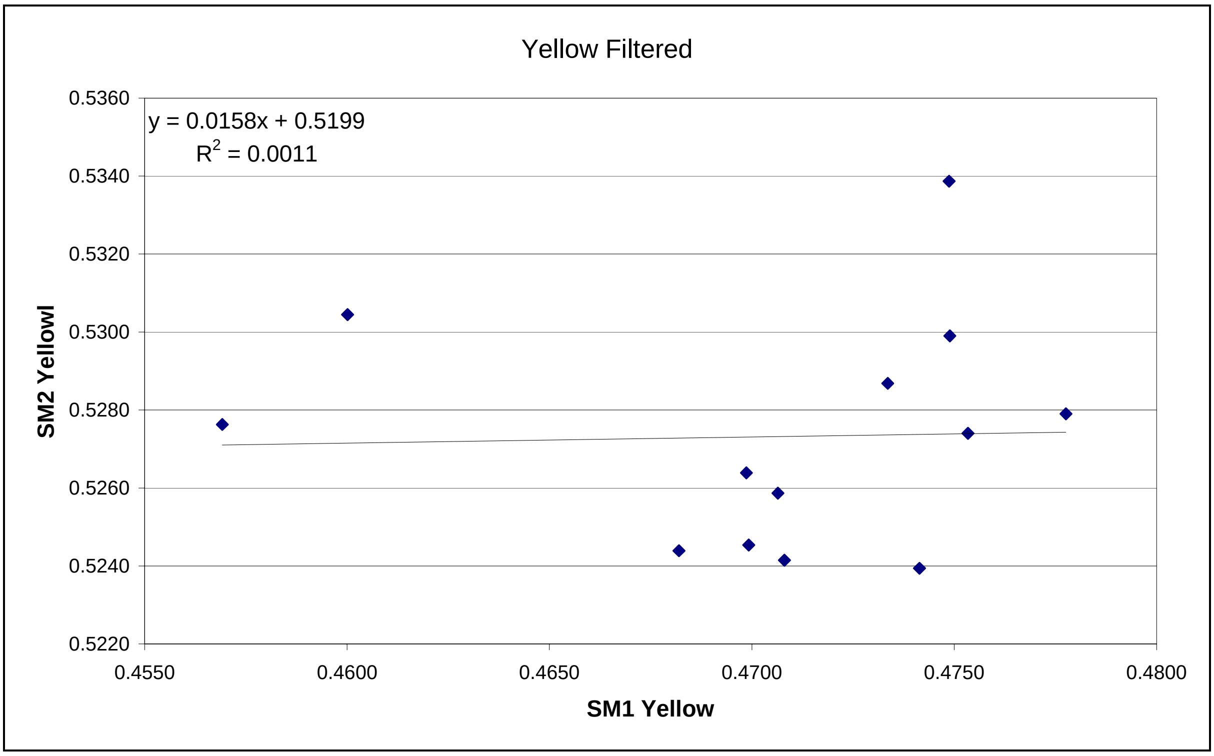


Figure 7 – Filtered yellow values, i.e. only images with AR > 30 are analyzed, by SM1 and SM2 for 12 of the 104 ITC fibre maturity reference samples

One instrument used to assess maturity of new (premium) breeding lines at ACRI

The SiroMat was extended to CPI breeders and agronomists at the ACRI for a short time in 2007 but the slow test throughput of the instrument at that time limited its value for the proposed work.

The instrument was re-located back to CMSE where it was used to test samples for the CRC Project 4.02.01 'Linking Farming Systems to Fibre Quality and Textile Performance'. The application of SiroMat to samples examined in this project is well documented in the final report of that project. Several formal publications (peer review and conference proceedings) describing the extent of SiroMat's use in this area appear in the publication list at the end of this report.

By way of example, Figure 8 shows the influence of maturity ratio measured by SiroMat, fineness or linear density measured by Cottonscan and Micronaire by HVI of new cultivars from CPI's Breeding Program on yarn strength. This graph is from a paper submitted in 2009 to Crop and Pasture Science (see Publication 1).

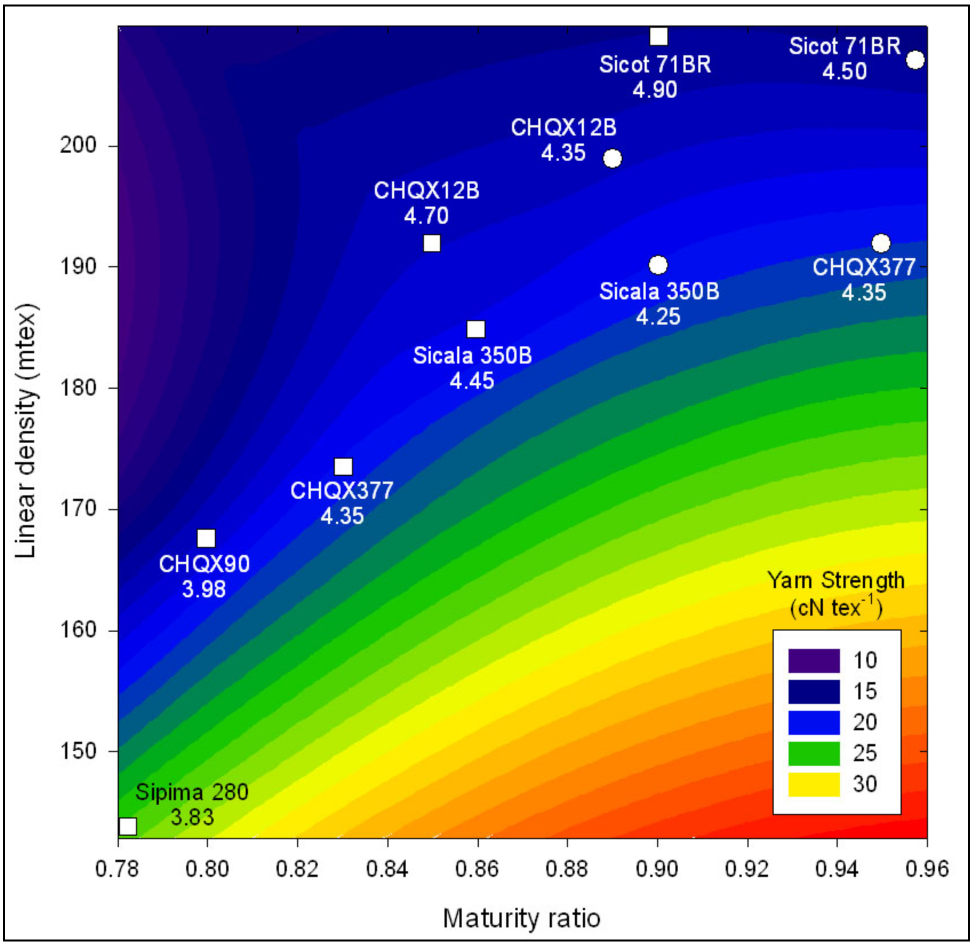


Figure 8 - Graphical representation of the effects of Micronaire and its influencing components (linear density and maturity ratio) on carded 20 tex yarn strength for genotypes in Exp. 1 (2005/ 2006) (○) and Exp. 2 (2006/ 2007) (□). Note the differences in yarn quality, fibre linear density (fineness) and maturity ratio, of some genotypes with similar Micronaire.

One instrument used to assess mill contracts by merchant

No instruments were extended to merchant classing laboratories due to time constraints and the relatively slow test time (~ 2.5 minutes/sample). It is hoped that the local merchants will be interested in BSC Electronics' Cottonscope, which will be faster (< 1 minute/sample) and simpler to operate in the classing situation.

In lieu of testing classing samples the SiroMat was applied to cotton used by Chinese spinning mills co-operating with CSIRO as part of the CRC Cottonspec project. Table II below shows the SiroMat, Cottonscan and HVI properties of cotton (laydown) samples used by three Chinese mills. SiroMat and Cottonscan measurements were performed at CMSE whilst HVI measurements were performed by Auscott Classing Services, Artarmon NSW. Notable is that nearly all export growths are measured as being relatively immature by SiroMat, and independently by calculation using Cottonscan and HVI Micronaire. This information is interesting in light of local hesitation to use SiroMat less it show Australian cotton as being immature. The information shows that all export cotton, including Xinjiang Chinese cotton, used by the mills leans to the immature side, i.e. the average maturity ratio value is < 0.85, which is accepted as a cut-off point between mature and immature. The results here fit with the production systems used by growers in the Xinjiang Province and in each of the export countries, i.e. high production systems and once over harvest.

The SiroMat is also currently being used to assess the 2008/09 crop samples being measured for neps as part of the CRDC Nep Survey Project. Calculated values of maturity by

Cottonscan and HVI Micronaire on samples collected for the 2006/07 and 2007/08 seasons have shown similarly low maturity levels as those in Table II.

Table II – Average fibre properties of laydown samples from three Chinese mills

	Maturity	Fineness	Micronaire	Length	Uniformity	Strength	Extension
China	0.73	195	3.88	1.14	82.4	30.0	6.8
Australia	0.75	214	4.04	1.13	82.9	31.0	7.5
Brazil	0.72	196	3.88	1.14	82.7	31.4	7.4
USA	0.78	202	4.26	1.13	82.3	29.8	6.4

Demonstrate ability of SiroMat data to predict and manage spinning mill quality, particularly with regards to avoiding barre in dyed knit fabric

This work was written up and presented at the 2008 Beltwide Cotton Conferences in New Orleans (see Appendix 6). The work showed the main value of fibre maturity measurements by SiroMat were in predicting dye uptake. SiroMat was able to pick up relatively subtle differences in dye uptake differences ($\Delta E < 1.0$) caused by small differences in fibre maturity (< 0.05 maturity ratio units). Maturity had little effect on yarn properties in this set, although linear density calculated using SiroMat maturity and HVI Micronaire values correlated strongly with yarn properties.

Use SiroMat to measure cotton fibre development from initiation at flowering to harvest

A study was completed where fibre development from cotton plants grown in a glasshouse was measured from 24 days post-anthesis (dpa) using SiroMat. This work was written up as a peer review paper in the Textile Research Journal, where currently it is in press (see Publication 2). The abstract from this paper serves as a summary of this work.

'Cotton fibers are trichome cells composed primarily of cellulose. Mature fibers have more cellulose and a greater degree of cell wall thickening, and perform better than less mature fibres during textile processing. An automated polarized light microscope instrument called SiroMat that measures cotton fiber cell wall thickening was employed to assess the maturity of developing fibers from single cotton fruit. Fruit were taken from the first fruiting branch and position on glasshouse grown *Gossypium hirsutum* L. (Upland) and *G. barbadense* L. (Pima) plants, sequentially harvested from 24 days post-anthesis (dpa) at approximately four day intervals up until approximately 50 dpa. The instrument assessed an average of 13,000 fiber snippets per fruit. Upland fibers matured at a slower rate than Pima fibers up to 35 dpa. However, after 45 dpa Upland fibers had achieved a higher average maturity [i.e. 0.99 birefringence maturity index (BMI), cf. 0.79 for Pima]. For both species the uniformity of fiber maturity increased as fibers matured up until 35 dpa for Upland and 29 dpa for Pima (i.e. the BMI coefficient of variation decreased as BMI increased during fruit development). It is envisaged that SiroMat will be a useful tool in helping to understand and manage fiber maturity by characterising the maturation dynamics of cultivars with different inherent fiber properties, and for cultivars subjected to different environmental and agronomic conditions.'

Conclusion

The aim of this project was to continue the technical support effort required to promote and demonstrate the SiroMat for research and commercial testing purposes.

The instrument was successfully licensed to BSC Electronics mid-way through 2009 after more than a year of promotion and negotiation with BSC Electronics and other cotton fibre instrument manufacturers. The licensing to BSC Electronics represents a good outcome for the SiroMat technology. The company is a small Australian enterprise with an excellent track record in taking fibre testing instruments to market. They will add to the SiroMat technology by making it quicker and easier to use from the opertors perspective. The addition of several new measurements such as ribbon width and linear density has also been discussed. BSC Electronics will deliver a new prototype of the instrument to CMSE before the end of this year to allow testing. BSC Electronics have also submitted a paper to the 2010 Beltwide Cotton Conferences introducing the new prototype, which they are calling Cottonscope.

A number of studies were carried out to demonstrate the value of the SiroMat instrument in being able to measure small specimens, e.g. specimens < 1,000 fibres, that otherwise would be difficult to measure, and in providing clear and accurate maturity values of samples for the purposes of predicting fineness and/or dye uptake. The use of SiroMat as a selection tool for new cultivars generated by the breeding team at CPI did not eventuate due to time constraints and the slow speed of the SiroMat instrument at the time. However, selected cultivars were tested at CMSE as part of the 'Linking Farm Systems' project and the results of these test have been reported in various peer review journals and conference proceedings. It is envisaged that the new Cottonscope test will be able to be applied in the future to cultivar selection, and to bale selection by merchants.

Extension Opportunities

During the course of this project the SiroMat instrument was successfully licensed to BSC Electronics. Work remains to extend the value proposition for SiroMat (Cottonscope) to the wider research and testing community. In this regard, the new CRDC/CRC project will be used to conduct this extension both here in Australia and internationally.

During the course of this project presentations were given to:

- ACGRA, Moree Australia, February 2008
- Beltwide Cotton Conferences, Nashville, USA January 2008
- Bremen International Cotton Conference, Germany, March 2008
- Australian Cotton Conference, Gold Coast, Australia, August 2008
- CCC CRC Science Forum, Narrabri, Australia October 2008
- ACSA, Sydney, Australia November 2008
- Beltwide Cotton Conferences, San Antonio, USA January 2009
- CSIRO Cotton Fibre Workshop, Canberra, Australia July 2009
- CRDC Post-Harvest Forum, Narrabri, Australia, August 2009

Publications

Refereed (peer review)

1. Long R.L., Bange M.P., Gordon, S.G., van der Sluijs, M.H.J., Naylor, R.S., and Constable G.A. (2009). Fibre quality and textile performance of some Australian cotton genotypes. In preparation for submission to Crop and Pasture Science

2. Long, R.L., Bange, M.P., Gordon, S.G., and Constable, G.A. (2009). Measuring the maturity of developing cotton fibres using an automated polarised light microscopy technique. Textile Research Journal. In press.

Conference papers

3. Gordon, S. G., Long, R. L., Lucas, S. R. and Phair-Sorensen, N. L., Using SiroMat to distinguish fibre maturity related issues in the mill, *proceed.* Beltwide Cotton Conferences, National Cotton Council, Nashville TN, Jan 2008.

4. Long, R. L., Bange, M., Gordon, S. G. and Van der Sluijs, M. J. H., The effect of different harvest aid timing treatments on fibre quality and textile performance, *proceed.* Beltwide Cotton Conferences, National Cotton Council, Nashville TN, Jan 2008

5. Gordon, S. G. and Naylor, G. R. N, Cotton fibre linear density and maturity measurement and application *proceed.* 29th International Cotton Conference, Bremen Germany, Apr 2008 (*invited paper*).

6. Higgerson, G. H., Gordon, S. G., Lucas, S. R. and Phair-Sorensen, N. L., The accuracy and precision of the SiroMat instrument for measuring cotton fibre maturity, *proceed.* Beltwide Cotton Conferences, National Cotton Council, San Antonio TX, Jan 2009.

7. Gordon, S.G., Long, R.L., Naylor, G.R.S. (2009) The measurement of cotton fibre linear density and maturity and its potential value to textile processing. Textile Institute Conference, NZ, In Press

Other

8. Van der sluijs, M., Gordon, S.G. and Long, R. (2008) A spinner's perspective on fibre fineness and maturity. The Australian Cottongrower. 29(no. 1), 30-32.

Part 4 – Final Report Executive Summary

SiroMat is an instrument that measures cotton fibre maturity directly and accurately. It was developed by CMSE with financial support from the CRDC and CCC CRC. Its advantage over other test methods is that it measures maturity directly and is able to measure the fibre-to-fibre distribution of maturity in a specimen. During this project a license to manufacture and market SiroMat was sold to an Australian SME (BSC Electronics) with a good track record in instrument development and manufacture. The licensing agreement was signed in June 2009. A new prototype of the SiroMat instrument has already been built (now called Cottonscope) by BSC Electronics and trials of it are planned for later this year.

During this project a number of studies were undertaken to demonstrate the value of SiroMat and SiroMat data to a variety of end-users from research agronomists interested in monitoring and measuring fibre development in immature bolls to spinners requiring more information to predict dye uptake and yarn quality.

Appendix 1
Press release for Australian Cotton Conference (August 2008)

Appendix 2
CSIRO Expression of Interest (EOI) call (September 2008)

Appendix 3
SiroMat tender document BSC Electronics (October 2008)

Appendix 4
SiroMat Business Case (August 2007)

Appendix 5
Higgerson, G. H., Gordon, S. G., Lucas, S. R. and Phair-Sorensen, N. L., The accuracy and precision of the SiroMat instrument for measuring cotton fibre maturity, *proceed.* Beltwide Cotton Conferences, National Cotton Council, San Antonio TX, Jan 2009

Appendix 6
Gordon, S. G., Long, R. L., Lucas, S. R. and Phair-Sorensen, N. L., Using SiroMat to distinguish fibre maturity related issues in the mill, *proceed.* Beltwide Cotton Conferences, National Cotton Council, Nashville TN, Jan 2008.

Materials Science and Engineering
Cnr Henry St and Colac Rd,
Geelong VIC 3216
P O Box 21, Belmont VIC 3216, Australia
Telephone: (03) 52464000 • Facsimile: (03) 52464057 • ABN 41 687 119 230

CSIRO

SiroMat™ on display at 14th Australian Cotton Conference

CSIRO will be showing SiroMat™, an instrument that measures cotton fibre maturity and the percent immature fibres in a cotton sample, at the CCC CRC stand at the 14th Australian Cotton Conference. This instrument, funded by CSIRO and Australian cotton growers through the CRDC and CCC CRC, is now nearly ready for commercialisation.

CSIRO and the CRDC have also organised for the internationally successful OFDA wool fibre diameter test instrument manufactured by an Australian company BSC Electronics http://www.ofda.com/ to be shown at the Conference.

This OFDA instrument is a related technology to the SiroMat™ and the instruments are being shown to demonstrate their similarity in terms of speed and practicality and to emphasise the industry readiness of SiroMat™.

BSC Electronics is being given this opportunity as it is one of three instrument manufacturing companies that have expressed interest in commercialising SiroMat™.

Enquiries to Dr. Stuart Gordon – stuart.gordon@csiro.au or mob. 0407 779 322

Cotton Catchment Communities CRC

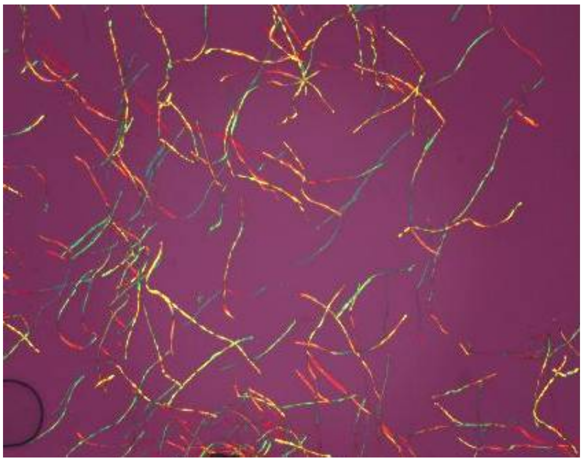
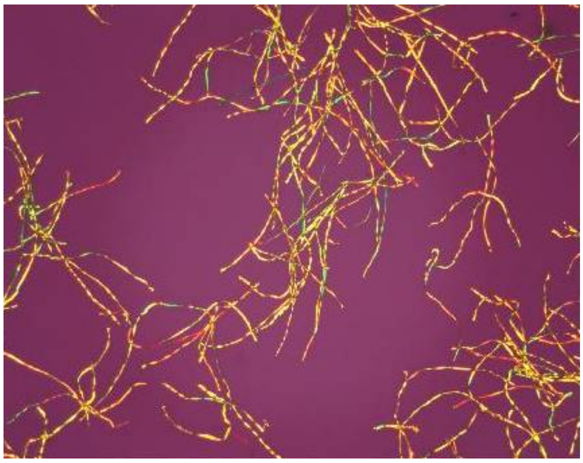
Australian Government
Cotton Research and Development Corporation

Request for

Expression of Interest

SiroMat a test instrument for measuring cotton fibre maturity directly and accurately

Closing Date: cob on 17th October 2008

www.csiro.au

CONTENTS

1. INTRODUCTION 4
1.1 Purpose of this EOI 4
1.2 CSIRO Profile 4
1.3 Background 4
1.4 Overview of Requirements 5
1.5 Objectives of this EOI 5
2. EOI STRUCTURE 5
2.1 EOI Structure 5
3. EOI PROCESS 6
3.1 Open EOI 6
3.2 CSIRO's Primary Contact Details 6
3.3 Timetable 6
3.4 Timetable Variations 7
4. PROCESS RULES 7
4.1 Closing Date and Time and Lodgement of EOI Response 7
4.2 Extension of Deadline for Lodgement of EOI Response 7
4.4 Exclusion of Late EOIs 7
4.8 Briefing and Clarification 7
4.9 Process Questions or Complaints 8
5. CONDITIONS OF PARTICIPATION 8
6. EVALUATION PROCESS 9
6.1 Evaluation Objective 9
6.2 Exclusion from Evaluation 9
6.3 Evaluation Process Overview 9
6.4 Evaluation Criteria 9
6.5 Respondent Presentations 10
6.6 Reference Checks and Further Information 10

6.7 Due Diligence on CSIRO [Optional] 11
6.8 Discussions and Negotiations with Respondents 11
6.9 Use of Information in the Evaluation 11
6.10 Debriefing 11

7. CONDITIONS OF EOI 11

7.1 Ownership of Response Material 11
7.2 Confidentiality of Information 12
7.3 Conflict of Interest 12
7.4 Ethical Dealing 13
7.5 EOI Validity 13
7.6 Right Not to Proceed 13
7.7 Costs Borne by Respondents 13
7.8 No Legal Relationship 14
7.9 Information 14
7.10 Respondents to Inform Themselves 14
7.11 Respondent Acknowledgements 14
7.12 Complaint Handling 14

8. INTERPRETATION OF EOI 15

8.1 Definitions & Interpretation 15
8.2 Governing Law 15

Appendix 1 – A Description of the Technology (SiroMat) 16
Appendix 2 – Results of the Cotton Fibre Test Instrument Market Survey 19

1. INTRODUCTION

1.1 Purpose of this EOI

CSIRO is issuing this Expression of Interest ("EOI") in order to seek proposals for **SiroMat** (herein referred to as the 'Technology') in accordance with the requirements specified in this EOI.

1.2 CSIRO Profile

CSIRO - the Commonwealth Scientific and Industrial Research Organisation - is Australia's largest scientific research organisation and one of the largest and most diverse scientific organisations in the World. Our purpose is:

> By igniting the creative spirit of our people, we deliver great science and innovative solutions for industry, society and the environment.

CSIRO's seeks to deliver benefits to industry and one of the means by which it does this is by commercialising the technologies that it develops.

CSIRO is an independent statutory authority constituted and operating under the provisions of the *Science and Industry Research Act 1949* and the *Commonwealth Authorities and Companies Act 1997*.

Further information about CSIRO can be found at www.csiro.au

1.3 Background

SiroMat is an instrument for measuring cotton fibre maturity developed by the Textile Program of the CSIRO Division of Materials Science and Engineering (CMSE) in conjunction with the Australian Cotton Research and Development Corporation (CRDC) and the Cotton Catchments Communities Co-operative Research Centre (CCC CRC).

SiroMat is a stand alone laboratory instrument that measures cotton fibre maturity directly, accurately and quickly. Its main strengths are that it:

- **Measures fibre maturity directly (no other instrument does this).**
- **Determines maturity on a per fibre (segment) basis and is therefore able to report a distribution of maturity in a sample as well as the average value.**
- **Requires no calibration cotton standards or pre-conditioning of samples.**
- **Provides a direct measurement of maturity in 2 ½ minutes.**

1.4 Overview of EOI

This document provides details of the requirements and terms considered under a ‘commercialisation’ agreement for the Technology between the interested party (herein the ‘Respondent’) and CSIRO and the original co-investors, i.e. the CRDC and CCC CRC, in the Technology.

CSIRO’s detailed requirements are set out in the Schedules to this EOI (see EOI structure in clause 2.1 below).

1.5 Objectives of this EOI

CSIRO is pursuing the following objectives through the issue of this EOI:

- To invite interested parties to submit proposals on how they might commercialise the Technology in a timely fashion if given an opportunity to do so.
- To identify from those parties who submit a proposal, a suitable company or companies that are able to demonstrate their ability to commercialise the Technology, including:
    - Their knowledge and experience in the application and deployment of the Technology or a similar technology, and
    - Their ability to further develop, manufacture, market and provide ongoing after sales support of the Technology.
    - Identification of a customer base for the Technology.

2. EOI STRUCTURE AND FORM OF RESPONSE

2.1 EOI Structure

This EOI and its attachments sets out information concerning CSIRO’s requirements in relation to the conditions of the EOI, evaluation methodology, evaluation criteria and all other matters concerning this process.

An overview on the technical background of the Technology, and a perspective on its market potential and value to the Australian (and International) cotton industry are also included.

(a) The attached appendices include:

(i) Appendix 1 – A Description of the Technology (SiroMat)

(ii) Appendix 2 – Results of the Cotton Fibre Test Instrument Market Survey

3. EOI PROCESS

3.1 Open EOI

3.1.1 This EOI is conducted as an open process. However, because of the specialised nature of the market for the Technology the EOI has not been published but has been tendered directly to the following companies that manufacture cotton fibre testing instrumentation for an expression of their interest:

- BSC Electronics P/L Australia
- Uster Technologies Inc. USA
- Premier Evolvics India

3.1.2 Respondents should register their contact details with the CSIRO Primary Contact nominated below so that they can be advised of any alteration, correction or notice in relation to this EOI.

3.2 CSIRO's Primary Contact Details

CSIRO's primary contact for all communications and contacts related to this EOI is (the 'Primary Contact'):

Name	Dennis Silvers
Role	Primary Contact
Email	dennis.silvers@csiro.au

3.3 Timetable

The following indicative timetable will apply to this EOI:

Event	Indicative Dates
Release of EOI to previously identified candidate companies	
EOI Response Closing Time and Date	Cob 17th October 2008
Evaluation of EOI responses	20th October 2008
Evaluation committee meets	During week beginning 20th October 2008
Selection and notification of finalist Respondent	28th October 2008
Interview of short-listed Respondents	During week beginning 4th

	November 2008
Due diligence and reference checks	TBD
Negotiation and further clarification with short-listed Respondents	TBD
Finalise contract with preferred Respondent	TBD
Sign contract with preferred Respondent	TBD
Technology Transfer/implementation	TBD
Hand over date	TBD

TBD = To Be Determined

3.4 Timetable Variations

The indicative timetable set out in clause 3.3 may be varied by CSIRO at any time at its discretion.

4. PROCESS RULES

4.1 Closing Date and Time and Lodgement of EOI Response

4.1.1 Completed EOI responses must be lodged electronically with the Primary Contact at the email address given on page 6 before **5.00 PM (Australian Eastern Standard Time) on Friday 17th October 2008** (the 'EOI Closing Time and Date').

4.2 Extension of Deadline for Lodgement of EOI Response

4.2.1 The EOI Closing Time and Date are at the sole and absolute discretion of CSIRO and may be extended at CSIRO's discretion at any time prior to the EOI Closing Time and Date published in this EOI.

4.2.2 Any extension of the EOI Closing Time and Date will be notified to those Respondents who have registered with the Primary Contact.

4.3 Exclusion of Late Responses

Late Responses will be excluded from the EOI process, and will not be admitted to evaluation.

4.4 Briefing and Clarification

4.4.1 Briefing sessions and/or clarification on the Technology and/or EOI can be arranged for Respondents through the Primary Contact.

4.4.2 Clarification Questions

Respondents may seek clarification of the meaning of the content of this EOI from CSIRO's Primary Contact at any time prior to the EOI Closing Time and Date. All enquiries must be in writing submitted to CSIRO's Primary Contact e-mail as identified at clause 3.2.

CSIRO will, in its sole discretion, determine whether or not to respond to such questions. Any election not to respond will be notified to the Respondent asking the question.

In all cases CSIRO reserves the right to forward any clarification of the meaning of the content of this EOI to all Respondents on a non-attributable basis.

4.4.3 New Information and Errors

If a line of questioning by a Respondent in a briefing reveals new information that, in the sole opinion of CSIRO may be material to the outcome of the EOI, or such questioning reveals an error in information previously distributed by CSIRO, the new or corrected information will be distributed to all Respondents.

4.5 Process Questions or Complaints

Any questions or complaints from Respondents relating to the EOI process should be directed to the Primary Contact in the first instance.

5. CONDITIONS OF PARTICIPATION

CSIRO will exclude a Respondent from further consideration and evaluation if CSIRO considers in its absolute discretion that the conditions of participation set out in this clause have not been met by the Respondent. Notwithstanding anything else contained in this EOI, only requirements listed in this clause will be deemed conditions of participation.

- Complete the attached Summary Response Template;
- An indicative business plan providing a basic outline of how the Respondent might integrate the Technology into the Respondent's business and the pathway to commercialise the Technology;
- The extent to which the Respondent will act to support and promote the Technology to the Australian cotton industry for an agreed period, e.g. using the Australian cotton industry as a test-bed market.
- Details of the Respondent's previous experience in commercialising; including product development, manufacturing, distributing and customer support for similar technologies;

– Details of the Respondent's financial standing including the last three years Financial Statements;

– Details of the Respondent's personnel who would be involved in development and commercialisation activities for the Technology.

6. EVALUATION PROCESS

6.1 Evaluation Objective

The purpose of the evaluation process is to identify and select the Respondent that CSIRO considers has the capacity to best commercialise the technology and deliver benefits to Australia, as assessed in accordance with the evaluation criteria and methodology adopted by CSIRO.

6.2 Exclusion from Evaluation

Respondents excluded under clause 5 will not be included in the evaluation.

6.3 Evaluation Process Overview

The evaluation process will include the following steps:

(a) Detailed evaluation of EOI responses from the Respondents;

(b) Selection of short-listed Respondents;

(c) Clarifications with and presentations from the Respondents;

(d) Reference checks, including site visits, if required;

(e) Due diligence of short-listed Respondents by CSIRO;

(f) Negotiations and further clarification with short-listed Respondents;

(g) Update evaluation; and

(h) Select preferred Respondent.

6.4 Evaluation Criteria

In ascertaining the Respondent who will best meet CSIRO's requirements, Respondents will be evaluated in accordance with the following evaluation criteria:

– Experience in commercialising similar technology;

- End user application knowledge;
- Manufacturing capability;
- Sales and applications support;
- Installation and repair capability;
- Software and hardware development capability;
- Financial capacity;
- Quality of business plan;
- Benefits to CSIRO, CRDC and the CCC CRC in terms of fees for the license or transfer of the Technology to the successful Respondent;
- Maximizing benefits or application of the Technology to the Australian cotton industry for an agreed period.

The order in which the evaluation criteria are listed does not indicate their importance relative to each other. CSIRO reserves the right to allocate weightings to the criteria in its evaluation process, at its discretion.

6.5 Respondent Presentations

6.5.1 CSIRO may require presentations from Respondents at any time during the evaluation process. Dates, times and venues for any such presentations will be notified to all Respondents participating in the evaluation should such presentations be required. A list of areas and issues for Respondents to address will be provided prior to the presentations.

6.5.2 Any time and travel expenses relating to Respondent presentations will be met by the Respondent. CSIRO may require any presentation be conducted using video-conferencing facilities.

6.6 Reference Checks and Further Information

Respondents are requested to submit a statement of facts as to previous experience and achievement in commercialising similar technologies in the market.

(a) CSIRO may conduct reference checks (including site visits, if relevant) on Respondents. Reference checks may be conducted with any referee proposed by the Respondent in its EOI response or with any other organisation selected by CSIRO at its discretion.

(b) CSIRO may also request further information from Respondents during the evaluation process.

6.7 Due Diligence on Technology

CSIRO may provide short-listed Respondents with the opportunity to conduct due diligence on the Technology subject to enter into a confidentiality agreement.

6.8 Discussions and Negotiations with Respondents

CSIRO will, as appropriate, engage in discussion or negotiations with any Respondent for the purpose of clarifying or improving its response. CSIRO may, in its absolute discretion, conduct simultaneous discussions to clarify or improve proposals with more than one Respondent. Where information of a material nature is provided to one Respondent, it will also be provided to all other Respondents (on a non-attributable basis) who are currently participating in the evaluation process.

6.9 Use of Information in the Evaluation

6.9.1 The Respondent's written EOI response to the requirements set out in the Schedules to this EOI will be used by the evaluation team to evaluate Respondents against the evaluation criteria.

6.9.2 The evaluation team may also use any relevant information obtained in relation to the EOI (whether from the Respondent as part of clarification, reference checks, negotiations, presentations or by any other independent inquiry) in the evaluation of EOIs.

6.10 Debriefing

Unsuccessful Respondents may request an EOI debriefing if a contract is awarded to a successful Respondent. Respondents requiring a debriefing should contact the CSIRO's Primary Contact.

7. CONDITIONS OF EOI

7.1 Ownership of Response Material

7.1.1 All material submitted in response to this EOI becomes the property of CSIRO. Such intellectual property as may exist in the information contained in the response will remain vested in the Respondent.

7.1.2 By submitting an EOI, the Respondent allows CSIRO to copy and do anything necessary to material, including the Respondent's intellectual property contained in the response, for the purpose of evaluating the Respondent's response and negotiating a contract if the Respondent proceeds to that phase of the process.

7.2 Confidentiality of Information

7.2.1 CSIRO's Confidential Information

Respondents are required to ensure that any of their employees, agents or sub-contractors involved in meeting CSIRO's requirements do not either directly or indirectly record, divulge or communicate to any person any confidential information concerning the affairs of the CSIRO or a third party acquired or obtained in the course of preparing a EOI response, or in discussions or negotiations with CSIRO. This confidential information includes any documents, data or information provided by CSIRO and which CSIRO indicates to Respondents is confidential or which Respondents know or ought reasonably to know is confidential.

7.2.2 Respondents' Confidential Information

CSIRO will treat as confidential any information provided by a Respondent which is nominated by the Respondent as confidential information. CSIRO's obligations in relation to Respondent provided confidential information will not be taken to have been breached to the extent that the information is:

(a) Disclosed by CSIRO to its advisers, officers, employees, subcontractors or advisors in order to conduct the EOI process, including the preparation of any resultant contract;

(b) Disclosed to CSIRO's internal management personnel or advisors, solely to enable effective management or auditing of the EOI process;

(c) Disclosed by CSIRO to its Department or to the responsible Minister;

(d) Disclosed by CSIRO in response to a request by a House or a Committee of the Parliament of the Commonwealth of Australia;

(e) Authorised or required by law to be disclosed; or

(f) in the public domain otherwise than due to a breach of the relevant obligations of confidentiality.

7.3 Conflict of Interest

During the EOI process, the Respondent must immediately advise CSIRO in writing of any circumstances or relationships constituting a Conflict of Interest or potential Conflict of Interest which might impact on CSIRO's determination as to the most appropriate party to commercialise the Technology. CSIRO may in its absolute discretion:

(a) Enter into discussions to seek to address such Conflict of Interest;

(b) Exclude the Respondent from the process and further evaluation; or

(c) Take any other action it considers appropriate.

7.4 Ethical Dealing

7.4.1 CSIRO's policy is to engage in the highest standards of ethical behaviour and fair dealing throughout the EOI process. CSIRO requires the same standards from those with whom it deals. EOIs should be compiled without improper assistance of employees or former employees of CSIRO and without the use of information improperly obtained or in breach of an obligation of confidentiality.

7.4.2 Respondents should not:

(a) Engage in misleading or deceptive conduct in the relation to the EOI process;

(b) Engage in any anti-competitive conduct, or any other unlawful or unethical conduct with any other Respondent, or any other person in connection with the EOI process; or

(c) Attempt to influence improperly any officer, employee or agent of CSIRO, or violate any applicable laws or CSIRO policies regarding the offering of inducements in connection with the EOI process.

7.4.3 CSIRO may exclude from consideration any EOI lodged by a Respondent which, in CSIRO's reasonable opinion, has engaged in any behaviour contrary to this section in relation to the EOI process.

7.5 EOI Validity

All EOIs will be deemed to be valid for a period of 90 days from the EOI Closing Time and Date unless otherwise indicated by a Respondent in its EOI response.

7.6 Right Not to Proceed

CSIRO is not bound contractually, or in any other way, with any Respondent who responds to this EOI. CSIRO reserves the right not to proceed with this EOI or any part of it, and to suspend or vary the EOI and/or its requirements at any stage.

7.7 Costs Borne by Respondent

All costs and expenses incurred by Respondents in any way associated with the development, preparation and submission of an EOI response, including but not limited to attendance at meetings, discussions, presentations and providing any additional material required by CSIRO, will be borne exclusively by the Respondents.

7.8 No Legal Relationship

No binding legal relationship will arise out of this process until execution of a contract with the preferred Respondent

7.9 Information

CSIRO will not be liable for any incorrect or misleading information or omission to disclose information.

7.10 Respondents to Inform Themselves

Respondents are considered to have:

(a) Examined this EOI, any documents referenced in this EOI and any other information made available by CSIRO to Respondents for the purpose of tendering;

(b) Examined all further information which is obtainable by the making of reasonable inquiries relevant to the risks, contingencies, and other circumstances having an effect on their EOI response;

7.11 Respondent Acknowledgements

EOIs are submitted on the basis that Respondents acknowledge:

(a) They do not rely on any representation, letter, document or arrangement, whether oral or in writing, or other conduct as adding to or amending these conditions;

(b) They do not rely upon any warranty or representation made by or on behalf of CSIRO, except as are expressly provided for in this EOI, but they have relied entirely upon their own inquiries and inspection in respect of the subject of their EOI response; and

(c) CSIRO is not responsible for any loss, damage, costs or expenses incurred by Respondents or any person if, for any reasons, a EOI or any other material or communication relevant to this EOI, is not received on time, is corrupted or altered or otherwise is not received as sent, cannot be read or decrypted or has its security or integrity compromised.

7.12 Complaint Handling

For complaints in relation to any item in this EOI or the EOI process contact the nominated CSIRO contact listed in clause 3.2.

8. INTERPRETATION OF EOI

8.1 Definitions & Interpretation

In this EOI, unless the contrary intention appears:

(a) Conflict of Interest means any matter, circumstance, interest, or activity affecting the Respondent (including the officers, employees, agents and subcontractors of the Respondent) which may or may appear to impair the ability of the Respondent to provide the requirements to CSIRO diligently and independently;

(b) Late EOI means a EOI that is not lodged by the EOI Closing Time and Date,

(c) Primary Contact means CSIRO's primary contact for all contacts in relation to this EOI, as specified in clause 3.2;

(d) EOI Closing Time and Date means the date and time set out in clause 4.1;

8.2 Governing Law

The governing law of Victoria applies to the EOI. The courts of Victoria have non-exclusive jurisdiction to decide any matter arising out of this EOI.

APPENDIX 1 – SIROMAT

Technical Background

Fibre maturity is a key attribute of cotton fibre quality. The property determines how well fibres process both from a chemical and physical perspective. Currently the cotton industry relies on the Micronaire instrument to 'indicate' maturity although the reading is confused by the sample's fineness. Because Micronaire is unable to differentiate between fineness and maturity, premium cottons, i.e. fine and mature cottons, are discriminated against for fear they are immature. As the needs of the Australian market become more sophisticated, the Micronaire value will increasingly fail to provide the information required for both growers and spinners.

SiroMat is an automated version of the polarized light microscopy technique that analyses the interference colors produced by cotton fibres placed between crossed polar lenses and a first order retardation plate. The percent area of different colors in captured images of fibre snippets relate directly to fibre maturity. The interference colors transmitted by cotton fibres have been classified by Grimes[1] in terms of the cotton fibre maturity they represent and incorporated into a well known ASTM Standard[2] for determining cotton fibre maturity.

The disadvantage of the test in the past has been that the operator must make an arbitrary assessment of colors assumed by fibres and this subjective decision contributes to large discrepancies in the results from different laboratories. The ASTM Standard in fact warns against using the method for acceptance testing because of poor precision. Furthermore, the test has been too slow for routine test applications.

SiroMat overcomes these issues by automatically scanning and analysing fibres on the basis of their interference colors. The automation means that selection of fibres and interpretation of their color is no longer subject to operator interpretation. An algorithm is used to match the interference colors that cotton fibre snippets assume with their cotton fibre maturity to produce an average value and measures of the dispersion of maturity values for the specimen. Previous work by CTFT[3] has shown that specific interference colors relate directly with theta (θ), which is generally accepted as being the 'true' expression of cotton fibre maturity. However, on the basis of convention measurements are expressed in terms of maturity ratio (MR) according to Peirce and Lord[4]. A MR value of 1.000 equates to a mean θ value of 0.577.

The average standard error associated with current SiroMat measurements is between ± 0.025 MR units for blended[5] specimens and ± 0.040 MR units for raw unblended specimens. Significant

[1] Grimes, M. A., 'Polarized Light: Preferred for Maturity Tests', *Textile World*, 161-163, February (1945).
[2] ASTM Standard Method D1422 Cotton Fibre Maturity by Polarized Light Microscopy
[3] Gordon, S. G. and Phair, N. L., An Investigation of the Interference Colours Transmitted by Mature and Immature Fibers Under Polarized Light Microscopy, *Proceed. Beltwide Cotton Conf.*, 2566-2573, 2005
[4] Peirce, F. T. and Lord, E., The Fineness and Maturity of Cotton, *J. Textile Inst., (trans.)*, T173-T210, 1939
[5] Specimens opened and blended through one passage of a 'Shirley' Analyser

differences currently occur between SiroMat instruments although a method of correcting the color differences between cameras, which cause large differences between instruments, has recently been devised, although not tested at this time. It is planned to re-test inter-instrument variability once the Siromat has been re-calibrated with the 104 International Textile Center (ITC) reference cottons[6].

Value to Industry

The following points describe the value to end-users from applying SiroMat measurements in the various sectors (research, grower, merchant and mill) of the cotton industry. It is very difficult to predict future returns from these applications. Assuming the instrument is satisfactorily developed from a technical perspective; uptake by these sectors will depend on the amount of time and investment in extending and marketing SiroMat to these sectors.

Plant, Crop and Fibre Researchers:

- As a selection tool for maturity and fineness in new experimental varieties.
- To measure effects of plant physiology, i.e. carbohydrate and nutrient flow and genetic coding, on the fineness and maturity of varieties.
- To measure effects of production variables, i.e. water, nutrient and harvest preparation, on fineness and maturity of varieties.
- To provide additional information to processors (spinners and dyers) on the potential quality of fibre, yarn and fabric production.

Growers (via Researchers, Merchants and Classing Houses):

- Better informed selection of varieties and growing conditions that produce fine and mature, i.e. premium fibre.
- Elimination of ambiguities in Micronaire discounts.
- Consistent production of fibre within current Micronaire/fineness premiums addresses market concerns.

Merchants:

- Consistent supply of fibre within current Micronaire/fineness premiums addresses market concerns.
- Instrument can be operated using small fibre, yarn or fabric samples and non-standard conditions enabling better identification of cotton through the processing pipeline.

Short-Staple Spinners:

- Consistent supply and management of fibre within current Micronaire/fineness premiums means better production efficiency and quality.
- Instrument can be operated using small fibre samples extracted from bale, yarn or fabric and non-standard conditions enabling better identification of cotton through the processing pipeline.

---

[6] Hequet, E. F., Wyatt, B., Abidi, N. and Thibodeaux, D. P., Creation of a Set of Reference Material for Cotton Fiber Maturity Measurements, *Textile Res. J.*, **76(7)**, 576-586, 2006

Patent protection history of SiroMat

Action	**Date/*App. No.***
CSIRO Invention Disclosure	June 2003
Provisional patent drafted	July 2003
IPM patent search results received	September 2003
Provisional patent draft approved	January 2004
Provisional patent lodged	February 2004 *2004900263*
International patent lodged	January 2005 *PCT/AU2005/000061*
Receive IPER, which agrees Siromat is patentable	February 2006
Enter national phase of International patent application. Countries include: – Australia – Brazil – China – EU – India – Indonesia – Japan – S. Korea – Mexico – USA – Vietnam	From July 2006 *2005205614* *application for exam Aug 2007* *application for exam Jul 2007* *05700093.7* *850/MUMNP/2006* *W-00200602019* *PA/A/2006/007712*

APPENDIX 2 – FIBRE FINENESS AND MATURITY INSTRUMENTATION SURVEY

March 2005

Introduction

A survey on requirements for cotton fiber fineness and maturity testing instrumentation in cotton test laboratories around the world was conducted.

A questionnaire (Appendix 1) was sent to 152 laboratories in July 2004 by the Fiber Institute of Bremen (Faserinstitut Bremen) Germany as part of the Bremen Cotton Round Test. The survey was written by CSIRO Textile and Fibre Technology in order to gain insight into the market for new instruments that measure fiber fineness and maturity. Fifty six (or 37% of the) questionnaires were returned and analyzed.

Whilst measurement of fiber fineness and maturity is considered important for managing the quality and efficiency of yarn production most merchants and mills do not measure these properties accurately. The reasons for this relate to the inability of current technologies to measure these properties quickly and directly (accurately); the market currently utilizes the Micronaire airflow method, a robust measure that is a combination of fiber fineness and maturity. The lack of a valid measurement has in turn not allowed the market value of cotton to be appreciated in terms of fiber fineness and maturity.

From a technical perspective fiber fineness and maturity are key attributes of cotton fiber quality determining how well fibers process both physically and chemically. Fiber fineness is a key determinant of spinning efficiency (and quality) of fine count ring spun yarns. Immature fibers give rise to neps, excessive waste generation and uneven (in griege and dyed) yarn (and fabric) appearance.

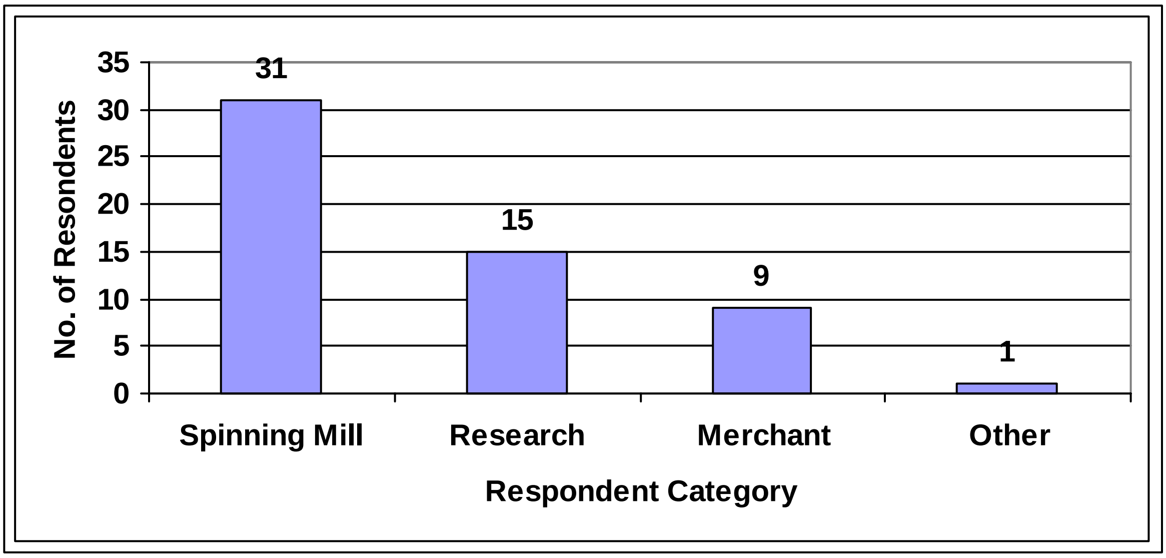
Under certain circumstances the Micronaire method can be used to predict and avoid the negative impacts of using coarse and/or immature cotton however it remains that the Micronaire method is unable to depict fine mature (premium) cotton from coarser immature cotton.

The value to the market of accurately determining fiber fineness and maturity of the cotton it uses is increasing in the face of increasing negative values arising along the processing chain. The negative values stimulating movement towards accurately measured fiber fineness and maturity are:

- Cotton's competition for textile fiber market share with synthetic fibers that are competitively priced and currently better specified.
- Increased demand for better specified cotton that performs efficiently through faster, more highly automated mill machinery i.e., carding, drawing and spinning.
- Consumer demand for high quality but less expensive goods (fabric).

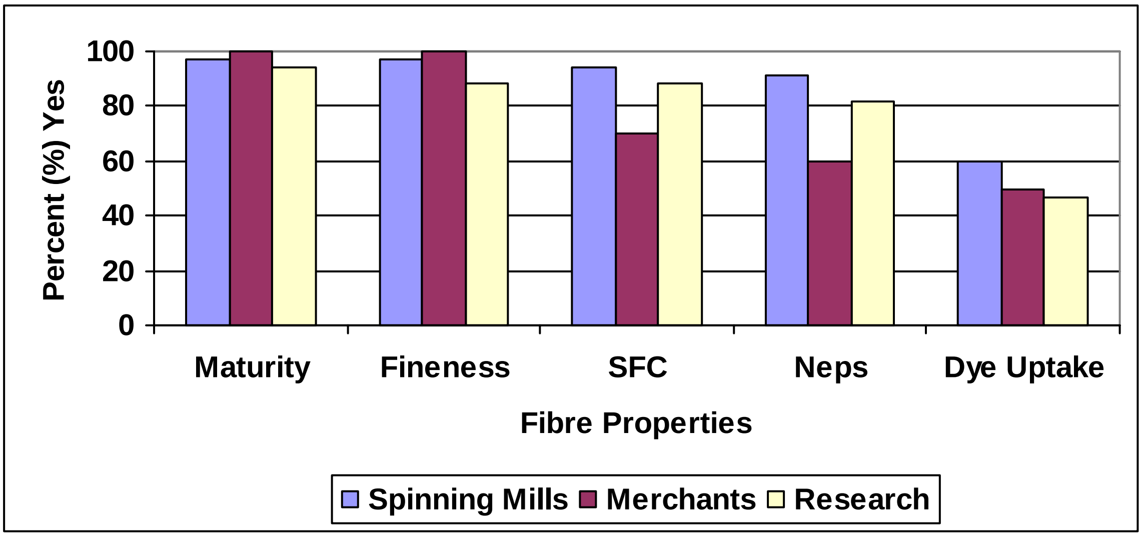
Results

Q1 - Do you perform fiber testing for:
a. Spinning mill quality control?
b. Cotton trading?
c. Merchant classing?
d. Research?
e. Other (please specify)?



Answers to Q1 provide background about the businesses in which laboratories were located. Fifty six (37%) were returned of which 31 indicated they tested samples for spinning mill quality control (identified as 'Spinning Mill'), 9 indicated they tested for trading or classing (identified as 'Merchant'), 15 indicated they tested for research purposes (identified as 'Research'); these were assumed to be laboratories in universities and private and public research institutes, plus 1 'Other', which was a non-woven mill.

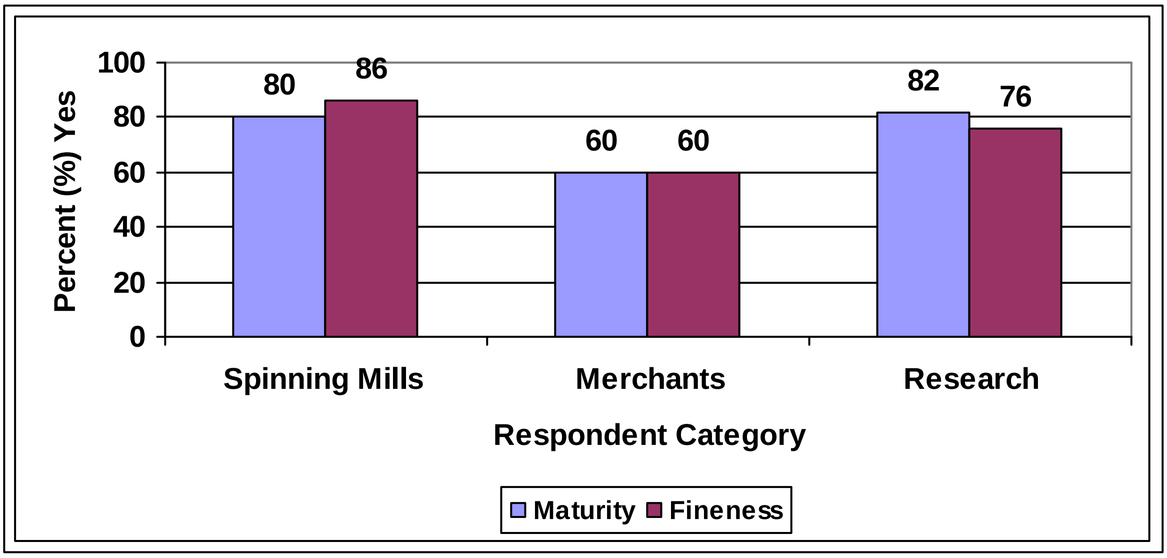
Q2 - Are these fiber properties important?	
a. Is fiber maturity an important property of cotton?	(Yes/No)
b. Is fiber fineness an important property of cotton?	(Yes/No)
c. Is short fiber content a concern for your business?	(Yes/No)
d. Is nep content a concern for your business?	(Yes/No)
e. Is dye uptake a concern for your business?	(Yes/No)



Spinning Mills and Merchant categories thought fiber maturity and fineness were equally important properties of cotton. Short fiber content (SFC), neps and dye uptake were less important, although the Spinning Mill category indicated these properties were more important than did laboratories in the Merchant category.

An inference about the suggested less importance of SFC, neps and dye uptake, could be that problems associated with these properties are predicted and thus mitigated by measuring fiber maturity and/or fineness.

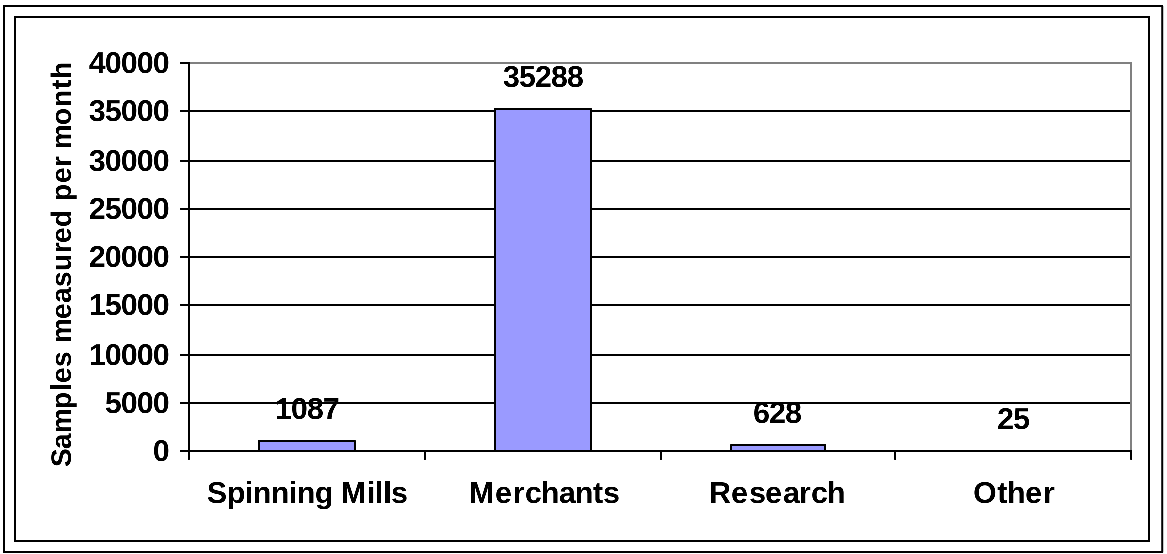
Q3 - Do you measure fiber maturity?	(Yes/No)
Q4 - Do you measure fiber fineness?	(Yes/No)



More than 80% of laboratories in the Spinning Mill category measured fibre maturity and fineness, or an aspect of these properties, by some method whilst only 60% of the Merchant category measured these properties, or an aspect of these properties.

The differences in these responses are due to the direct importance that maturity and fineness have on Spinning Mill profitability and the lack of a high throughput method for measuring maturity and fineness available to laboratories in the Merchant category (this point is quantified in Q5).

Q5 - If yes how many samples would you test per month?

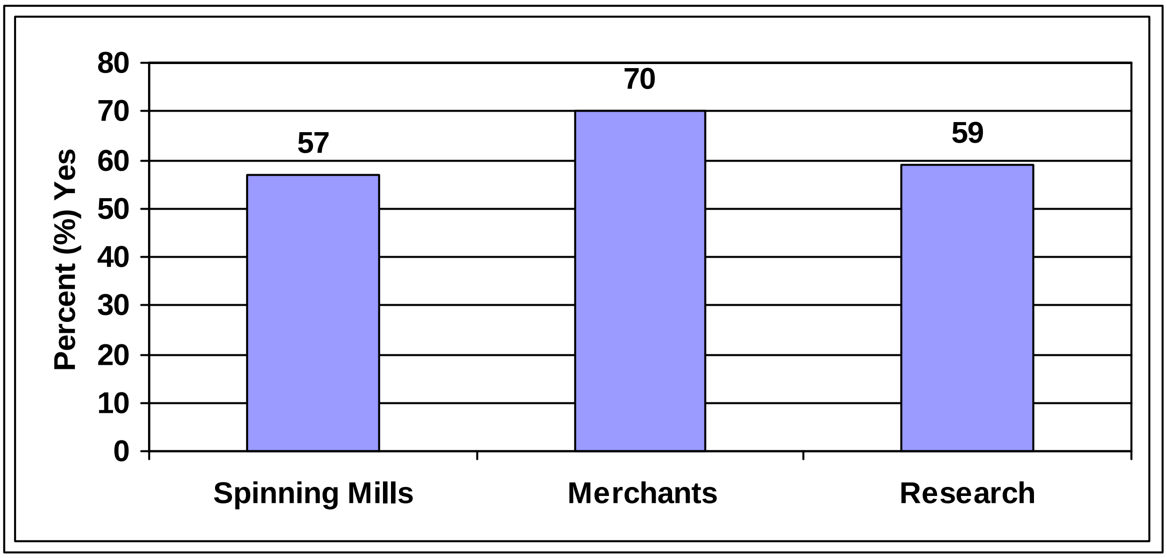


The high number of tests required by laboratories in the Merchant category is evident from the response to this question. On this basis any new technology needs to be able to process a high volume (fast test speed) of samples to be useful to laboratories (classing houses) in the Merchant category.

The response from laboratories in the Spinning Mill category indicates that low or medium volume instrumentation suffices (this is qualified further in Question 6).

The average Merchant response (35,288 samples) equates to one high volume instrument (HVI) working (at one sample per minute) one eight hour shift per day for 15 days per month. The largest number of samples was 126,000 per month.

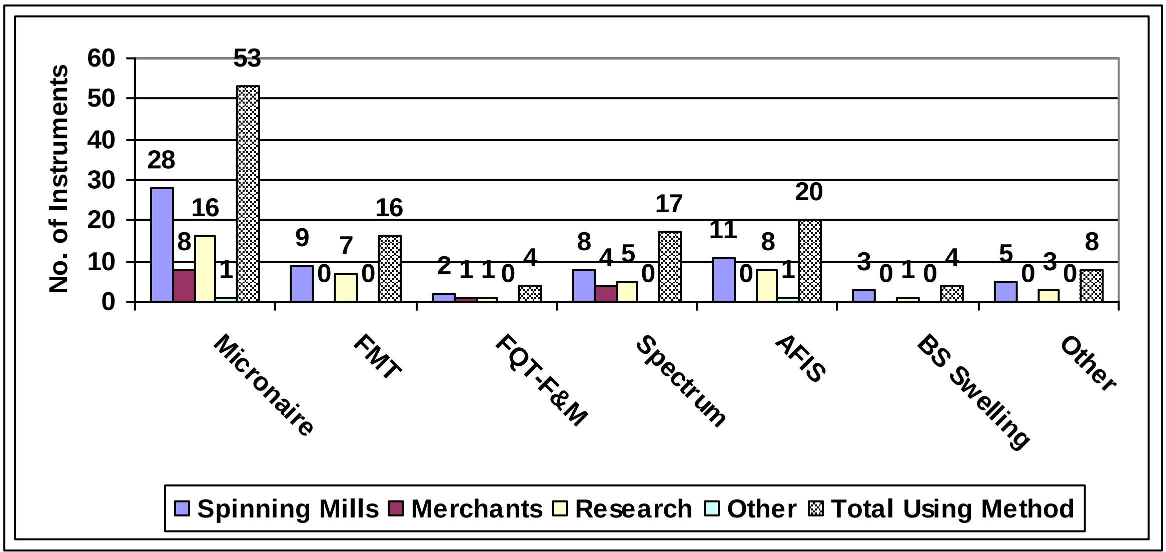
Q6 - Would you test more samples if it were economical to do so? (Yes/No)



Responses to this question highlight the need for high volume instrumentation to measure fiber maturity and fineness, particularly by the Merchant category. Fast test speed is less of a concern for laboratories in the Spinning Mill and Research categories although over half the laboratories from these categories would prefer a faster test.

Q7 - What technology do you use for this purpose?

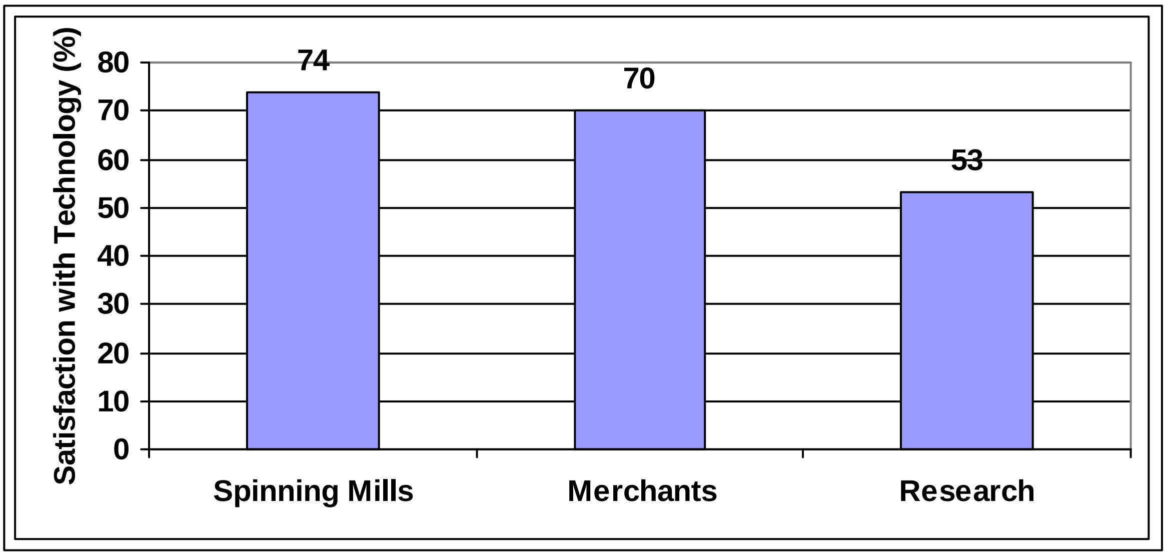
a Micronaire (HVI or stand alone)
b. 'Shirley' FMT/Micromat
c. Lintronics FQT-FM
d. Uster HVI Spectrum with Maturity
e. Uster AFIS with Maturity (please specify module)
f British Standard Sodium Hydroxide Swelling Method
g. Fiber cross-sectional analysis
h. Other (please specify)



Fifty three of the 56 laboratories surveyed utilized Micronaire, either as a stand alone instrument or integrated within a HVI, to assess fiber maturity and/or fineness. However, most laboratories and particularly those from the Spinning Mill and Research categories also used other instruments to provide additional information on fiber maturity and fineness.

These instruments, except for the Uster Spectrum, which calculates a value of maturity from HVI Micronaire, strength and extension values, tended to be slower in terms of test throughput. The most popular were the Uster AFIS (20 instruments), the Uster Spectrum (17) and the 'Shirley' FMT (16).

Q8 - Are you satisfied with this technology? (Yes/No)
Why?



Suggests general satisfaction with current technology although respondents, mostly from the Researcher category (53% satisfaction), had some criticism of current fineness and maturity testing technology. Criticisms included:

- Inaccuracy
- Slow (test speed)
- Labor intensive
- Lack of calibration (for the AFIS)
- Lack of reproducibility (operator dependent)
- Lack of service (unreliable)
- Doesn't measure maturity (Micronaire)
- Doesn't measure maturity distribution i.e., immature fiber content

Those respondents satisfied with the current technology, mostly from the Spinning Mill and Merchant categories (74% and 70% satisfied respectively), gave the following reasons for their satisfaction:

- Accurate
- Fast (test speed)
- Reproducible (stable, easy to use, controllable and precise)
- Recognizable values
- Indicates fiber fineness and maturity (Micronaire)

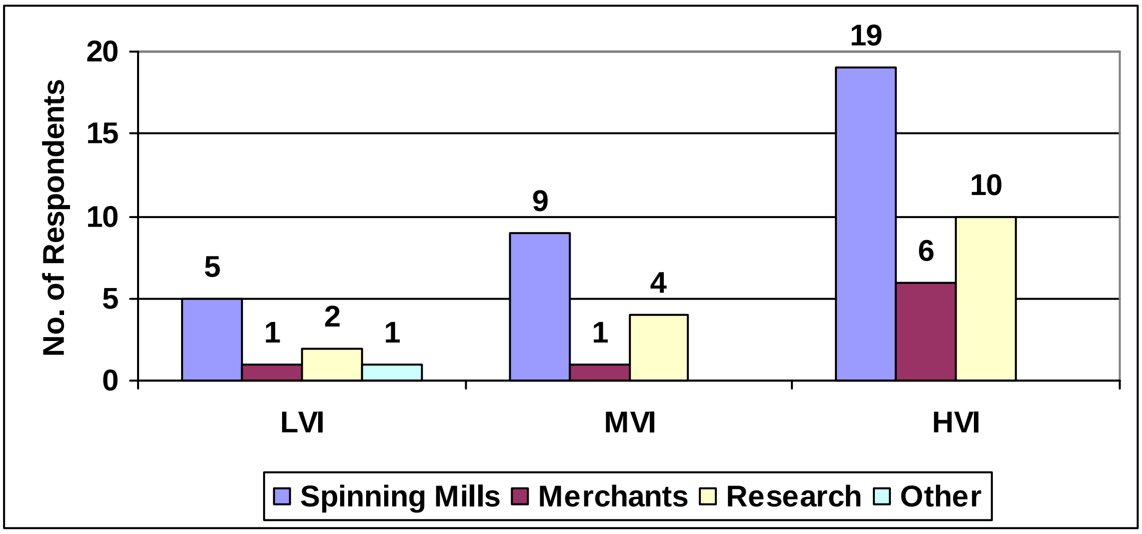
Interpolating these results the surveyors suggest criticisms of current technology are more focused on the accuracy and precision (including reliability) of the technology rather than its test speed. Interpolating again the surveyors suggest that whilst maturity and fineness are rated high in importance by the Spinning Mill and Merchant categories there is a gap in their knowledge with regards to measurement of these properties. This contrasts with laboratories in the Research category, which (it is assumed) understand the shortcomings of current test methods, and for whom the current technology was more unsatisfactory.

Q9 - What form of fiber maturity instrument would be most appropriate for your business?

a Low Volume, e.g., one sample every 4 minutes

b. Medium Volume, e.g., one sample every 1 minute

c. High Volume, e.g., one sample every 30 seconds



LVI = low volume instrument, MVI = medium volume instrument and HVI = high volume instrument.

Responses to this question highlight the market desire for HVIs capable of a fast test speed, although the responses suggest that LVI and MVI options are suitable for significant proportion of Spinning Mill category.

Q10 - What would you be willing to pay for such an instrument?

Answers ranged up to $AUD70,000 ($US50,000) and, for this, the new technology must overcome short comings in the current technology (noted in Q8) and be able to be integrated with other testing technologies e.g., the current HVI or AFIS were mentioned in this regard.

Conclusion

The survey results indicate that fiber fineness and maturity values are important parameters, particularly for users of cotton i.e., the spinning mills. However, there appears to be an information gap with respect to the best way of measuring (and using) these properties.

Most laboratories, whether they were located within Spinning Mill or Merchant-type businesses, used Micronaire as the main indicator of fiber fineness and maturity. However, most Spinning Mills and Merchants also desired further information on these properties. Hence, laboratories utilized other test instruments to gain this information. The most popular of these was the Uster AFIS, followed by the Uster Spectrum and Shirley FMT.

There is a suggestion in responses to Q8 (Are you satisfied with this technology?) that Spinning Mills and Merchants do not fully appreciate or understand the measurement of fiber fineness and maturity by various instruments. (*It is the view of the surveyors that current test instruments do not properly measure fiber fineness or maturity*). There was a significant difference in the response by the Spinning Mills and Merchant categories and the Research category, which tended to be less satisfied with current technology.

Test speed is an issue for laboratories in the Merchant category and the survey results suggest that the reason fiber fineness and maturity may not be measured by this category because test methods for these properties are not fast enough. Test speed is much less of an issue for the Spinning Mill and Research categories.

Acknowledgements

CSIRO Textile and Fibre Technology gratefully acknowledge staff from the Faserinstitut in Bremen for their kind and cheerful assistance in sending out questionnaires with the Bremen Round Test Cottons in July 2004 and for collating the responses.

Business Plan for the Development and Commercialisation of SiroMat, a New Instrument for the Measurement of Cotton Maturity

Mark Brims

BSC Electronics Pty Ltd

www.ofda.com

October 2008

a. EXECUTIVE SUMMARY

CSIRO has developed SiroMat, a new instrument to measure the maturity of cotton that is claimed to be more accurate than any other automatic method. CSIRO has written a number of papers on the positive correlation of SiroMat with manual maturity measurement [1]. CSIRO has applied for a patent for SiroMat, and has completed a survey on the market for an improved maturity measurement instrument [1].

"SiroMat is a stand alone laboratory instrument that measures cotton fibre maturity directly, accurately and quickly. Its main strengths are that it:

- Measures fibre maturity directly (no other instrument does this).
- Determines maturity on a per fibre (segment) basis and is therefore able to report a
- Distribution of maturity in a sample as well as the average value.
- Requires no calibration cotton standards or pre-conditioning of samples.
- Provides a direct measurement of maturity in 2 ½ minutes."

Due to a history of successful development and commercialisation of similar technology (OFDA), BSC Electronics Pty Ltd offers a faster and safer route to market. BSC is Australian based and therefore will benefit with the transfer of technology from CSIRO and the early adoption of SiroMat to benefit Australian growers. BSC is keen to establish an alliance with CSIRO to further develop, manufacture and market SiroMat and is ready to commence immediately upon reaching a mutually acceptable agreement.

b. NEEDS ANALYSIS

CSIRO has completed a survey on the market for an improved maturity measurement instrument [1]:

"The survey results indicate that fibre fineness and maturity values are important parameters, particularly for users of cotton i.e., the spinning mills. However, there appears to be an information gap with respect to the best way of measuring (and using) these properties. Most laboratories, whether they were located within Spinning Mill or Merchant-type businesses, used Micronaire as the main indicator of fibre fineness and maturity. However, most Spinning Mills and Merchants also desired further information on these properties."

c. MISSION

- To complete the technical development and increase the speed of operation of SiroMat

- To investigate the possibility of adding other measurements to SiroMat
- To manufacture SiroMat at a competitive price
- To market SiroMat worldwide to spinning mills, cotton merchants and research laboratories

d. VISION

2009

To commercialise and market SiroMat in Australia. To obtain technical and market feedback from customers to further improve the performance of SiroMat.

2010 – 2015

Commence international marketing and improve performance of SiroMat based on the initial feedback from Australian customers.

2015 onwards

Continue the international marketing and pursue the adoption of SiroMat as a global standard. Investigate the possibility of integrating SiroMat into the HVI system.

e. Project Plan

SiroMat utilises similar technology to the OFDA family. Both use a CCD or CMOS camera on a microscope, illuminate fibres with an ultrabright LED and move an automatic stage holding a glass slide containing the fibres.

The OFDA software includes a large library of proven routines for the user interface, image display, data storage and retrieval, spreadsheet output, debug log file output and printing of results.

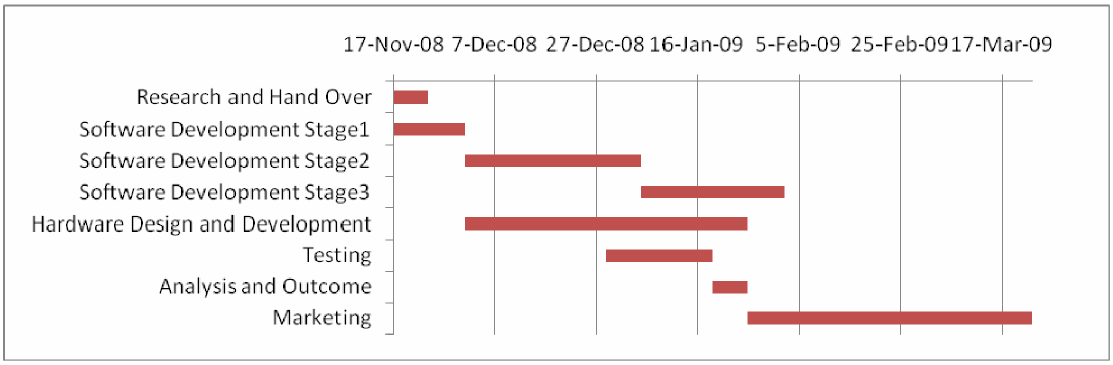
The technical development of SiroMat will include the following tasks.

1. Convert software to C++ to allow use with the BSC image processing tools.
2. Speed up the image processing to allow faster measurement of images during development phase, and to allow possible access to a wider market.
3. Experiment with camera, optical and LED configurations to obtain repeatable measurements over time and between instruments
4. Develop efficient sampling, spreading and slide cleaning devices
5. Experiment with the possibility of incorporating the OFDA fineness measurement hardware and software to allow the instrument to measure ribbon width and maturity simultaneously

6. Incorporate the OFDA software library to allow the rapid completion of a commercial prototype
7. Test standard maturity samples at BSC and provide a prototype to CSIRO
8. Provide instruments to initial Australian customers for testing

Development Schedule

Tasks	Start Date	Duration (Weeks)	End Date
Research and Hand Over Study existing analysis software	17-Nov-08	1	24-Nov-08
Software Stage 1 Develop a basic user interface (UI) Interface with hardware devices such as control board and camera	17-Nov-08	2	1-Dec-08
Software Stage 2 Convert SiroMat software to c++ Develop analysis code	1-Dec-08	5	5-Jan-09
Software Stage 3 Resolve technical issues from testing Refine UI	5-Jan-09	4	2-Feb-09
Hardware Design and Development	1-Dec-08	8	26-Jan-09
Testing	29-Dec-08	3	19-Jan-09
Analysis and Outcome	19-Jan-09	1	26-Jan-09
Marketing	26-Jan-09	ongoing	



f. MARKETING STRATEGIES

Promotion strategy

1. Establish an internet site as a central point for communication to existing and potential customers. Promotion of the importance of cotton maturity and convenient access to all technical literature about SiroMat.
2. Direct marketing via internet cotton sites and industry magazines.
3. Direct marketing to the test houses and organizations such as Chinese CIQ and SGS.
4. Continue to attend the cotton meetings in Bremen, either CSIRO attends or agent to continue the technical development and raise the awareness of SiroMat.
5. Stand at trade fairs such as ITMA China 2010 and ITMA Barcelona 2011. Cost will be reduced by sharing space with existing OFDA marketing.
6. Use existing network of agents that have contacts with the fibre industry to keep marketing costs low.
7. Possible cooperation with Uster later (5 years) when the technology is proven and accepted, possible integration with HVI.

Pricing strategy

Pricing will need to be flexible to cope with various market conditions and exchange rate fluctuations.

Estimated initial pricing is AUD $85,000, which is similar to the OFDA2000 and is set below the AFIS pricing since this is known price point that the market has accepted. The build and support costs are highly volume dependent, but the estimated price from BSC in low volume (<10/yr) is $AUD50,000. This leaves $AUD35,000 for marketing including global agent, local agents and royalty payments. Local agent commission is usually around 15% mark-up = $11,000.

Price breakdown

- BSC 50,000
- CSIRO/CRC royalty x% of BSC price or a fixed dollar amount?
- Global marketing 24,000 less royalty
- Local agent 11,000
- Installation and shipping not included, varies upon destination

The marketing costs are much lower than traditionally charged by a global marketing company such as Uster, where mark-up exceeds 100%. The internet and improved global communication is the main reason that it is now possible for smaller niche products to gain a market share with a reduced marketing cost.

Sales objectives

	Aim	**Sales Volume (Units)**	**Gross income (AUD)**
2009	Initial sales are within Australia to allow refinement of the instrument without the high costs of international shipping	5	$425,000
2010	Commence international marketing of SiroMat	20	$1,700,000
2011 onwards	Manufacture and marketing	50/yr	$4,250,000

Distribution strategy

Over the last 15 years of marketing the OFDA family and exhibiting at ITMA. BSC has acquired a network of agents and contacts in the field of fibre measurement instruments. BSC has local OFDA agents in Switzerland, Italy, China, India, Australia and South America. BSC also has personal relationships with senior personnel at Uster and SGS due to their previous OFDA marketing roles.

In some test houses, wool testing is performed in the room next to the cotton testing room. This represents a major sales opportunity for BSC to market SiroMat to existing clients.

g. RISK ANALYSIS

Potential risks

- SiroMat does not perform to required speed and accuracy: this risk is reduced by BSC's experience in manufacturing the fastest and most accurate fibre image analysis systems.
- First world company copies SiroMat or develops a similar instrument: this risk is reduced due to patent protection, copyright and the cost of developing an instrument without CSIRO IP.

- Chinese / Indian low cost competitors copy SiroMat or develop a similar instrument: patent protection is not so useful in this case but SiroMat is essentially a software product which makes it difficult to copy.
- Decline of the Cotton industry: the size of BSC allows it to adapt to rapidly changing market conditions, as demonstrated by its successful history in the volatile wool industry.

h. PROFILE OF BSC Electronics Pty Ltd

The founder of BSC Electronics Pty Ltd, Mark Brims worked at AWTA Ltd from 1980 to 1986 and during this time invented FIDAM, a prototype instrument for the measurement of wool fibre diameter. In 1985, Brims worked with the first CCD camera ever released and altered the electronic circuitry to improve its performance.

After leaving AWTA, Brims worked in various companies developing image processing and robotic technology. In 1990, a technique for high accuracy measurement of diameter was developed that utilized custom hardware and software. This was a different and superior technique used in FIDAM, and led to the development of the OFDA100 (Optical based Fibre Diameter Analyser).

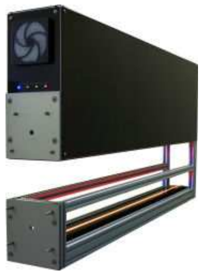
The OFDA100 was released in 1991, the same year that AWTA announced it was discontinuing FIDAM and changing to use the Laserscan developed by CSIRO.

The use of OFDA for the measurement of cotton was explored around 1993 when Brims attended the Moree Cotton conference where he met Stuart Gordon. Brims then visited the USDA in Lubbock Texas and demonstrated the OFDA100 and discussed the requirements of cotton measurement and learnt about the shortcomings of the existing maturity measurement instruments. The OFDA was also demonstrated to the cotton measurement division of SGS in Tennessee (the world's largest inspection agency and parent company of a previous OFDA100 agent SGS Wool Testing Services).

BSC Manufacturing and office

Technical History of the OFDA Instrument Family

1991	OFDA100 released	
1992	OFDA100 international trials	
1993	OFDA100 awarded IWTO Test Method status. First and only image processing instrument to receive an IWTO TM	
1994 – 1998	New measurements of medullation (hollow fibres) and curvature added to OFDA100	
2000	OFDA2000 instrument released. First portable image processing diameter measurement instrument. First instrument to measure diameter of greasy wool and the diameter profile showing history of the fibre growth.	
2002	Largest fleece testing trials performed by AWI confirm the accuracy of the OFDA2000	
2002	Development of OFDA4000 commenced. OFDA4000 is the first instrument to combine the measurement of hauteur and diameter of wool tops. OFDA4000 is the first instrument to measure length directly (as opposed to hauteur, which is cross section based length). It provides a much more accurate measurement of short fibre in samples where the fibre diameter varies by length.	
2002 – 2008	Several trials are undertaken between OFDA4000 and OFDA100, Laserscan and Almeter100.	

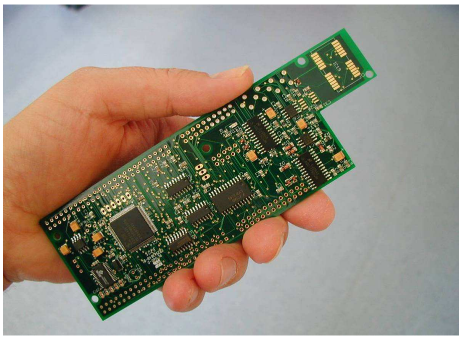
2003 – 2008	Development of the OFDA MFX instrument. Designed as an online application to measure monofilament fibres that are extruded from a die and aligned in a parallel manor. It measures up to 400 fibres simultaneously at a rate of 15,000 frames per second. Using ultra high speed cameras to measure diameter and faults such as slubs, thick and thin places. It is currently employed in factories in Europe.	
2005	OFDA5000 developed for the measurement of ultrafine fibres ranging from 0.5um to 50um in diameter. OFDA5000 was calibrated against atomic force microscope measurements of graticule lines.	
2006 – Present	conversion of OFDA2000 to USB based camera to allow control from a notebook PC	
2006 – 2008	Development of the OFDA MA instrument. A multi-axes optical measurement system measuring diameter and roundness, measures three or six axes simultaneously. Currently being trialled in Europe.	

Concurrent with the development of the OFDA family, several other projects were undertaken in the field of image processing.

- A unique software suite was developed that allows rapid visual development of image processing applications using c++. It is different to commercially available packages and was used to develop the OFDA4000 and OFDA5000 software. The package allows development of very complex and very fast image processing routines. For example, the OFDA2000 detects and measures fibres to sub micron resolution in images at a speed of over 1000 images per second.

- Commencing in 2003 BSC developed the OFDA MF, a version of the OFDA technology for the online measurement of monofilaments and wire. Over $1 million has been invested in this product, and it involved the design of a low cost, high speed, smart line scan CCD camera. Each instrument contains 9 smart cameras connected via Ethernet.

BSC Designed and Manufactured high speed smart camera



Marketing History of the OFDA Instrument Family

1991	OFDA100 released. Initial sales in Australia. SGS Wool testing appointed as agent.
1992:	OFDA100 displayed at ITMA Hanover. Peyer AG of Switzerland appointed as sub agent of SGS.
1995:	Peyer is purchased by Zellweger Uster which becomes the new worldwide agent for OFDA.
1998	Uster ceases sales of wool testing instruments and focuses on cotton instruments such as AFIS and HVI. Herbert Hornik of Hornik Fibertech becomes OFDA agent for most of the world.
2000	BSC appoints Australian company IWG Pty Ltd as agent for the portable OFDA2000 instrument.
2006	Last OFDA100 sold (175 sold in total). Components of OFDA100 are no longer available, replaced by OFDA2000.
2000 – Present	Over 110 OFDA2000s sold, over 15 OFDA4000s sold. OFDAs have been sold in over 30 countries.

Key personnel

Mark Brims BSc (Physics), MAppSc (Electronic Engineering)

Director and founder of BSC Electronics: 27 years experience writing high speed image processing and robotic software. Extensive experience with the physics of solid state image sensors and digitizing video. Designed and built 7 video digitisers.

1987 Automatic video vending machine

!989 7 axis force feedback robot for deboning beef

Hy Hwang BEng (Electronic Engineering)

Joined BSC Electronics in 1997. Extensive experience writing image analysis software, electronic design, electronic prototyping, digital video, motor control and Windows user interface.

Joe Zeitek

Joined BSC Electronics in 2007. Electronic technician: 37 years experience designing electronic test circuits, aerospace quality control, assembling, servicing, repair of electronic and mechanical devices and maintenance and support of PC based instruments. International and national servicing experience

Clive Jarman

Principle subcontractor for BSC since 1991. 42 years experience designing and machining high quality mechanical devices for optical, robotic, atomic research, military and aerospace applications. Designer of many of the mechanical components of the OFDA family.

References

1. Request for Expression of Interest: SiroMat a test instrument for measuring cotton fibre maturity directly and accurately

Business Case Report to the CRDC and ACGRA

Support and Extension of SiroMat (Generation I)

CRC Project Number 4.04.02

Milestone 1.1

August 2007

Contents

Page 3 – Business Case Scope

Page 4 – Technical Background

Page 5 – Investment to date

Page 6 – Market Potential

Page 7 – SiroMat Pricing at Different Segments

Page 8 – Value to Industry

Page 9 – Technical Actions to Market

Page 10 – Business Actions to Market

Page 11 – Appendix 1 – Patent numbers

Page 12 – Appendix 2 – Uster Evaluation Plan

Scope of Business Case

This report describes the technical and business directions for SiroMat, an instrument for measuring cotton fibre maturity developed by CSIRO Textile and Fibre Technology (CTFT) in conjunction with the Australian Cotton Research and Development Corporation (CRDC) and the Cotton Catchments Communities Co-operative Research Centre (CCC CRC).

SiroMat is a stand alone laboratory instrument that measures cotton fibre maturity directly, accurately and quickly. Its main strengths are that it:

- **Measures fibre maturity directly (no other instrument does this).**
- **Determines maturity on a per fibre (segment) basis and is therefore able to report a distribution of maturity in a sample as well as the average value.**
- **Requires no calibration cotton standards or pre-conditioning of samples.**
- **Provides a direct measurement of maturity in 2 ½ minutes.**

Much of the potential for the SiroMat instrument in the fibre testing instrument market depends on the technical capability of the instrument in terms of reliability, precision and repeatability and on education of the market about the value of using maturity to describe cotton for sale and manufacture. These are not insubstantial tasks and they remain core objectives of the current SiroMat project (CRC 4.04.02), which runs to June 2009. The technical background and requirements to make SiroMat ready for market are described in the sections 'Technical Background' and 'Technical Actions to Market'.

There are a number of perspectives from which the investors in SiroMat can view their potential return on investment (ROI). One perspective is the value of the market opportunity brought by SiroMat in defining Australian cotton quality. There exists a range of potentially significant benefits for each sector in the cotton production pipeline from using SiroMat to test fibre quality. For example, Australian cotton breeders could use SiroMat to select varieties that best fit particular end-uses. This would raise the level of fibre quality supplied from Australia and ensure or improve the current basis (premium) paid for Australian cotton. The potential benefits of applying SiroMat to the various sectors are described in the section 'Value to Market'. It is noted that delineating the potential effects of these applications on the current basis received for Australian cotton is beyond the scope of this report.

Another perspective for investors is the ROI from instrument sales. There are a number of possibilities based around licences and/or contracts granted to manufacture, market and/or sell SiroMat instruments. The issues, mix and timing of these activities are covered in the sections 'Market Potential' and 'Business Actions to Market', along with details of potential commercial partners.

Technical Background

Fibre maturity is a key attribute of cotton fibre quality. The property determines how well fibres process both from a chemical and physical perspective. Currently the cotton industry relies on the Micronaire instrument to 'indicate' maturity although the reading is confused by the sample's fineness. Because Micronaire is unable to differentiate between fineness and maturity, premium cottons, i.e. fine and mature cottons, are discriminated against for fear they are immature. As the needs of the Australian market become more sophisticated, the Micronaire value will increasingly fail to provide the information required for both growers and spinners.

SiroMat is an automated version of the polarized light microscopy technique that analyses the interference colors produced by cotton fibres placed between crossed polar lenses and a first order retardation plate. The percent area of different colors in captured images of fibre snippets relate directly to fibre maturity. The interference colors transmitted by cotton fibres have been classified by Grimes[1] in terms of the cotton fibre maturity they represent and incorporated into a well known ASTM Standard[2] for determining cotton fibre maturity.

The disadvantage of the test in the past has been that the operator must make an arbitrary assessment of colors assumed by fibres and this subjective decision contributes to large discrepancies in the results from different laboratories. The ASTM Standard in fact warns against using the method for acceptance testing because of poor precision. Furthermore, the test has been too slow for routine test applications.

SiroMat overcomes these issues by automatically scanning and analysing fibres on the basis of their interference colors. The automation means that selection of fibres and interpretation of their color is no longer subject to operator interpretation. An algorithm is used to match the interference colors that cotton fibre snippets assume with their cotton fibre maturity to produce an average value and measures of the dispersion of maturity values for the specimen. Previous work by CTFT[3] has shown that specific interference colors relate directly with theta (θ), which is generally accepted as being the 'true' expression of cotton fibre maturity. However, on the basis of convention measurements are expressed in terms of maturity ratio (MR) according to Peirce and Lord[4]. A MR value of 1.000 equates to a mean θ value of 0.577.

The average standard error associated with current SiroMat measurements is between ± 0.025 MR units for blended[5] specimens and ± 0.040 MR units for raw unblended specimens. Significant differences currently occur between SiroMat instruments although a method of correcting the color differences between cameras, which cause large differences between instruments, has recently been devised, although not tested at this time. It is planned to re-test inter-instrument variability once the Siromat has been re-calibrated with the 104 International Textile Center (ITC) reference cottons[6].

---

[1] Grimes, M. A., 'Polarized Light: Preferred for Maturity Tests', *Textile World*, 161-163, February (1945).
[2] ASTM Standard Method D1422 Cotton Fibre Maturity by Polarized Light Microscopy
[3] Gordon, S. G. and Phair, N. L., An Investigation of the Interference Colours Transmitted by Mature and Immature Fibers Under Polarized Light Microscopy, *Proceed. Beltwide Cotton Conf.,* 2566-2573, 2005
[4] Peirce, F. T. and Lord, E., The Fineness and Maturity of Cotton, *J. Textile Inst., (trans.)*, T173-T210, 1939
[5] Specimens opened and blended through one passage of a 'Shirley' Analyser
[6] Hequet, E. F., Wyatt, B., Abidi, N. and Thibodeaux, D. P., Creation of a Set of Reference Material for Cotton Fiber Maturity Measurements, *Textile Res. J.*, **76(7)**, 576-586, 2006

Investment to Date

Development and testing of the SiroMat has been co-funded 50:50 by CSIRO and the Australian cotton industry through the CRDC. More recently (2005/06) industry funding has been split between the CRDC and CCC CRC.

Table I lists the investment to date of each of the parties, and their resultant equity in SiroMat.

Table I – CRDC Investment: Proposed and funded monies to Polarized Light Microscopy and SiroMat projects across all phases of development

Project	Year	Project Phase	CSIRO Funding	CRDC Funding	CRC Funding
CWT6	2000/01	Feasibility	$75,967	$75,967	0
	2001/02	Feasibility and development of prototype	$88,366	$88,366	0
	2002/03	Development of prototype	$125,263	$100,263	0
CTFT8C	2003/04	Development and build 3 instruments	$75,000	$75,000	0
	2004/05	Development and build 3 instruments	$75,000	$75,000	0
		Partner equity	**51.5**	**48.5**	**0.0**
CRC91	2005/06	Development and test instruments	$169,967	$80,000	$80,000
	2006/07	Development and application	$123,169	$58,309	$58,309
		Partner equity	**51.5**	**38.8**	**9.7**
CRC4.04.02	*2007/08*	*Application and commercial preparation*	*$101,944*	*$53,073*	*$57,098*
	2008/09	*Application and commercial preparation*	*$107,897*	*$54,891*	*$61,252*
		Partner equity	**50.7**	**35.5**	**13.8**
	Sub-total		$942,573	$660,869	$256,659

Patent costs for the SiroMat invention have to date amounted to $86,697.43, which have been borne by CTFT. A list of patent application dates and numbers for various countries appear in Appendix 1.

CTFT notes from its own history that technologies with strong IP protection have become international standards and have achieved dominant sales positions.

Market Potential

Survey of the Fibre Maturity and Fineness Instrument Use and Opinion

Researchers from CTFT undertook a survey of (56) international cotton fibre test laboratories in late 2005 to understand the needs for instrumentation to measure cotton fibre maturity and fineness.

The results of the survey showed maturity and fineness were considered very important fibre properties by a range of users from merchants through to spinners, although there was no clear accepted method to measure these properties. Most laboratories used Micronaire as a measure of both fineness and maturity, although most (83%) also utilized other test instruments to gain further information on these properties.

The most popular instruments for this were the Uster Advanced Fibre Information System (AFIS), followed by the Uster High Volume Instrument (HVI) Spectrum and the 'Shirley' Fineness and Maturity Tester (FMT). Whilst there was a reasonable degree of satisfaction with these instruments, there was a suggestion that users did not fully understand or were not confident in the measurement given by these instruments. The major issues associated with these instruments were test speed, accuracy (largely around the lack of a calibration standard) and reproducibility of results.

The Fibre Instrument Market

The potential number and rate of uptake of SiroMat instruments by the fibre testing market is difficult to predict. Assuming the instrument is technically ready, marketed widely and accepted by the market we can look to the sales history of equivalent instruments such as the HVI, AFIS, 'Shirley' FMT and the Optical Fibre Diameter Analyser (OFDA), a wool diameter measuring instrument manufactured in Australia by BSC Electronics (Table II), in order to gain an appreciation of potential ROI with respect to instrument sales. The OFDA is included here because it most closely resembles the SiroMat in terms of its build cost and technical specifications. The price listed for SiroMat is the build cost multiplied by the cost and margin factors for a large international instrument manufacturing and distribution company (Table III).

Except for the OFDA, which is manufactured and distributed locally by its original inventor, each of the instruments in Table II has been bought from the inventor by manufacturers and/or distributors with a larger suite of products and distribution networks. Over time the new owner/licensee has made on-going improvements to the operation efficiency and design of the original instrument.

The total income in today's prices for each instrument is calculated from the numbers in Table II. No information was available about the current rate of uptake or decline in sales of these instruments, though we note a large increase in the number of HVI units sold (>300) into China over the last two years and expectations that the percentage of fibre lots tested will rise over the next decade under the influence of China's dominance in cotton production, import and export markets.

We note also that only 30 to 40%[7] of the world's cotton is objectively assessed; the remainder being subjectively classed. Objective measurement of raw cotton is currently being promoted by

[7] Estimated percent of cotton objectively tested by CSITC

industry representative groups such as the International Textile Manufacturer's Federation (ITMF) Cotton Test Method Groups and the International Cotton Advisory Committee (ICAC) Commercial Standardisation of the Instrument Testing of Cotton (CSITC) Working Group.

Table II – Fibre Testing Instrument Prices and Numbers

Instrument	**Current Manufacturer**	**Sales Period From -**	**Current Price $AUD**	**Number Sold**	**Total Income $AUD**
HVI	Uster, Premier	1980 -	380,000[8]	2,000[9]	$760M
AFIS	Uster	1993 -	300,000[8]	850[10]	$255M
'Shirley' FMT	SDLAtlas[11]	1975 -	40,000[12]	>250	>$10M
OFDA	BSC Electronics	1987 -	85,000[13]	250	$21M
SiroMat		2009 -	98,000	?	?

SiroMat Pricing for Different Market Segments

Table III below lists the build cost (parts and CTFT labour) range of SiroMat instruments without margin. Presented then is the likely cost and margin of outsourcing manufacture of the instrument to a private company. The multipliers used to calculate these costs (1.6X) and the cost and margin (2.5X) for distributing, selling and supporting the instrument are from previous CTFT experience in commercialising the Sirolan Laserscan wool diameter instrument.

One-off certification of compliance costs for electrical safety, radiation emissions and mechanical safety, nominally in the order of $AUD20K for similar types of instruments, are not included, nor are specimen preparation tools such as a Fibrosampler™ or consumables such as microscope slides and mounting media.

Table III – SiroMat Build Costs and Pricing

Build costs at CTFT	**$AUD**
Microscope	5,000 - 6,500
Digital Colour Camera	5,000 - 6,000
Microscope Stage & Control	2,000
Computer	2,500 - 3,500
Guillotine	1,500
Snippet Spreader	2,500
Labour	3,000 - 3,500
Total build costs at CTFT	**22,500 - 26,500**
Build costs outsourced to outside manufacturer	**36,000 - 42,400**[14]
Selling price of outsourced-made instrument by outside agency includes distribution, marketing, sales and warranty costs	**90,000 – 106,000**[15]

[8] Prices paid by CSIRO in 2006 & 2007 for HVI & AFIS instruments with all test modules
[9] Number provided July 2007 by L. Hunter past-chair of ITMF HVI Test Method Group
[10] Number provided July 2007 by A. Schleth Uster Technologies
[11] Not current manufacturer; SDLAtlas market, sell and distribute only
[12] Quoted price to CPI in 2003 and estimated numbers
[13] Average price and number of instruments sold provided August 2007 by M. Brims BSC Electronics
[14] Multiplication factor of 1.6 for private company manufacture costs and profit
[15] Multiplication factor of 2.5 for distribution and marketing costs and profit by large private company

Value to Industry

The following points describe the value to end-users from applying SiroMat measurements in the various sectors (research, grower, merchant and mill) of the cotton industry. It is very difficult to predict future returns from these applications. Assuming the instrument is satisfactorily developed from a technical perspective; uptake by these sectors will depend on the amount of time and investment in extending and marketing SiroMat to these sectors.

Plant, Crop and Fibre Researchers:

- As a selection tool for maturity and fineness in new experimental varieties.
- To measure effects of plant physiology, i.e. carbohydrate and nutrient flow and genetic coding, on the fineness and maturity of varieties.
- To measure effects of production variables, i.e. water, nutrient and harvest preparation, on fineness and maturity of varieties.
- To provide additional information to processors (spinners and dyers) on the potential quality of fibre, yarn and fabric production.

Growers (via Researchers, Merchants and Classing Houses):

- Better informed selection of varieties and growing conditions that produce fine and mature, i.e. premium fibre.
- Elimination of ambiguities in Micronaire discounts.
- Consistent production of fibre within current Micronaire/fineness premiums addresses market concerns.

Merchants:

- Consistent supply of fibre within current Micronaire/fineness premiums addresses market concerns.
- Instrument can be operated using small fibre, yarn or fabric samples and non-standard conditions enabling better identification of cotton through the processing pipeline.

Short-Staple Spinners:

- Consistent supply and management of fibre within current Micronaire/fineness premiums means better production efficiency and quality.
- Instrument can be operated using small fibre samples extracted from bale, yarn or fabric and non-standard conditions enabling better identification of cotton through the processing pipeline.

Technical Actions to Market

In order for SiroMat to be taken up by the wider industry its utility needs to be realised by the wider research and commercial cotton testing and marketing segments. During a recent meeting with Uster Technologies, a large international fibre and textile instrument manufacturer, interest was expressed in the SiroMat on this basis.

In order to highlight its value to industry SiroMat tests will be recorded on samples from a wide number of Australian and international industry sponsored cotton breeding, agronomy and textile projects. Effort will also be required to measure and control inter-instrument and inter-laboratory variation. The results of these studies would be presented at industry forums and published in scientific and industrial journals.

Thus the broad technical objectives for SiroMat over the next two years, the milestones of which are described in the proposal for CCC CRC project 4.04.02, are to:

1. Conduct, and publish where appropriate, a series of studies with scientific, industry and commercial partners designed to demonstrate the value of SiroMat data in managing (and improving) fibre quality in the following areas:
    a. Plant physiology and genetic modification (with CSIRO Plant Industry (CPI), Canberra)
    b. Variety selection (with CPI at the Australian Cotton Research Institute (ACRI), Cotton Seed Distributors (CSD) and Deltapine)
    c. Agronomic and crop physiology (with CPI at the ACRI and CSD)
    d. Spinning mill and dye house management (with Uster Technologies and the Australian Cotton Shippers Association (ACSA)).
2. Calibrate SiroMat using the 104 ITC reference cottons and publish data demonstrating the goodness of SiroMat to predict fibre maturity.
3. Match SiroMat instruments and measure their random and experimental error according to the classical fineness and maturity models elucidated by Montalvo *et al* of the United States Department of Agriculture (USDA) Agricultural Research Service (ARS). Publish data showing the examination of error by the classical fineness and maturity models.

In recent discussions with the CRDC (August 2007) formal demonstration of SiroMat with respect to spinning mill set-up and yarn quality via a yarn prediction system was proposed. The yarn prediction system would combine SiroMat and other fibre tests with yarn data in order to demonstrate SiroMat's usefulness to spinners. Data from an overseas spinning mill using premium Australian cotton, e.g. Sicala 350B, would be used to model the yarn prediction system. A separate preliminary research proposal to look at how mills would use this type of data; entitled 'Predicting Yarn Quality from Cotton Fineness and Maturity Measurements', has been submitted to the CRDC.

Business Actions to Market

With the aforementioned technical information in hand the objective of the Business Plan is to continue communication and engagement with the three companies that to date have indicated formally via written email or letter an interest in the SiroMat technology, and which have capability to manufacture and/or distribute the instrument. Table IV below lists the particular companies, their relative size and interest in SiroMat.

As the technical objectives of SiroMat are achieved formal meetings will be arranged with these companies to discuss the action of commercialising SiroMat. At this point in time CTFT regards Uster Technologies as the best opportunity for SiroMat with BSC Electronics having a possible role in the manufacture of SiroMat. The evaluation plan agreed with Uster Technologies in April of this year appears in Appendix 2.

Table V lists planned meetings and subjects to be raised with each company.

Table IV – Companies Interested in Developing SiroMat

Company	Location	Size	Response to SiroMat
Uster Technologies	Knoxville, TN, USA	Largest	Interested – licensee
Premier Evolvics	Coimbatore, India	Medium	Interested – licensee
BSC Electronics	Perth, WA, AUS	Small	Interested – manufacturer

Table V – Planned Face-to-Face Meetings between CTFT and Interested Companies during 2007/2008

Company	Meeting Date & Location	Subject
Uster Technologies	Sep 2007, Knoxville TN USA	Discuss SiroMat and Cottonscan progress
	Jan 2007, Nashville TN USA	Report SiroMat progress against evaluation plan – ability to predict dyeing
	Apr 2008, Bremen Germany	Report SiroMat progress against evaluation plan – inter-instrument variation and colour correction
	before Jun 2008, Knoxville TN USA	Assessment of SiroMat progress against evaluation plan
Premier Evolvics	Apr 2008, Bremen Germany	Report SiroMat progress – inter-instrument variation and colour correction
BSC Electronics	Nov 2007, Perth WA	Discuss SiroMat progress
	before Jun 2008, Belmont VIC	Assessment of SiroMat progress

APPENDIX 1

Patent protection history

Action	**Date/*App. No.***
CSIRO Invention Disclosure	June 2003
Provisional patent drafted	July 2003
IPM patent search results received	September 2003
Provisional patent draft approved	January 2004
Provisional patent lodged	February 2004 *2004900263*
International patent lodged	January 2005 *PCT/AU2005/000061*
Receive IPER, which agrees Siromat is patentable	February 2006
Enter national phase of International patent application. Countries include: – Australia – Brazil – China – EU – India – Indonesia – Japan – S. Korea – Mexico – USA – Vietnam	From July 2006 *2005205614* *application for exam Aug 2007* *application for exam Jul 2007* *05700093.7* *850/MUMNP/2006* *W-00200602019* *PA/A/2006/007712*

APPENDIX 2

Proposed Uster/CSIRO SiroMat Evaluation Trials 2007

Background
Following a demonstration of the SiroMat polarized light microscopy instrument at Uster Technologies in Knoxville TN on January 8th 2007 it was proposed that Uster, as a party interested in the SiroMat technology, combine with CSIRO to evaluate the instrument according to the two objectives detailed below.

Under the proposal CSIRO will provide Uster with information describing the performance of the SiroMat in differentiating cotton of same micronaire but different maturity. In return Uster can provide feedback, samples and direction with regards to this assessment.

Furthermore, CSIRO will provide test statistics on the inter-instrument variation between SiroMat instruments.

Objective A:
Test ability of SiroMat to distinguish cotton with same micronaire but different maturity. It was noted during discussions at Uster that the SiroMat had ranked a set of 10 cotton samples (supplied by Uster) differently in terms of fibre maturity – see the report 'Comparison between CSIRO SiroMat and AFIS test results on maturity' by Dr. Roger Riley and Anja Schleth. Thus in this objective the ability of SiroMat to distinguish maturity will be measured on two sets of fibre samples containing cottons with the same micronaire. The sample sets have been supplied from the ITC at Texas Tech and CSIRO Plant Industry.

The ITC set (set one) is a sub-set of samples from the 104 international cottons that have been cross-sectioned according to Dr. Devron Thibodeaux and measured for theta, wall area and perimeter by image analysis by Dr. Bugao Xu. SiroMat maturity values for cottons in the ITC set will be compared with cross-sectional reference data from the ITC set and maturity measured on the ITC and CSIRO AFIS instruments.

The CSIRO samples (set two) contain pairs of cottons with similar micronaire values but different maturities. Cottons from this set will be tested on HVI, AFIS and SiroMat, spun into 20 tex yarn, knitted into the same fabric and dyed together in the same dyebath. SiroMat values for this set will be compared with dye uptake and fabric appearance tests including colorimetry tests on fabric created from each fibre sample. Selected fibre property values for each set are listed in Tables I and II.

Objective B:
Demonstrate agreement between (3) SiroMat instruments and partition variation according to each optical component i.e., camera, waveplate, illumination (lamp and power supply) and between replicate specimens.

Materials:
Two sets of cotton have been gathered. Set one contains (10 g) samples from the ITC International set of cross-sectioned cottons (Table I). The sub-set has been selected on basis of same micronaire (X) but different fibre maturity (M). The maturity values in this sub-set are corroborated by cross-sectional data. Set two contains samples (200+ g) of pre-release varieties that have same micronaire but different maturity and fineness co-ordinates (Table II).

Table I – Sub-set of samples from ITC International set of cross-sectioned cottons for analysis by SiroMat

ID	X	M*	Θ	P
2684	3.4	0.88	0.52	45.8
3170	3.4	0.83	0.432	55.7
2952	4.0	0.89	0.536	47.7
3119	4.0	0.83	0.474	54.8
3122	4.22	0.91	0.542	49.4
3138	4.22	0.85	0.451	57.7
3152	4.32	0.89	0.513	53.3
3165	4.32	0.84	0.53	53.1
3042	4.49	0.90	0.517	50.6
3159	4.49	0.82	0.49	58.1
3143	5.12	0.95	0.594	50
3196	5.12	0.87	0.578	52.7

*** AFIS determination**

Table II – Set of samples from CSIRO for analysis by SiroMat

ID	X	M**	H**
531 mv - 55	4.8	0.96	207
531 mv - 50	4.8	0.95	202
531 mv - 44	4.9	0.99	183
531 mv - 58	4.7	0.99	182
531 mv - 38	4.4	0.93	183
531 mv - 67	4.4	0.93	183
531 mv - 71	4.4	0.97	174
531 mv - 70	4.4	0.98	173

**** FMT determination**

Timeline and Reporting:

April07 – Feedback to CSIRO on proposal and sample sets to be tested

May07 – SiroMat and CSIRO AFIS testing complete

Jul07 – CSIRO samples spun and knitted

Aug07 – CSIRO fabric samples dyed and colorimetry

Oct07 – Report on inter-instrument variation

Jan08 – Full report describing completion of objectives A and B

Apr08 – Full report given at Bremen ITMF Committee Meeting

The Accuracy and Precision of the SiroMat™ Instrument

Graham Higgerson, Stuart Gordon, Nicole Phair-Sorensen, Stuart Lucas and Susan Miller

Cotton Research Unit,
CSIRO Materials Science and Engineering,
Belmont VIC 3216,
Australia

Abstract

The accuracy and precision of the SiroMat™ instrument, an instrument that directly measures cotton fiber maturity is examined. The accuracy of SiroMat™ is illustrated using a sub-set of international cottons with reference values of fiber maturity measured according to the recognized fundamental method. The precision of the SiroMat™ instrument is measured by assessing the repeatability of test results on mature and immature cotton. The accuracy and precision of the instrument are largely defined by the relationship between color area measurements and measured maturity values of a reference material. It is noted that the inherent experimental error of the reference material measurements is likely to be significant in determining the accuracy of SiroMat™.

Introduction

SiroMat™ is an automated version of the polarized light microscopy (PLM) Standard Test Method (ASTM D1442, 2000), which uses interference colors transmitted by cotton fibers placed between crossed polar lenses and a first order retardation plate, to identify the maturity of a cotton specimen. In previous work Gordon and Phair (2005a) surveyed a wide range of cotton fibers from different cotton plant species that had widely divergent cross-sectional fiber properties. They found the yellow hue transmitted by fibers under PLM was independent of cross-sectional wall area and perimeter and dependent only upon relative fiber wall thickening. This suggested the case for an automated and therefore objective version of the PLM test would be successful.

Previous work has illustrated how SiroMat™ data including measurements of the maturity distribution in a specimen, may be used with respect to establishing linkages between agronomy and crop physiology work and fiber quality (Gordon *et al*, 2007; Long *et al*, 2008 and Bange *et al*, 2009) and in determining and controlling mill quality with respect to fiber maturity (Gordon *et al*, 2008). This paper discusses the accuracy and precision of the SiroMat™ in relation to the image analysis processes used by the instrument to capture information about fiber maturity. The paper represents an interim report on work currently being undertaken to calibrate SiroMat™ with the 104 International Textile Center (ITC) fiber maturity reference cottons (Hequet *et al*, 2006). For this paper the accuracy of SiroMat™ is demonstrated on a small sub-set of the ITC cottons, whilst precision is demonstrated in terms of repeat measurements over time.

Materials and Methods

Selection and preparation of cotton samples

A small sub-set (N = 15) of the 104 ITC reference cottons representing a wide range of maturity (theta) and fineness (cross-sectional area & perimeter) values was selected. Theta measured from the dimensions of fiber cross-sections is regarded as the most accurate measure of relative fiber wall thickening (Lord and Heap, 1988). Table I lists the cottons in this sub-set with their cross-sectional fiber maturity and fineness values. Figure 1 provides an illustration of the range of maturity values included in the set. For convention theta values are converted to maturity ratio values using the conversion co-efficient of 0.577 determined by Pierce and Lord (1939); i.e. maturity ratio = theta/0.577.

Preparation of SiroMat™ specimens from the ITC cottons involved guillotining a fiber beard prepared using a 'Fibrosampler' to obtain between 2 to 3 mg of 1 mm snippets from two cuts near the aligned end of the beard. Snippets were collected and then spread in an annular pattern on a 5 cm x 7 cm glass slide using an OFDA™ fiber spreader. A clean 5 cm x 7 cm slide was used to cover the specimen. Castor oil (refractive index = 1.477 – 1.481) was used as the mounting medium to enhance the contrast of the fiber snippets to their background. Four specimens were prepared and tested for each of the selected ITC cottons.

Instrument testing – image analysis

Preparing the SiroMat™ instrument for testing involves allowing the light source to reach its optimum color temperature (for a halogen light source) and adjusting the digital camera settings (U balance, V balance and shutter speed) to a prescribed background (magenta) color in terms of red, green and blue (RGB) ratios. The prescribed background co-ordinates are predetermined empirically by measuring a range of fiber maturity samples to determine the greatest range in terms of percent area of yellow hue in the snippets presented. Background colors are checked at regular intervals during testing to minimize drift in instrument readings.

SiroMat™ automatically captures and analyses cotton fiber snippet images in 36 fields of view; each of approximately 9 mm^2, as shown in Figures 2a and 2b. From these images the percent area of particular interference colors assumed by the snippets under PLM is determined. These area measurements are then converted to conventional maturity values via a conversion or calibration equation.

The percent area measurement is determined using a series of standard image analysis functions starting with edge detection to find the boundaries of fibers, followed by image dilation to join small disconnected pieces (pixels) together. At this stage the image is converted to a binary image based on a grey-scale threshold, which is then subject to the processes of image dilation and erosion; these are standard image processing techniques used to close small holes in images. The resultant image is used as a mask to select the fiber area from the background.

Following creation of the mask the image is broken up into fiber sections according to image cross-over points. To do this the mask image is skeletonised to reveal branch points, which are used to segregate and label fiber sections. The image at this point is a mask with a number of labeled segments; each segment containing a portion of a single fiber snippet. A background correction and normalization is applied to the original color image before the proportion of pixels in each color threshold bin, i.e. yellow, red, green and blue, is counted for each segment in the mask. Color threshold levels are set according to a digital color space model, e.g. HSL, which defines changes in hue according to numerical segments between the values of 0 and 255.

Total pixel number and proportion of yellow, red, green and blue color pixels per segment are counted along with the major and minor lengths from which the aspect ratio is calculated and reported. Small segments can be filtered and excluded from the data set at this stage, although the optimum segment size is still being assessed. A conversion equation is then applied to produce a maturity scale number; for convention the scale is given in terms of maturity ratio, the number reported by the ASTM Standard Test Method D1442 (2000).

The analyzed segments now with a maturity ratio value can be then be sorted according to their frequency into a distribution of MR segments from which the mean, standard deviation and skewness can be calculated and reported.

Data analysis

Raw color image analysis measurements (Table II) were related to ITC reference values in a correlation matrix in order to determine the legitimacy of independent variables (IVs), i.e. percent area of the yellow, red, green and blue, for inclusion in a regression to predict the dependent variable (DV) maturity ratio. Table III lists the Pearson correlation and probability values for the relationship between each variable.

Maturity ratio values (DV) determined from theta values by Hequet *et al* (2006) were regressed with measured color data (IVs) from SiroMat™ in a forward stepwise regression using Minitab 15. Given the small number of samples ($N = 15$) and relatively large number of IV ($k = 5$) the F-to-enter value for inclusion of any IV into the regression equation was set at 4. Table IV lists the statistics including R-squared, adjusted R-squared, predicted sum of squares (PRESS) and Mallow's Cp, and the conversion equation coefficients and constant determined by the regression.

To determine precision one slide each with mature (no. 3074) and immature specimens (no. 3089) were run for 40 consecutive tests; a period covering around 3.5 hours. The respective variation in values over the test period is shown in Figures 3 and 4. A summary of the mean and variation in values appears in Table V.

Results

The statistical data presented in Tables III and IV shows the strong relationship between the yellow color and the ITC reference values of maturity. The significant correlation between the yellow and the measurement of maturity ratio, and the poor relationship between the yellow and perimeter ratifies earlier work by Gordon and Phair (2005a), who showed that the yellow hue of fibers varied only with fiber maturity or relative wall thickening. The poor relationship between cross-sectional area and perimeter, a result of including a number of samples with the same maturity but different perimeter and cross-sectional area combinations, further enhances the legitimacy of the set's predictive power. Indeed, a poor relationship between absolute wall thickening and perimeter is a preferred condition in a maturity 'calibration' set, as the relationship between any IV predicting maturity and maturity ratio can be compromised by a high degree of co-linearity between these properties.

The high degree of co-linearity between red and yellow colors is regarded as inconsequential as the red color is not considered unique in the conversion of measured color area to a maturity result. Indeed the color references for the ASTM Standard Test Method do not include red as a color to differentiate mature from immature fibers (Grimes, 1945; ASTM, 2000), and differentiation of the small amount of orange hue associated with very immature fibers from the red hue range is considered too difficult in the application of the (SiroMat™) test. It is interesting to note that the proportion of red analyzed in SiroMat™ images can be reduced by inserting a day light filter across the field of view. A day light filter also increases the proportion of yellow and green analyzed although not the range of values.

Considering the small set tested here, the resulting regression shows abundantly the significance of the yellow and green colors as the primary IVs used to predict fiber maturity; the two term (yellow and green) multiple linear regression has an adjusted R-squared of 86.8 for the relationship with theta. The goodness of this relationship is reflected in the selection of the yellow color as the most significant variable and the green color as the second most important variable. Whilst a stepwise regression includes IVs only upon their statistical strength in the model, both the yellow and green are important physical variables is deciding the relative maturity of a fiber as per the original descriptions of the PLM test (Grimes, 1945; ASTM, 2000). Further, the Mallow's Cp statistic (3.0) calculated for this small subset is consistent with the ideal Mallow's Cp value, which should indicate the number of predictors (2) plus the constant (1); a value close to this number indicates the model is relatively precise and unbiased in predicting future response (Minitab 15, 2006).

Interestingly, the standard error of estimate (S) (0.052) and the PRESS (0.053) results whilst not directly comparable are within the same range as standard error of estimate values calculated when using SiroMat™ results to predict the percent of immature fibers in purposely constructed mature and immature fiber blends (Gordon *et al*, 2007). At that time SiroMat™ was calibrated using maturity ratio values determined from an IIC 'Shirley' FMT; the conversion equation for this calibration set also containing the yellow and green color values (Gordon and Phair, 2005b). It remains to be seen what effect a larger set of ITC reference samples has on this regression equation and what experimental error effects associated with SiroMat™ and the ITC reference values can be highlighted and partitioned.

Whilst repeat measurements over time showed no significant statistical differences between mean results measured at t_1 and t_{40}, there were significant trends away from the value recorded at t_1 for the immature sample. Longer examination and consideration of the light source used to illuminate the SiroMat™ specimen is required to understand these trends further.

Conclusion

In this paper a small sub-set of ITC with accepted reference values of fiber maturity (theta) measured according to the fundamental method were measured by SiroMat™. Raw color values measured by SiroMat™ were cast as IVs and subject to a competitive stepwise regression process with the maturity reference values. The results of this analysis reflected previous unpublished work (Gordon and Phair, 2005b), which showed the yellow and green hues of fibers under PLM were the most appropriate variables, both from statistical and physical perspectives, to predict fiber maturity.

Longer examination and consideration of the light source used to illuminate SiroMat™ specimens is required to understand the variation seen between repeat tests particularly for immature fiber specimens.

Acknowledgements

The authors would like to acknowledge the financial support of the Australian Cotton Research and Development Corporation, the Cotton Catchment Communities Co-operative Research Centre and CSIRO Materials Science and Engineering.

References

American Society for Testing and Materials Designation: D1442-00, Standard test method for maturity of cotton fibers (sodium hydroxide swelling and polarized light procedures), 354-359, 2000

Bange, M., Long, R. L., Constable, G. and Gordon, S. G., Evaluation of in-field monitoring methods to reduce neps, *proceed.* Beltwide Cotton Conferences, National Cotton Council, San Antonio TX, Jan 2009

Gordon, S. G. and Phair, N. L., An investigation of the interference colours transmitted by mature and immature cotton fibre under polarised light microscopy, *proceed*. Beltwide Cotton Conferences; New Orleans LA, Jan 2005a

Gordon, S. G. and Phair, N. L., Unpublished work, Jun 2005b

Gordon, S. G., Long, R. L., Bange, M., Lucas, S. and Phair-Sorensen, N. L., Measurement of average maturity and maturity distribution statistics by SiroMat in Cotton fibre subject to differential defoliation timing treatments, *proceed.* Beltwide Cotton Conferences, National Cotton Council, New Orleans LA, Jan 2007

Gordon, S. G., Long, R. L., Lucas, S. R. and Phair-Sorensen, N. L., Using SiroMat to distinguish fibre maturity related issues in the mill, *proceed.* Beltwide Cotton Conferences, National Cotton Council, Nashville TN, Jan 2008

Grimes, M. A., ‘Polarized Light: Preferred for Maturity Tests’, *Textile World*, 161-163, February 1945

Hequet, E. F., B. Wyatt, N. Abidi and D. P. Thibodeaux, Creation of a set of reference material for cotton fiber maturity measurements, *Textile Res J*, **76(7)**: 576-586, 2006

Long, R. L., Bange, M., Gordon, S. G. and Van der Sluijs, M. J. H., The effect of different harvest aid timing treatments on fibre quality and textile performance, *proceed.* Beltwide Cotton Conferences, National Cotton Council, Nashville TN, Jan 2008

Lord, E. and Heap, S. A., The origin and assessment of cotton fibre maturity, International Institute for Cotton, 40 pp., 1988

Pierce, F. T. and E. Lord. The fineness and maturity of cotton, *J. Textile Inst.*, **30**:T173-T210, 1939

Table I – Measured cross-sectional properties of ITC sub-set

Sample	XS Area (μm^2) Mean	Perimeter (µm) Mean	Theta Mean	Maturity ratio Mean
2684	84.6	45.8	0.52	0.90
2999	89.7	51.1	0.45	0.78
3008	82.1	48.0	0.47	0.81
3074	134.4	54.7	0.57	0.99
3089	91.5	61.3	0.33	0.57
3096	100.4	57.6	0.40	0.69
3104	106.5	56.9	0.43	0.75
3112	121.7	54.3	0.54	0.93
3115	97.2	59.0	0.37	0.64
3156	115.3	50.0	0.59	1.02
3159	125.5	58.1	0.49	0.85
3167	124.3	53.4	0.56	0.98
3183	121.0	55.4	0.51	0.89
3212	108.6	47.7	0.61	1.05
4409	124.8	54.3	0.55	0.94

XS = cross-sectional

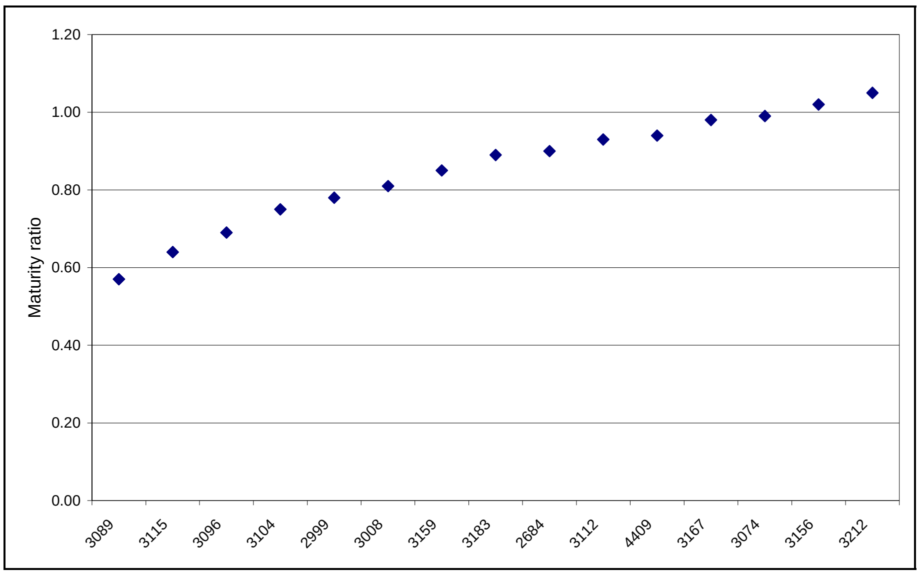
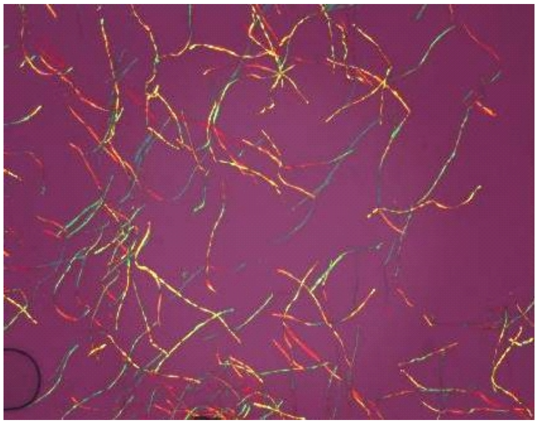


Figure 1 – Range of maturity ratio values in the tested ITC sub-set



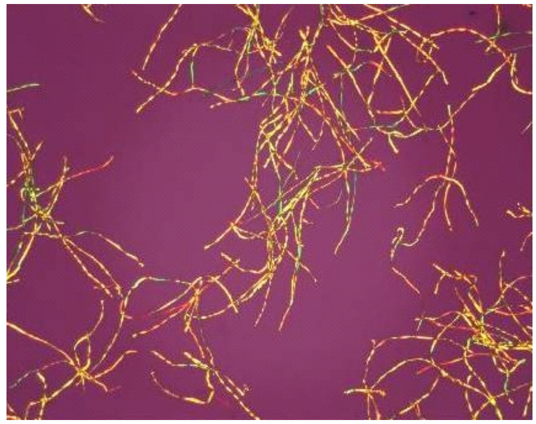


Figure 2a **Figure 2b**

Immature (2a) and mature (2b) fibers in the SiroMat™ field of view

Table II – Unfiltered image analysis color results – color values represent percent of color area (pixel) measured in analysis

	Yellow	**Red**	**Green**	**Blue**
2684	28.87	68.03	0.39	0.93
2999	25.48	71.93	0.27	0.59
3008	19.60	78.40	0.08	0.21
3074	35.43	62.24	0.23	0.22
3089	17.29	79.98	0.22	1.03
3096	22.83	74.15	0.33	1.04
3104	34.46	62.11	0.50	1.10
3112	33.18	64.34	0.30	0.37
3115	26.29	69.73	0.47	1.83
3156	35.70	61.65	0.31	0.41
3159	30.10	67.14	0.32	0.70
3167	35.85	61.43	0.37	0.53
3183	32.84	64.44	0.39	0.61
3212	31.78	65.94	0.17	0.23
4409	33.07	64.41	0.28	0.41

Table III – Correlation matrix (Pearson correlation and *probability*) of ITC and SiroMat™ IA values

	XS Area	**Perimeter**	**XSMR**	**Yellow**	**Red**	**Green**	**Blue**
Perimeter	0.254 *0.361*	-					
XSMR	0.582 *0.023*	-0.631 *0.012*	-				
Yellow	0.778 *0.001*	-0.180 *0.521*	0.766 *0.001*	-			
Red	-0761 *0.001*	0.143 *0.612*	-0.721 *0.002*	-0.997 *0.000*	-		
Green	0.133 *0.637*	0.358 *0.190*	-0.212 *0.448*	0.383 *0.159*	-0.453 *0.090*	-	
Blue	-0.380 *0.162*	0.550 *0.162*	-0.759 *0.001*	-0.327 *0.155*	0.249 *0.235*	0.693 *0.370*	-

Table IV – Stepwise regression statistics

Response is XSMR on 4 predictors, with N = 15		
Step	1	2
Constant	0.3102	0.3875
Yellow	1.84	2.38
P-value	*0.001*	*0.000*
Green		-77
P-value		*0.000*
S	0.0956	0.0521
R-Sq	58.72	88.68
R-Sq (adj)	55.55	86.80
Mallows Cp	32.9	3.0
PRESS	0.16237	0.053105

Table V – Mean and variation in SiroMat™ repeat measurements (n = 40) over time

	ITC sample no.	
	3074 Mature	**3089 Immature**
Mean	0.942	0.705
Std	0.002	0.004
CV%	0.19%	0.60%

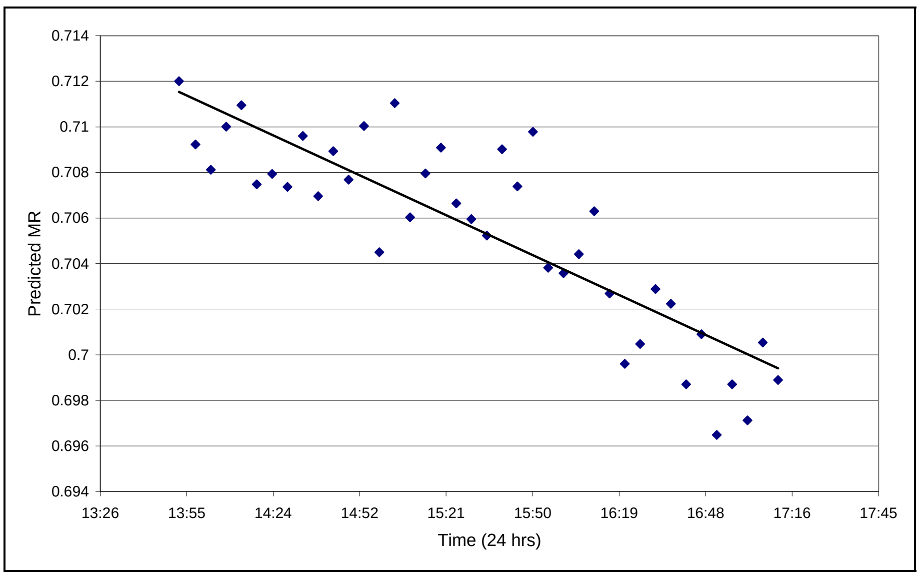


Figure 3 – MR test results over time (t_1 – t_{40}) for immature fiber specimen

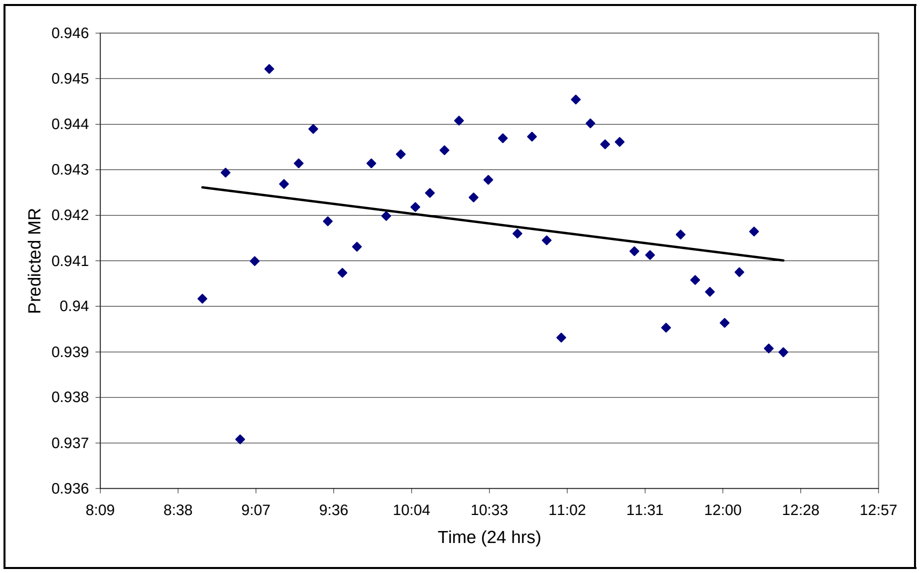


Figure 4 – MR test results over time (t_1 – t_{40}) for mature fiber specimen

USING SIROMAT TO DISTINGUISH FIBER MATURITY RELATED ISSUES IN THE MILL

S. G. Gordon
R. L. Long
S. R. Lucas
N. L. Phair-Sorensen
CSIRO Textile and Fibre Technology
Belmont, Victoria, Australia

Abstract

Fibre maturity is regarded as a central characteristic of cotton fibre through its direct and indirect correlation with physical and chemical properties of commercial and technical importance. SiroMat is an automated version of the polarized light microscopy technique, which analyzes interference colours transmitted by cotton fibres when they are placed between crossed polars and a first order retardation plate. The percent areas of colours in images of fibre snippets relate directly to fibre maturity. Moreover, because fibres are analyzed on an individual basis a maturity distribution for a sample can also be measured. In this study two sub-sets of cotton each with the same average Micronaire but with different fibre maturity values as measured by SiroMat were processed from raw fibre through to dyed finished knit fabric. The objective of the study was to examine the sensitivity of SiroMat average maturity and distribution values in predicting differences in griege yarn and dyed fabric quality. Results of the study demonstrate the relevance of SiroMat test results in terms of predicting fibre maturity and fineness related quality problems and in particular the potential for SiroMat to be used as a tool for managing dye uptake problems at the mill laydown.

Introduction

From the spinners' perspective, both fibre maturity and fineness are key parameters in determining mill productivity and quality. For example, yarn is specified in terms of its weight per unit length and fibre linear density or fineness determines the number of fibres in a given yarn cross-section. The use of finer fibres increases the number of fibres in the cross section of a given yarn, which improves spinning efficiency and yarn evenness. Equally cotton fibre maturity is an important property to spinners and fabric manufacturers. Whilst many textile processing stages in the transformation of fibre through to fabric are sensitive to fibre properties that are contiguous with fibre maturity, the property of fibre maturity *per se* is more often not the dominant factor [Smith, 1991] in the same way that fineness, staple length and bundle strength dominate yarn quality parameters. The exception is perhaps the non-uniform dyeing of fabric; manifest as shade bands and repeats along fabric lengths, colour yield, barré and under-dyed or undyed neps, which is directly related to fibre maturity variations in the cotton being processed.

A central problem in managing fibre fineness and maturity has been the absence of accurate and convenient test methods to assess these properties. CSIRO Textile and Fibre Technology have developed the SiroMat technology that measures fibre maturity directly and automatically using polarized light microscopy [Gordon et al., 2005]. The interference colors transmitted by cotton fibres under this system are the result of the optical phenomena where cotton fibres behave like uni-axial optical (birefringent) crystals under polarized light. Previous work has shown that specific interference colours vary directly with theta (θ) [Gordon and Phair, 2005], which is generally accepted as being the 'true' expression of cotton fibre maturity [Lord and Heap, 1988].

By combining SiroMat values of maturity, which are calibrated in terms of maturity ratio, with the specimen's Micronaire value a measure of fineness can also be calculated using Lord's quadratic [Lord, 1956].

The objective of this study was to examine the sensitivity of SiroMat average maturity and distribution values (standard deviation and skewness values) in predicting differences in griege yarn and dyed fabric quality. Results of the study demonstrate the relevance of SiroMat test results in terms of predicting fibre maturity related quality problems such as non-uniform dyeing, and the potential for SiroMat to be used as a tool for managing mill laydowns.

Materials and Methods

Eight, small fibre samples (150 grams) of CSIRO pre-release cotton varieties grown on experimental plots at the Australian Cotton Research Institute (ACRI) in Narrabri, NSW were selected and processed through to a dyed knit fabric. The fibre samples were selected on the basis of having the same or similar Micronaire value but different maturity and fineness combinations. Table I lists the primary properties of the samples (designated A through to H) determined by an Uster Technologies 1000 high volume instrument (HVI). Two equal sub-sets are evident in the set of samples collected; one sub-set with samples having Micronaire values around 4.8 and one with Micronaire values of 4.4.

Specimens of each cotton sample were prepared for SiroMat testing by blending them through one passage of a 'Shirley' Analyser. Specimen preparation then involves guillotining a fibre beard prepared using a 'Fibrosampler' to obtain between 2 to 3 mg of 1 mm snippets from two cuts near the aligned end of the beard. The snippets were collected and then spread in an annular pattern on a 5 cm x 7 cm glass slide using an OFDA™ fibre spreader. A clean 5 cm x 7 cm slide was used to cover the specimen. Castor oil (refractive index = 1.477 – 1.481) was used as the mounting medium to enhance the contrast of the fibre snippets to their background. Preparing the SiroMat instrument involved adjusting the digital camera settings (U balance, V balance and shutter speed) and the microscope lamp intensity to match a prescribed background (magenta) colour in terms of red, green and blue ratios. Background colours were also checked at regular intervals during testing to minimize drift in instrument readings. Three specimens were tested per sample.

SiroMat maturity ratio (M) results were combined with HVI Micronaire (X) results to calculate fibre linear density or fineness (H) using Lord's quadratic equation [Lord, 1956] – see Equation (1). Table II lists the measured and derived SiroMat test results for each cotton sample.

$$MH = 3.86X^2 + 18.16X + 13 \qquad (1)$$

Spinning

One hundred and twenty-six grams (3 x 42 g lots) of machine harvested ginned lint (not lint cleaned) was sub-sampled from each experimental sample. Each 42 g lot was separately carded twice and drawn once using a 'Shirley' miniature spinning plant card and draw frame (Platt brothers, England); machine settings (e.g. roller distances and draft ratio) were constant for all samples. The four miniature drawn slivers were then drawn together once using a Trützschler HSR1000 draw frame. The resulting single sliver was converted into twisted roving using a Zinser 660 roving frame, which was then spun into yarn using a Zinser 350 ring spinning frame. For the full-scale processing, draft and twist was optimised for each sample to deliver a 20 tex yarn with a twist factor (αe) of 4.0 (798 turns per metre). Yarn bobbins were collected (two per sample) and tested for count, evenness (Uster Tester 4) and tensile (Uster Tensorapid) properties using industry standard methods. Table III lists standard yarn test results for each cotton sample.

Knitting and Dyeing

Yarn bobbins were waxed and wound but not cleared onto packages for knitting into fabric. Yarns were then knitted with a cover factor of 1.32 and a tightness factor of 15.4, on a Lawson Hemphill 10 inch F.A.K. knitting machine.

Knitted fabric was scoured and then dyed with Cibacron blue LS3R (1%) reactive dye. Colour measurements ($L^*a^*b^*$) were taken of fabrics illuminated using a D65 source at 10 degrees in a Gretag-Macbeth Color-Eye 7000A spectrophotometer. Average $L^*a^*b^*$ values (Table IV) represent nine spectrophotometric measurements taken in different places along the length of fabric from each cotton sample. Table V lists the ΔE values between each sample.

Selected dyed fabric samples (A, D, F & H) were also subject to extended pilling tests using the Atlas Random Tumble method [ASTM D3512]. Fabric samples were graded at 10 minute intervals up to 30 minutes and then subject to an additional 30 minutes treatment in the device. Fabric weight was recorded before and after the treatment in order to determine fibre loss.

Data Analysis

Fibre, yarn and fabric property results for each sample were cross-correlated using Minitab 15.1 to determine significant inter-relationships between samples in the set, and the fibre properties best used to predict yarn and fabric quality. The emphasis in this analysis is to investigate the ability of the SiroMat instrument to predict product quality in a mill. Table VII lists the primary fibre, yarn and fabric properties examined in the discussion. Significance was measured in terms of the Pearson Correlation Co-efficient (r) and the (linear) relationship probability. Whilst a linear relationship may not accurately describe particular relationships here, it is satisfactory in describing the significance of differences between extreme values in the small sets (n = 8) examined here.

Colour differences between the dyed fabric samples were measured in terms of ΔE on the CIELAB system [Westland and Ripamonti, 2004], which allows for differences to be better recognised in surface colours. Delta E describes the mathematical distance between two colours, e.g. $L_1a_1b_1$ and $L_2a_2b_2$, where $L_1a_1b_1$ might, although not in the case here, be a reference colour – see Equation (2).

$$\Delta E = \text{SQRT}\ (L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2 \qquad (2)$$

We identify ΔE values near or greater than one between any two fabrics here as being significant on the basis of the monochromatic nature of the dyed samples and the fact that in industry the samples would be viewed side-by-side as adjacent bands in knitted fabric.

Results and Discussion

The cotton samples were grown and harvested under near commercial conditions and as such reflect fibre maturity and fineness values that might be expected in similar grade cottons for a particular season. The range of maturity values in the set as measured by SiroMat was 0.90 to 0.98. According to Lord and Heap [Lord and Heap, 1988] this range qualifies all cottons in the set as being ‘mature’ or ‘above average’ in maturity; the ‘mature’ range extending from 0.85 to 0.95 and the ‘above average’ range extending from 0.95 – 1.00. From this perspective none of the cotton samples selected rate as being dangerous in terms of the impact their maturity (or fineness) might have on processing efficiency or product quality.

Of the samples in the set, sample H is nominally the best on the basis of its length (1.31 inches), strength (35.3 g/tex), fineness (171 mtex) and maturity (0.98). These properties clearly enabled a yarn with the best evenness and tensile properties to be spun (see Table III). In terms of fabric properties, sample H achieved a deeper colour (lowest L^* value) as dyed fabric, and exhibited, albeit together with a sample (F) with the lowest measured maturity, the best pilling grade after extended tumbling treatment. The pilling results whilst completed in triplicate and conducted according to the ASTM Standard [ASTM D3512] rely on subjective assessment and must therefore be viewed with caution.

Following the above example, examination of the correlation coefficient matrix (see Table VII) shows that fibre fineness measured either as Micronaire or linear density, staple length and bundle strength have a strong influence on basic yarn quality parameters such as evenness, imperfections and tenacity. No fibre maturity measurements were highlighted as being significant contributors to yarn properties.

However, average SiroMat maturity ratio and the SiroMat measure of the skew of the fibre maturity ratio distribution were strongly associated with bulk dye uptake measured in this study by reflectance (L^*) (lightness) measurements on the dyed fabric. Fabric samples constructed from more mature fibre, e.g. a maturity ratio > 0.94, dyed a deeper blue colour (lower reflectance) than samples with maturity ratio values < 0.94 by virtue of the greater uptake of blue dyestuff by the secondary cellulose of the more mature cotton. Skew values indicate that more mature cottons have a longer immature tail. This relationship has been described previously [Gordon, et al, 2007]. Figure 1 illustrates a typical fibre maturity distribution and the long immature tail of ‘mature’ cotton, as measured by SiroMat. Figures 2 and 3 illustrate the relationship between reflectance measurements and average maturity and the skew of a fibre maturity distribution. Relationships between fibre properties and actual colour (hue) values, a^* (red-green) and b^* (yellow-blue) were subdued because the hue components of the CIELAB colour system are not significantly affected by the achromatic changes measured by L^*.

The extent of the differences in dye uptake between cotton samples in this set as a result of their different maturity properties is demonstrated by calculating the ΔE values between pairs of the samples. Table V lists the ΔE values. Noted is that sample F, which has the lowest maturity ratio value (0.90) records ΔE values close or in excess of one for 4 out the five more mature samples, i.e. A, B, C and H in the set.

Conclusion

In this study we have demonstrated the value of SiroMat maturity, maturity distribution and calculated fineness values to predict primary quality in yarn, fabric and dyed fabric. Calculated fibre fineness from HVI Micronaire and SiroMat maturity ratio values was very strong in predicting yarn evenness and imperfections, whilst SiroMat skewness of the maturity distribution and average maturity ratio were strong in predicting dye shade variation. Interestingly, significant shade variation between samples occurred even though the range of maturity ratio values was between 0.90 and 0.98, which by convention would classify all samples examined as being 'mature' or 'above average' in maturity. The results show that mixing (yarn) samples that differ in terms of their maturity ratio scale by > 0.04 maturity ratio units will create dye shade problems, i.e. ΔE > 1.00, irrespective of the fibre being 'immature'.

Acknowledgments

The authors acknowledge the Cotton Catchments Communities Co-operative Research Centre, the Australian Cotton Research and Development Corporation and the CSIRO for financial support. The authors are also very grateful to Dr. Greg Constable from the ACRI for the fibre samples and HVI results used in this study, and to Fred Horne, Mark Freijah, Susan Miller, Geni Kozdra and Susan Horne for their technical assistance.

References

ASTM D3512-96, Standard Test Method for Pilling Resistance by the Random Tumble Method.

Gordon, S. G., Long, R. L., Bange, M., Lucas, S. and Phair-Sorensen, N. L., Measurement of Average Maturity and Maturity Distribution Statistics by SiroMat in Cotton Fibre Subject to Differential Defoliation Timing Treatments, Proceedings Beltwide Cotton Conferences, National Cotton Council, New Orleans LA, January 2007

Gordon, S. G., Lucas, S and Phair, N. L., 'Method and Apparatus for Testing Fibres', Patent No. AU2005000061, 2005

Gordon, S. G. and Phair, N. L., An Investigation of the Interference Colours Transmitted by Mature and Immature Cotton Fibre under Polarised Light Microscopy, *proceed*. Beltwide Cotton Conferences, New Orleans, LA, January 2005

Lord, E., Air through plugs of textile Fibres, Part II. The Micronaire Test for Cotton, *J. Textile Inst.*, **47**, T17-T47, 1956

Lord, E. and Heap, S. A., 'The Origin and Assessment of Cotton Fibre Maturity', International Institute for Cotton (pub.), 40 pp., 1988.

Smith, B., A Review of the Relationship of Cotton Maturity and Dyeability, *Textile Res. J.*, **61**, 137-145, 1991

Westland, S. and Ripamonti, C., Computational Colour Science using MATLAB, John Wiley and Sons (pub), 205 pp., 2004

Table I – HVI Test Results

Sample	LEN (inches)	SFC (%)	STR (g/tex)	MIC (µg/inch)
A	1.18	9.1	30.6	4.8
B	1.20	10	31.4	4.8
C	1.21	8.9	31.7	4.9
D	1.21	8.3	33.4	4.7
E	1.24	9.8	31.8	4.4
F	1.26	8.7	32.9	4.4
G	1.27	9.9	32.6	4.4
H	1.31	8.2	35.3	4.4

Table II – SiroMat Test Results

Sample	SiroMat MR	SiroMat MR SD	SiroMat MR SK	SiroMat FIN
A	0.97	0.44	-2.37	194
B	0.95	0.47	-2.43	199
C	0.94	0.46	-2.28	207
D	0.93	0.48	-2.29	198
E	0.93	0.48	-2.21	180
F	0.90	0.50	-2.12	185
G	0.96	0.45	-2.41	174
H	0.98	0.44	-2.49	171

Table III – Yarn Test Results

Sample	Evenness CVm (%)	Thin -50%	Thick +50%	Neps +200%	Tenacity (cN/tex)	Elongation (%)
A	17.5	35	368	234	14.7	6.1
B	18.1	45	463	242	14.9	6.2
C	18.1	30	587	658	16.3	5.9
D	16.5	18	318	274	18.9	5.4
E	16.0	9	282	298	17.1	6.1
F	15.7	14	230	266	16.5	5.6
G	15.7	2	266	233	18.5	5.2
H	15.1	3	255	274	19.7	5.4

Table IV – Dye Uptake in Fabric Results

Sample	L	a	b
A	42.98	-2.06	-28.36
B	42.59	-1.95	-28.42
C	42.91	-2.12	-28.07
D	43.27	-2.25	-28.03
E	43.51	-2.14	-28.31
F	43.89	-2.21	-28.03
G	43.30	-2.18	-28.19
H	42.48	-2.08	-28.26

Table V – Differences in Colour (ΔE) between Dyed Fabric Samples

Sample	ΔE A vs.	ΔE B vs.	ΔE C vs.	ΔE D vs.	ΔE E vs.	ΔE F vs.	ΔE G vs.
B	0.411	-	-	-	-	-	-
C	0.301	0.497	-	-	-	-	-
D	0.471	*0.834*	0.387	-	-	-	-
E	0.529	*0.937*	0.647	0.386	-	-	-
F	**0.969**	**1.374**	**0.985**	0.619	0.477	-	-
G	0.374	0.775	0.412	0.175	0.247	0.609	-
H	0.515	0.235	0.470	*0.840*	**1.031**	**1.432**	*0.828*

Table VI – Differences in Pilling (Grade & Weight Loss) between Selected Dyed Fabric Samples

Sample	Pilling Grade				Weight in (g)	Weight out (g)	Fibre loss (%)
	10 min	20 min	30 min	60 min			
A	3	2.5	2	1.5	3.403	3.364	1.14
D	3.3	3	3	1.8	3.495	3.456	1.11
F	4	4	3.6	3	3.577	3.536	1.13
H	4	3.2	3.2	3	3.352	3.309	1.28

Table VII – Correlation Coefficients between Selected Fibre and Yarn and Fabric Properties

	CVm	Thin	Neps	Ten	*L**	*a**	*b**
LEN	**-0.870** ***0.005***	**-0.848** ***0.008***	-0.181 *0.667*	**0.746** ***0.033***	0.051 *0.905*	-0.260 *0.533*	0.185 *0.661*
STR	**-0.748** ***0.033***	-0.690 *0.058*	-0.145 *0.733*	**0.880** ***0.004***	-0.123 *0.772*	-0.348 *0.399*	0.367 *0.372*
MIC	**0.943** ***0.000***	**0.876** ***0.004***	0.481 *0.227*	-0.587 *0.126*	-0.443 *0.272*	0.403 *0.322*	-0.093 *0.826*
SM MR	0.036 *0.933*	0.018 *0.967*	-0.145 *0.733*	0.137 *0.747*	**-0.799** ***0.017***	0.538 *0.169*	-0.592 *0.122*
SM FIN	**0.898** ***0.002***	**0.833** ***0.010***	0.539 *0.168*	-0.588 *0.126*	-0.146 *0.731*	0.179 *0.672*	0.150 *0.724*
SM SDMR	-0.077 *0.856*	-0.004 *0.992*	-0.018 *0.966*	-0.098 *0.817*	**0.713** ***0.047***	-0.433 *0.284*	0.456 *0.256*
SM SKMR	-0.063 *0.882*	-0.080 *0.851*	0.220 *0.600*	0.193 *0.647*	**0.864** ***0.006***	-0.579 *0.132*	0.557 *0.152*

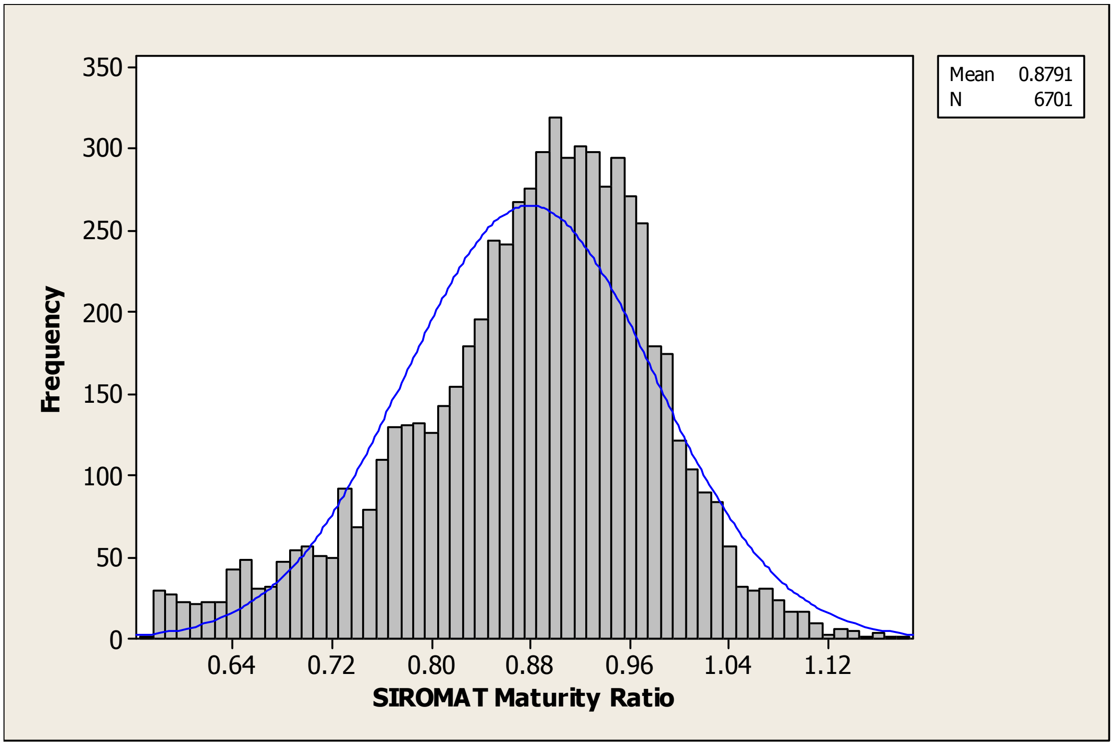


Figure 1 – Typical SiroMat MR distribution obtained for 'mature' cotton. Note negative skew with long immature tail for the average MR value of 0.88

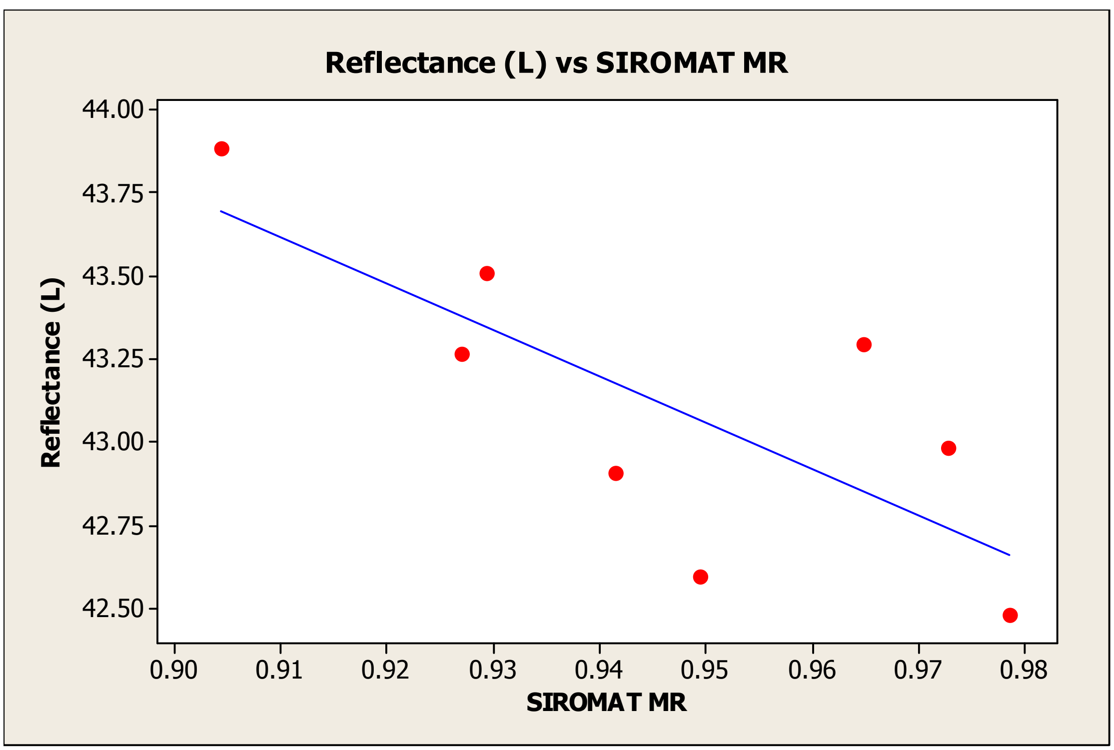


Figure 2 – Relationship between SiroMat MR and bulk dye uptake as measured by the reflectance off blue dyed knit fabric

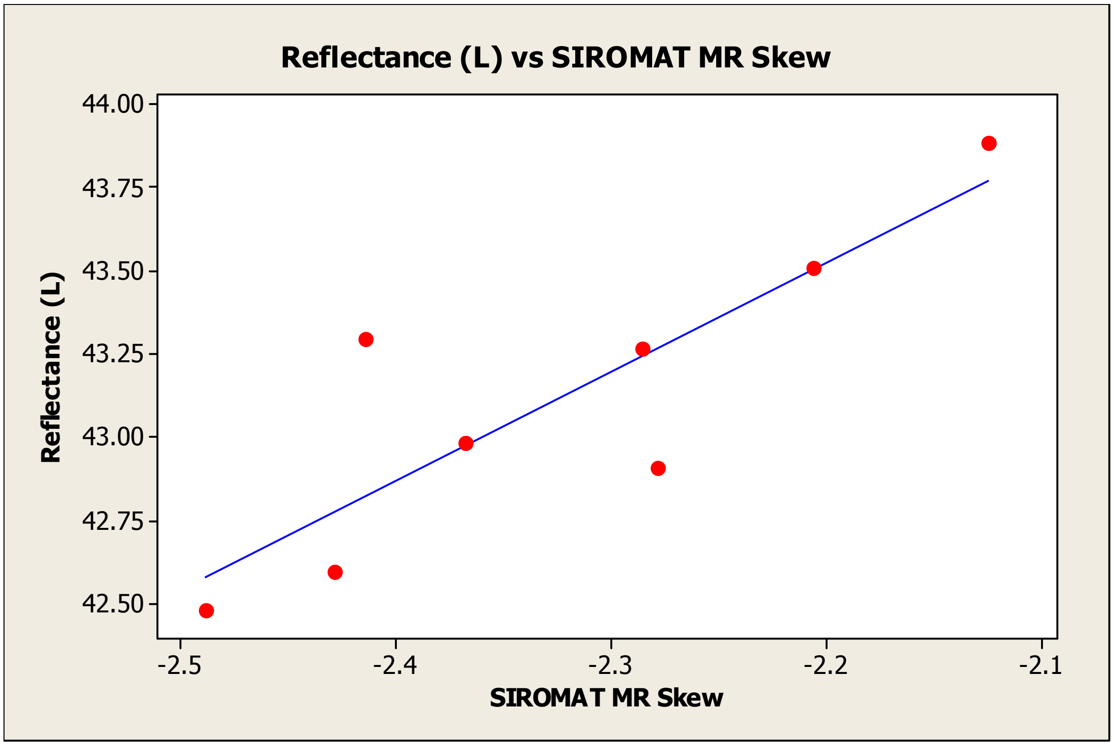


Figure 3 – Relationship between the skewness of the SiroMat MR distribution for each sample and bulk dye uptake as measured by the reflectance off blue dyed knit fabric

ASSESSING THE IMPACT OF HARVEST AID TIMING ON FIBRE QUALITY AND TEXTILE PERFORMANCE

Robert L. Long
CSIRO Textile and Fibre Technology
Belmont, Australia
Michael P. Bange
CSIRO and Cotton Catchment Communities CRC
Narrabri, Australia
Stuart G. Gordon
CSIRO Textile and Fibre Technology
Belmont, Australia

Abstract

Currently there are concerns relating to high micronaire, short fibre content and neps in Australian cotton. This study investigates the influence that harvest aid management practice has on fibre quality and textile performance, with the aim of minimising these problems. Harvest aid treatments were systematically applied at different times from 29% to 100% open bolls for field grown *Gossypium hirsutum* plants. Yield was significantly less for treatments applied up to 56% bolls open, yet remained constant for later harvest aid treatments. The range of fibre maturity across treatments was small (maturity ratio 0.88 for the earliest cf. 0.91 for late treatment application), while micronaire and linear density were significantly less for treatments applied up to 42% open bolls, yet similar for later treatments. Nep content was high for all treatments (>250 counts/ g with no lint cleaning) with later treatments trending to have less nep. The addition of lint cleaning significantly generated neps at approximately 100 counts/ g per lint cleaner passage. No significant differences between timing of harvest aid treatments were noted for yarn performance attributes (yarn irregularities and strength for carded 20 tex ring spun yarns). There was however, a significant relationship between fabric colour intensity (b*) and time of harvest aid treatment with the earlier treatments taking up less dye. This study is part of an ongoing and larger initiative linking crop management practices with textile performance to enhance quality at all levels of the production chain.

Introduction

In recent years there have been concerns relating to high micronaire, short fibre content and small entanglements or neps in Australian cotton (Gordon et al., 2004). In the case of micronaire it has been suggested that improvements in agronomic practices (e.g. soil and plant nutrition) that encourage better growth and yields along with the adoption of integrated pest management strategies and the introduction of Bollgard II® (Monsanto) that improves fruit retention, coupled with years with warmer than average seasons, have all contributed to this issue. Growers in Australia are discounted when micronaire is too high or too low (optimum G5 range is 3.8 to 4.9). While currently there is no discount to growers when there is a high incidence of neps, it can affect overall industry reputation when cotton arrives at the mill.

Micronaire is an index of fibre maturity, linear density and diameter. Maturity relates to the degree of thickening of the cell wall during fibre development. Immature fibres with little cell wall thickening (and thus displaying lower micronaire) will be more prone to nep formation during mechanical manipulation such as lint cleaning (Mangialardi and Lalor, 1990). Neps are undesirable as they decrease mill processing efficiency and typically absorb less dye and reflect light differently and may appear as 'flecks' on finished fabrics (Goynes et al., 1997; Anthony et al., 1988). Fibre immaturity has also been associated with yarn irregularities, non-uniform dyeing of fabrics and decreased processing efficiency (Gordon et al., 2004; Smith. 1991).

There are concerns that management practices that force open immature bolls to include in the harvest to increase yield or to reduce micronaire may increase the incidence of the textile issues described above. The chances of higher levels of immature fibres are also exaggerated when crops are still actively growing at the end of a season and experience an abrupt end caused by a cold finish. Premature application of harvest aids will also cause the same effect (Anthony et al., 1988; Snipes and Baskin, 1994; Bednarz et al., 2002). The generally recommended practice for harvest aid application is to apply harvest aids when approximately 60% or more of the bolls on a plant are open (Faircloth et al., 2004).

Recently studies by Bednarz et al. (2002) have explicitly shown that management practices such as the timing of harvest aids can increase the incidence of immature fibre. However, no studies have attempted to vary the amount of immature fibre present in the crop, quantify this, and relate this to fibre quality (including neps) and textile performance. A field experiment was conducted to systematically vary the timing of harvest aids, with the intention of generating different amounts of immature fibre at harvest and assess fibre quality and textile performance. This information will form part of a larger study that aims to develop crop management guidelines that optimise both crop yield and fibre quality that aim to meet textile production standards.

Materials and Methods

Cultural details

An experiment that systematically imposed different timings of harvest aids, was conducted at the Australian Cotton Research Institute (ACRI), Narrabri (30º S 150º E). This is a semi-arid environment with a uniform grey cracking clay (USDA Soil Taxonomy: Typic Haplustert).

The Experiment was sown on 15 October 2005 with a commercial row crop planter using the Bollgard II® Roundup Ready® (Monsanto) *Gossypium hirsutum* cultivar Sicot 71BR (CSIRO, Australia). The experiment was established and grown with full irrigation using non-limiting nitrogen and thorough insect control as previously described (Hearn and Fitt 1992). Nitrogen was applied as anhydrous ammonia, injected below and to the side of the plant line, implemented 4 weeks before sowing at a rate of 200 kg ha^{-1}.

Treatment plots (9 m by 4 m), contained four rows spaced at 1 m. In the centre two rows of each plot harvest aid (Defoliant and a boll opener) were applied at approximately five day intervals from 143 days after sowing resulting in 8 harvest aid treatments (Table 1). The experiment was a randomised complete block design (RCBD) replicated four times. Harvest aids were sprayed with a calibrated CO_2 pressurised 2.0 m hand boom using flat fan nozzles (110-01) at 200 k Pa delivering 100 L ha^{-1} of spray solution. The chemical and rates were: 0.2 L ha^{-1} Dropp Liquid® (Bayer CropScience, active constituent 500g L^{-1}Thidiazuron); 3 L ha^{-1} Prep 720® (Bayer CropScience, active constituent 720g L^{-1} Ethephon); and 2 L ha^{-1} D-C Tron® (Caltex, active constituent 991ml L^{-1} Petroleum Oil).

Crop Measurements

To establish crop status when harvest aid treatments were applied a fixed area of 1m of row in each control plot was monitored to determine the percentage of bolls open. To determine lint yield the third row (9 m) of each plot was harvested with a spindle picker and the seed cotton was weighed. A sub-sample of approximately 400 g of seed cotton was taken from each plot and ginned to determine gin turnout (% lint) used to calculate lint yield. Samples were saw ginned using a 20 saw gin located at the ACRI.

Lint cleaning

Sub-samples of ginned lint were subjected to one and two passes of lint cleaning. Lint cleaning was conducted with an experimental lint cleaner having a sample feed loading ratio of 100g m^{-2}, a saw speed of 855 rpm and a combing ratio of 23. The lint cleaner had four grid bars each located at a distance of 0.5mm from the saw.

Fibre quality measurements

Sub-samples of ginned lint (not lint cleaned) were subjected to high volume instrument (HVI) testing (ACRI, Narrabri).

Recovered HVI material was blended through one passage of a 'Shirley' Analyser, and then tested for maturity ratio via the CSIRO SiroMat maturity tester (Gordon et al., 2005) and for linear density via the CSIRO CottonScan (Naylor and Purmalis, 2005).

Preparation of SiroMat specimens involved guillotining a fibre beard prepared using a 'Fibrosampler' to obtain between 2 to 3 mg of 1 mm snippets from two cuts near the aligned end of the beard. The snippets were collected and then spread in an annular pattern on a 5 cm x 7 cm glass slide using an OFDA™ fibre spreader. A clean 5 cm x 7 cm slide was used to cover the specimen. Castor oil (refractive index = 1.477 – 1.481) was used as the mounting medium to enhance the contrast of the fibre snippets to their background. Preparing the SiroMat instrument involved adjusting the digital camera settings (U balance, V balance and shutter speed) and the microscope lamp intensity to match a prescribed background (magenta) colour in terms of red, green and blue ratios. Background colours were also checked at regular intervals during testing to minimize drift in instrument readings. Three replicates were tested per experimental sample.

For linear density determination, samples were passively conditioned for at least 48 hours under standard conditions (20^{o}C +/- 2^{o}C and 65% relative humidity +/- 3%). Fifteen grams of cotton lint was pressed in a corer to produce approximately 100mg of 2mm snippets which was weighed and then analysed by the CottonScan instrument. Five replicates were tested per experimental sample.

Samples from lint cleaning treatments (including a control sample with no lint cleaning) were subjected to Uster AFIS PRO fibre quality analysis. Samples for the AFIS PRO were passively conditioned for at least 48 hours under standard conditions and tested according to the manufacturer's instructions. Five replicates were tested per experimental sample.

Yarn Manufacture - Spinning

One hundred and sixty eight grams (4 x 42g lots) of machine harvested ginned lint (not lint cleaned) was sub-sampled from each experimental sample. Each 42g lot was separately carded twice and drawn once using a 'Shirley' miniature spinning plant card and draw frame (Platt brothers, England); machine settings (e.g. roller distances and draft ratio) were constant for all samples. The four miniature drawn slivers were then drawn together once using a Trutzschler HSR 1000 draw frame. The resulting single sliver was converted into twisted roving using a Zinser 660 roving frame which was spun into yarn using a Zinser 350 ring spinning frame. For full-scale processing, draft and twist was optimised for each sample to deliver a 20 tex yarn with a twist factor of αe 4.0 (798 turns per metre). One yarn bobbin per sample was tested for count, twist, evenness and imperfections (Uster tester 4-SX), and tensile properties (Uster Tensorapid 3). Yarn was waxed and wound but not cleared using a Schlafhorst 238RM winding machine.

Fabric Production - Knitting and dyeing

Yarns were knitted with a cover factor of 1.32 (a tightness factor of 15.4 $tex^{1/2}$ mm^{-1}), on a Lawson Hemphill 10 Inch F.A.K. knitting machine.

Knitted fabric was scoured and dyed with Cibacron blue LS3R (1%) reactive dye. Reflectance colorimetric measurements were taken of fabrics using a Gretag Macbeth Color-Eye 7000A spectrophotometer. Three measurements were acquired per experimental sample.

Colour differences between the dyed fabric samples were measured in terms of ΔE, which describes the mathematical distance between two colours, e.g. $L_1a_1b_1$ and $L_2a_2b_2$, where 1 in this case was the control harvest aid treatment (100% open bolls) (Equation 1).

$$\Delta E = SQRT\ (L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2 \qquad (1)$$

We identify ΔE values near or greater than one between any two fabrics here as being significant on the basis of the monochromatic nature of the dyed samples and the fact that in industry the samples would be viewed side-by-side as adjacent bands in knitted fabric.

Data analysis

ANOVA of data was conducted using Minitab 15.1. Data were analysed as a randomised complete block design. Least significant difference (LSD) values (5% level of significance) were reported for significant ANOVA ($P<0.05$), with the level of significance being reported as: *$0.01<P<0.05$, **$0.001<P<0.01$, ***$P<0.001$. NS denotes non significant ANOVA ($P>0.05$).

Results and Discussion

Fibre yield and quality

Yield of cotton lint from harvest aid treatments applied up to 42% open bolls, were significantly less than later treatments, with yield being similar for treatments applied from 68% open bolls (Table 1).

HVI fibre length was between 1.14 and 1.19 inch. Length was significantly less by an average of 0.03 inch for treatments applied up to 68% open bolls and short fibre trended less for harvest aid treatments applied from 77% open bolls. There was no significant difference in bundle strength across treatments (Table 2).

Fibre micronaire and linear density were significantly less for harvest aid treatments applied up to 42% open bolls, yet no significant differences were noted between treatments from 56% open bolls (Table 3). The range of fibre maturity ratio across treatments was small, although the earliest treatments (29 and 42% open bolls) had maturity ratios less than 0.9 (Table 3).

Lint cleaning and neps

Neps were higher than expected across treatments (>250 counts per gram), and although not strongly significant, there was a slight trend for higher neps for earlier treatments, but no significant interaction was noted between harvest aid treatment application and the amount of lint cleaning. As expected lint cleaning had a strong influence on nep generation, with each lint cleaner passage generating approximately 100 counts per gram (Table 4). Each lint cleaner passage significantly removed trash from lint, and significantly impacted short fibre content (Table 4). This result suggested that changes in harvest aid management had little impact on nep generation in this study but rather the mechanical process of lint cleaning had the greater affect.

Textile performance

No significant differences were noted across treatments for important yarn performance parameters such as yarn irregularities, imperfections and tenacity (Table 5). For fabric dye uptake analysis, early treatments (at 29 and 42 % open bolls) displayed delta E values greater than 1, which was in-line with these two early treatments having significantly more positive b* values than later treatments (Table 6). This change in the intensity of b* (blue to yellow) is corroborated by a reasonable linear relationship between the timing of harvest aid application and b* ($R^2 = 0.69$) (Fig. 1). More mature fibres will have absorbed more blue dye molecules and thus appear a more intense blue hue indicated by a more negative b* value.

Table 1 – Time of harvest aid implementation and corresponding % open bolls, and lint yield. N=4.

Harvest aid treatment (days after sowing)	% open bolls	Lint Yield (kg/ ha)
143	29.2	2424a
147	41.9	2444a
152	56.0	2620a
157	68.4	2745b
161	76.9	2814b
166	85.9	2739b
171	93.0	2632b
183 (Control)	100.0	2781b
LSD	-	213**

Table 2 – High volume instrument fibre length and tensile properties for machine harvested ginned (not lint cleaned) lint for cotton subjected to different harvest aid treatments. N=4.

Harvest aid treatment (% open bolls)	Length (decimal inches)	Length uniformity (%)	Short fibre index (% <0.5 Inch)	Strength (cN/tex)	Elongation (%)
29.2	1.14a	81.9	10.2	31.1	4.2
41.9	1.17a	82.1	10.0	31.4	4.2
56.0	1.15a	81.9	10.1	30.3	4.1
68.4	1.14a	82.4	10.1	29.6	4.6
76.9	1.19b	82.6	9.6	31.7	3.9
85.9	1.18b	82.2	9.2	30.8	3.7
93.0	1.17b	83.6	8.8	30.7	4.1
100.0	1.18b	83.5	8.9	31.4	4.3
LSD	0.03*	NS	NS	NS	0.3***

Table 3 – High volume instrument micronaire, CottonScan fibre linear density and SiroMat maturity ratio for cotton subjected to different harvest aid treatments. N=4.

Harvest aid treatment (% open bolls)	HVI Micronaire	CottonScan linear density (mtex)	SiroMat maturity ratio
29.2	4.08a	172a	0.89
41.9	4.15a	181a	0.88
56.0	4.55b	194b	0.92
68.4	4.55b	191b	0.93
76.9	4.33b	183b	0.92
85.9	4.68b	195b	0.90
93.0	4.58b	196b	0.90
100.0	4.58b	193b	0.91
LSD	0.36*	12**	NS

Table 4 – Uster AFIS PRO Neps, Short fibre content and Trash, for machine harvested ginned lint subjected to 0, 1 or 2 lint cleaner (LC) passages, for cotton subjected to different harvest aid treatments. N=4.

Harvest aid treatment (% open bolls)	Neps (Count/ g)			Short fibre content – weight (% <0.5 inch)			Trash (Count/ g)		
	0 LC	1 LC	2 LC	0 LC	1 LC	2 LC	0 LC	1 LC	2 LC
29.2	403	490	643	13.2	12.5	14.3	143	71	47
41.9	337	450	576	12.7	13.3	14.8	162	55	37
56.0	272	341	471	10.1	10.9	13.3	130	72	58
68.4	308	317	440	13.2	11.1	13.7	133	65	44
76.9	344	419	570	13.0	12.0	14.1	113	48	32
85.9	369	495	637	13.1	13.8	15.7	113	47	38
93.0	333	368	520	11.7	11.6	13.2	106	44	39
100.0	309	410	528	11.4	12.1	13.5	103	51	37
LSD	NS	112*	NS	NS	1.9*	NS	NS	NS	NS
Mean	314	411	503	11.5	12.2	12.8	118	53	39
LSD		52***			1.2**			13***	

Table 5 – Spinning results for cotton subjected to different harvest aid treatments: percent loss during miniature carding, yarn eveness and imperfections, and yarn strength attributes for carded 20 tex ringspun yarns. N=4.

Harvest aid treatment (% open bolls)	Card loss (%)	CVm%	Thin -50%	Thick +50%	Neps +200%	Elongation (%)	Tenacity (cN/tex)
29.2	14.0	17.3	15.0	408.1	326.9	5.6	14.7
41.9	13.8	18.1	50.0	516.3	371.3	5.7	15.1
56.0	13.9	18.2	33.1	485.6	382.5	5.5	14.2
68.4	14.0	18.7	51.9	507.5	383.1	5.5	13.2
76.9	13.1	17.4	17.5	405.0	344.4	5.5	15.1
85.9	12.6	17.7	23.1	413.8	318.8	5.3	13.8
93.0	13.6	17.6	36.3	443.1	358.1	5.4	13.6
100.0	13.4	18.1	49.4	422.5	343.8	5.6	15.0
LSD	NS	0.9*	NS	NS	NS	NS	NS

Table 6 – Colour space results for reflectance colorimetric analyses of fabric dyed with Cibacron blue LS3R (1%), for different harvest aid timing treatments. N=4.

Harvest aid treatment (% open bolls)	L*	a*	b*	ΔE from 100% open bolls
29.2	44.303	-2.207	-27.910a	1.10
41.9	44.532	-2.258	-28.015a	1.29
56.0	42.619	-1.998	-28.370	0.68
68.4	43.028	-2.015	-28.344	0.28
76.9	43.486	-2.124	-28.262	0.21
85.9	42.384	-1.921	-28.577	0.96
93.0	42.571	-1.958	-28.562	0.77
100.0	43.292	-2.110	-28.340	0
LSD	NS	NS	0.322**	-

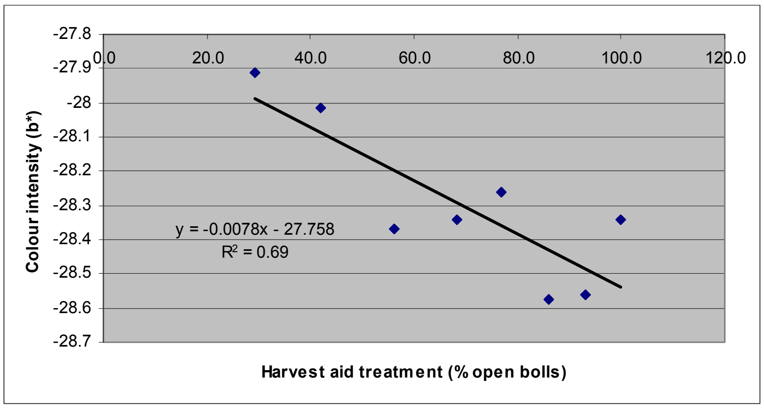


Figure 1 - Colour space result (b*) for reflectance colorimetric analysis of fabric dyed with Cibacron blue LS3R (1%), for different harvest aid timing treatments (% open bolls).

Conclusion

Harvest aids were systematically applied at different times from 143 DAS (29% open bolls) to 183 DAS (100% bolls open). Yield was significantly less for treatments applied up to 56% open bolls, yet remained constant for later harvest aid treatments. The range of fibre maturity across treatments was small (maturity ratio 0.88 for the earliest cf. 0.91 for late treatment application), although micronaire and linear density were significantly less for treatments applied up to 42% open bolls. Lint cleaning significantly generated neps at 100 counts/ g per lint cleaner passage but there was no strong evidence that the changes in fibre quality measured in the early treatments exaggerated the effect of lint cleaners on the level of neps and short fibre. No significant differences were noted for yarn performance attributes for 20 tex ring spun yarns manufactured from lint across all harvest aid treatments. This was not expected and it is hypothesised that a finer count yarn may accentuate greater differences in yarn performance (particularly tensile properties) between early and late treatments. Dye uptake in knitted fabric was significantly less for treatments applied up to 42% open bolls, which is due to less mature (lower linear density and micronaire) fibre in these treatments. Indeed the current industry standard practice of applying harvest aids at or more than approximately 60% open bolls will insure maximum yield, fibre quality and textile performance for this commonly grown Australian *G. hirsutum* variety.

Acknowledgments

The authors acknowledge input from CSIRO colleagues Geoffrey Naylor and Rene van der Sluijs. We thank the Cotton Catchments Communities Co-operative Research Centre, the Australian Cotton Research and Development Corporation and the CSIRO for financial support, and we greatly thank Jane Caton, Darin Hodgson, Rebecca Giles, Fred Horne, Mark Freijah, Susan Miller, Geni Kozdra, Susan Horne and Colin Brackley for technical assistance.

References

Anthony, W.S., Merideth, W.R. and Williford, J.R., 1998. Neps in ginned lint: The Effect of Varieties, Harvesting, and Ginning Practices. Textile Research Journal November, 633-640.

Bednarz, C.W., Shurley, W.D. and Anthony, W.S., 2002. Losses in Yield, Quality, and Profitability of Cotton from Improper Harvest Timing. Agronomy Journal 94, 1004-1011.

Faircloth, J.C., Edmisten, K.L., Wells, R., Stewart, A.M., 2004. Timing Defoliation Applications for Maximum Yields and Optimum Quality in Cotton Containing a Fruit Gap. Crop Sci. 44, 158-164.

Gordon, S. G., van der Sluijs, M.H.J. and Prins, M. W., 2004. Quality Issues for Australian Cotton from a Mill Perspective. Australian Cotton CRC, Narrabri.

Gordon, S.G. and Phair, N.L.P., 2005. An Investigation of the Interference Colors in Mature and Immature Cotton Fibres. Proc. Beltwide Cotton Conference, New Orleans.

Goynes, W.R., Bel-Berger, P.D. and Von Hoven, T.M., 1996. Microscopic Tracking of White Speck Defects from Bale to Fabric. Proc. Beltwide cotton conference., Memphis, Volume 2 pp 1292-1294.

Hearn, A.B. and Fitt, G.P., 1992. Cotton Cropping Systems. In: Pearson, C.J. (Ed.), Ecosystems of the World - Field Crop Ecosystems. Elsevier, London, pp. 85-142.

Mangialardi, G.J. and Lalor, W.F., 1990. Propensity of Cotton Varieties to Neppiness', Transactions of the ASAE September, 1748-1758.

Naylor, G.R.S. and Purmalis, M., 2005. Update on Cottonscan: An Instrument for Rapid and Direct Measurement of Fibre Maturity and Fineness. Proc. Beltwide Cotton Quality Conference 2302-2306.

Smith, B., 1991. A Review of the Relationship of Cotton Maturity and Dyeabilty. Textile Research Journal March, 137-145.

Snipes, C.E., Baskin, C.C. 1994. Influence of Early Defoliation on Cotton Yield, Seed Quality, and Fibre Properties. Field Crops Res. 37, 137-143.