FINAL REPORT

Part 1 - Summary Details

Cotton CRC Project Number: 4.01.07 CRC1114

Project Title:	Validation of Cottonspec; a program for predicting cotton yarn quality

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Cotton CRC Program: **Value Chain**

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1. Background

Cottonspec is a cotton fiber and yarn quality management software package that aims to predict yarn property from measured fiber quality parameters (Yang and Gordon, 2012)[1]. The purpose of this project was to conduct validation trials of the software in current project partner mills located in China. The trials would enable the software's prediction algorithms to be validated using a larger industry database, and initiate extension of the software as a marketing tool for high quality Australian cotton.

The ability of Cottonspec as a marketing tool for Australian cotton lies in the association between high quality yarn and Australian cotton. This association exists because Cottonspec's prediction algorithms favour fine, long, strong cotton, i.e. play on the characteristics of Australian cotton fibre.

Cottonspec validation trials have been carried out with three Chinese partner mills since December 2010. In this time Cottonspec algorithms have been upgraded using a comprehensive industrial spinning database, which has been collected and developed with strong support from these mills. The upgraded software has been tested using data collected from the partner mills. Results show the upgraded Cottonspec algorithms have greater prediction power than previous versions.

The Cottonspec software will enhance the cotton industry's drive towards the production of high quality fibre that is differentiated by its inherent quality and the information around its quality. The software will enhance understanding amongst the growing, ginning and merchant sectors of the importance of fibre quality. The combination of industry understanding and demand pull from spinners of Australian cotton will help fulfil the industry's ambitions to develop a high quality product.

[1] Yang S. and Gordon S., Cottonspec – Preliminary Results of Cottonspec Validation Trials, Procedings Beltwide Cotton Conferences, Orlando, Florida, US, Jan. 2012

2. Objectives

The stated objectives of the project and whether they have been achieved are listed in Table 1.

Table 1 – Project objectives, milestones, performance indicators and achievement

Objective	Milestone	Performance Indicator	Achieved
Validate Cottonspec algorithms and beta test software with real mill data.	Identify international partner mills for Cottonspec validation trials. Complete initial validation and adjustment of Cottonspec software. Complete longer trials that show effects of cotton quality on yarn quality.	Partner mills identified, visited by Drs Yang and Gordon and Cottonspec trial planning discussed. Summary report to CRDC and Cotton CRC detailing results of validation trials. Summary report and seminars to industry detailing the Cottonspec validation results.	Achieved
Determine market value of Cottonspec.	Review market potential for Cottonspec as a stand alone product and/or as a marketing tool for Australian cotton.	Business plan is written and tendered to CRDC (CCC CRC) and ACSA for discussion and action.	Achieved

3. Methods

Partner mills

Four Chinese cotton spinning mills were selected for validation trials. The mills included Chongqing Sanxia No. 1 Mill, Chongqing Sanxia No. 2 Mill, Wenshang Tianrong Mill and Shandong Demian Mill. Guangdong Esquel was originally identified as a potential partner mill for Cottonspec validation trial, but was withdrawn after a visit to the mill in December 2010 because of technical limitations. Cottonspec was designed for griege cotton spinning and mainly for fine count yarns of Ne 50 or above. The Esquel Mill (in Foshan City near Guangzhou) was not suitable for the validation trial because it produced mainly dyed cotton spun yarns of medium to low yarn count, i.e. Ne 40 and below. Furthermore, it was identified from the ATC[2] project benchmarking trial using Australian long staple (ALS) cotton that yarn quality from this particular mill was of lower quality than other mills. The yarn quality from Esquel was poorest among the six participating mills.

Instead, Chongqing Sanxia Spinning No. 2 Mill was chosen to replace Esquel for Cottonspec validation trial. Drs. Yang and Gordon visited the four partner mills in November-December 2010 and discussed the validation trial planning.

Validation trials were conducted in three stages; Stage 1, Stage 2 and Stage 3. At each stage the mill database used to model the yarn quality response to fibre properties, was improved by the addition of more data from partner mills. In general, each of the stages reflects input of new data and the refinement of prediction algorithms. In addition to this the purpose of Stage 1 was to conduct preliminary validations on the existing software, which was developed from a small database with all samples tested at CSIRO, and to develop directions for a larger scale database with data provided by partner mills.

The purpose of Stage 2 was to rectify issues identified in Stage 1 and to upgrade the algorithms utilising the expanded database. In Stage 3 algorithms were again fine tuned utilising again a now larger database. At this final stage it was hoped industry would consider implementing a fibre quality monitoring program in which the fibre and yarn quality in a select number of mills using Australian cotton could be monitored over longer periods using Cottonspec.

Stage 1

Stage 1 started in December 2010 and was completed in April 2011.

Cotton and yarn data from Chongqing Sanxia No. 1 and No. 2 Mills and Shandong Demian Mill was collected, screened and added to the database. Cotton samples were also obtained from these mills and tested locally on HVI (by Auscott Classing Offices) and other CSIRO testing equipment (AFIS, Cottonscan and Cottonscope), although only HVI values were incorporated into the database.

Yarn testing by each of the partner mills was reasonably consistent; yarn evenness was tested in each mill using the same model Uster 3 Yarn Evenness Tester and yarn tensile properties were tested using the same Chinese manufactured yarn tensile strength tester. The same data collection procedure was used for the Wenshang Tianrong Mill.

During Stage 1 some problems with the Cottonspec software package were identified. For example, users (Chinese mill operators) could not type in data in some data input fields and the ‘Print’ function of the Chinese version would not work. These interface problems were soon rectified.

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[2] Australia-China Agricultural Technical Cooperation (ATC) Program

Also identified in Stage 1 was the limited practical use of AFIS and CSIRO instrument data in the Cottonspec models. At the moment Chinese mills do not have ready access to this instrumentation. Estimated values of AFIS and fineness and maturity data were tested but these led to large variations being observed between predicted and measured yarn properties. As a result only HVI values (Micronaire, length (upper half mean length - UHML), short fibre content (SFC) and tenacity (FT) were used in developing algorithms in Stages 2 and 3.

Another issue leading to unsatisfactory results in Stage 1 was the comparatively small size of the Cottonspec database and the inclusion of coarser count yarns. Prior to this latest project the database was relatively small and focused more on lower yarn counts (< Ne 50).

Stage 2
Stage 2 started in May 2011 and was completed in October 2011.

During Stage 2 the Cottonspec prediction algorithms were upgraded using sophisticated theoretical modelling and an enhanced, larger database developed from Stage 1. The Cottonspec interface was also upgraded with some new functions included. For example, a sophisticated plot function was included.

To facilitate application of the software in partner mills a Chinse language verson was developed. This upgraded software was distributed to partner mills during Dr Yang's trip to China in July 2010. In October-November 2011 Drs. Yang and Gordon visited the partner mills to monitor the validation trial progress. Trial data was collected from the mills for evaluation. During the visit to the Chongqing Sanxia No. 1 Mill agreed to provide more spinning data to upgrade the Cottonspe database.

Stage 3
Stage 3 started in November 2011 and will be completed in June 2012.

Algorithms from Stage 2 were upgraded again in February 2012. These upgrades were distributed to partner mills in late February for continued validation trials.

An excel version of the Cottonspec software is being developed as specified in the business plan. The Excel version will allow multiple data entry fields to be entered by the mill and improve mill usability.

4. Results

Cottonspec is aimed at fine count yarns (Ne 50 and Ne 60) that can be spun using Australian long-staple (ALS) cotton, i.e. 1.25 inch length, 32 grams per tex tenacity and G5 Micronaire. Much of the production of these yarns occurs on compact spinning frames; therefore in this study focus has been given to this type of spinning.

4.1 Cotton fibre properties

Cotton properties for compact spun Ne 50 and Ne 60 count yarns from partner mills Chongqing Sanxia No. 1 and No. 2 Mills and the Wenshang Tianrong Mill (No. 3) are listed in Table 2.

The HVI properties for the Chongqing Sanxia mills were measured at the same local fibre testing centre (China Fibre Insection Bureau (CFIB)), while fibre fineness data was measured in the mill using a Chinese airflow method. The Wenshang Tianrong HVI data were measured in Australia at Auscott Classing Offices with fibre fineness measured at CSIRO using Cottonscan. Fibre elongation data was not included because CFIB HVI did not provide the elongation data for the Chongqing Sanxia No. 1 and No. 2 Mills. Note that Tiangrong's SFC data measured in Australia was originally expressed as the percent fibres (by weight) < 12.7 mm. The data shown in Table 2 is expressed as the percent fibres (by weight) < 16 mm using a conversion equation; there is a 1:1 conversion between HVI SFC measures at 12.7 and 16 mm.

Comparison of fibre tenacity, length and SFC for the three mills is shown in Figures 1 and 2 for Ne 60 and 50 yarns respectively. Comparison of fibre fineness is shown in Figure 3.

Table 2 – Cotton fibre properties by HVI and local fineness test instruments

Mill	Fibre Property	Ne60				Ne50			
		Mean	SD	Min	Max	Mean	SD	Min	Max
C'qing Sanxia No. 1 Mill	**Fineness Ne**	6609	484	5570	7667	6243	338	5656	7135
	UHML mm	32.5	2.0	28	37	31.41	1.42	28.95	34.51
	UNI%	84	1.5	81	87	84	1.17	80	86
	SFC%<16mm	14	3.6	2	22	16	2	11	17
	Mic	4.12	0.2	3.61	4.42	4	0.11	4	5
	FT cN/tex	35.8	3.3	28	41	33	2.42	30	39
C'qing Sanxia No. 2 Mill	**Fineness Ne**	5719	237	5375	6030	5934	167.7	5628	6142
	UHML mm	29.67	0.83	28.1	31.09	28.99	0.929	28	30.47
	UNI%	83.24	0.79	81.82	84.2	82.5	0.75	81.8	83.8
	SFC%<16mm	17.84	1.71	15.28	21.03	19.36	1.39	17.4	21.15
	Mic	4.43	0.25	3.9	4.75	4.2	0.344	3.82	4.75
	FT cN/tex	28.96	0.65	27.41	29.54	29.08	0.717	28.15	30.65
W'shang Tianrong No. 3 Mill	**Fineness Ne**	5819	100	5700	5900	6044	194.5	5721	6223
	UHML mm	30.74	0.51	30.30	31.51	28.4	1.15	27.76	31.4
	UNI%	84.5	0.63	83.12	85.1	82.55	0.694	82	84.8
	SFC%<16mm	14.1	2.99	11.7	18.6	17.26	1.98	13.2	19.12
	Mic	4.46	0.10	4.23	4.6	4.33	0.14	4.2	4.68
	FT cN/tex	32.54	0.89	31.5	34.12	31.85	0.556	30.61	33.6
	C'scan mtex	217	13.0	199	228	204.4	10.54	197	235

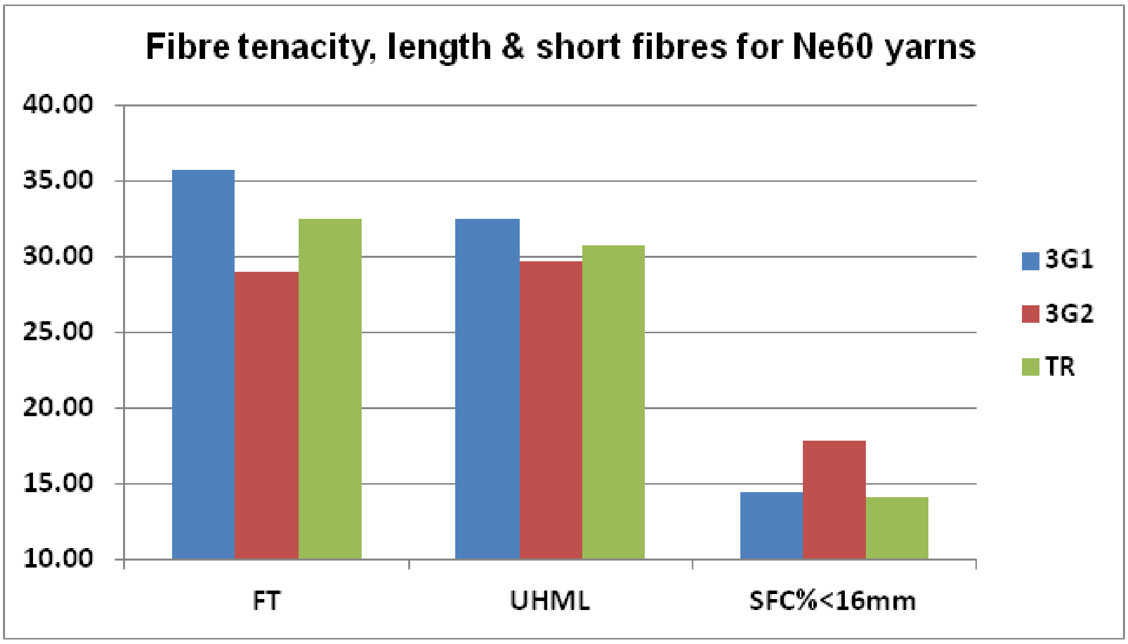


Figure 1 – Comparison of mean fibre tenacity, length and SFC for Ne 60 yarns; 3G1 = Chongqing Sanxia No. 1 Mill, 3G2 = Chongqing Sanxia No. 2 Mill and TR = Tianrong No. 3 Mill

Figure 2 – Comparison of mean fibre tenacity, length and SFC for Ne 50 yarns; 3G1 = Chongqing Sanxia No. 1 Mill, 3G2 = Chongqing Sanxia No. 2 Mill and TR = Tianrong No. 3 Mill

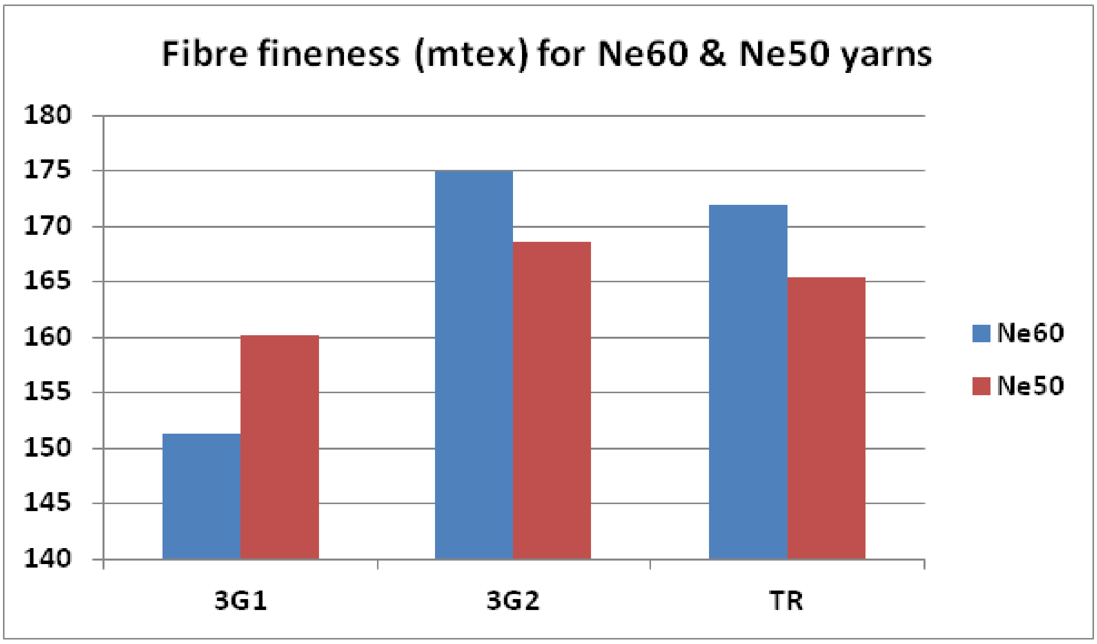


Figure 3 – Comparison of mean fibre fineness for Ne 60 and Ne 50 yarns ; 3G1 = Chongqing Sanxia No. 1 Mill, 3G2 = Chongqing Sanxia No. 2 Mill and TR = Tianrong No. 3 Mill

It is seen from Table 2 and Figures 1 to 3 that the fibre quality used by Chongqing Sanxia No. 1 Mill was the best. For Ne 60 yarns the mean FT used was 35.8 cN/tex, UHML was 32.5mm, SFC <16mm was 14.5% and fibre fineness was 151 mtex (converted from mill measured fibre fineness count). For Ne 50 yarns the fibre quality in the No. 1 Mill was 33.4 cN/tex, mean fibre length 31.5mm, SFC <16mm 15.6% and fibre fineness 160 mtex.

On average, Tianrong's fibre quality ranked second compared with the fibre used by Mill's No. 1 and 2. The reason for such a big difference in fibre quality between Chongqing Sanxia No. 1 and No. 2 Mills is that the products from the No. 1 mill is destined for export market, while yarn from the No. 2 Mill is for the Chinese domestic market.

4.2 Yarn properties

All yarn properties were measured by mills using their own test instruments with Chongqing Sanxia No. 1 and No. 2 Mills using the same testing facilities. Strictly speaking there is no direct comparison of fibre and yarn quality between the three mills given the fact that both fibre and yarn properties were measured using different instruments and facilities. However, the HVI used by the No. 1 and No. 2 Mills was subject to the calibration regime adopted by the CFIB, and the HVI testing for Wenshang Tianrong was undertaken by personnel at Auscott Classing Offices, who regularly achieve excellent test results in international round trials.

Yarn evenness (CV%) for all yarns from all mills was measured using the Uster Evenness Tester. The test regime for this measurement is well known in industry and measurement errors between mills were assumed to be insignificant. For yarn tensile testing most mills used similar yarn strength testers made by only a handful of manufacturers. Given the ubiquity of this test method and the instruments that are used, it was reasonable to assume for this comparison that test results for both fibre properties and yarn properties were comparable between mills.

Yarn properties for Ne 60 and 50 yarns for the three mills are shown in Table 3.

Table 3 – Yarn properties for Ne 60 and Ne 50 yarns

Mill	Yarn	Ne 60				Ne 50			
	Property	Mean	SD	Min	Max	Mean	SD	Min	Max
C'qing Sanxia No. 1 Mill	YT cN/tex	21.27	2.02	16.38	26.1	20.18	1.645	17.47	24.67
	ELO%	5.12	0.46	4.28	6.47	5.19	0.38	4.4	6.23
	CV%	12.58	0.45	11.42	13.51	12.03	0.37	11.24	12.69
	Nep(+200%)	43	15	12	83	26.5	9.4	13.0	49.0
	NYT	0.595	0.024	0.537	0.678	0.605	0.029	0.56	0.681
C'qing Sanxia No. 2 Mill	YT cN/tex	17.35	0.65	16.26	18.77	18.21	0.5	17.51	19.52
	ELO%	4.45	0.38	3.5	5.1	5.19	0.358	4.6	5.8
	CV%	13.27	0.32	12.75	13.9	11.88	0.229	11.5	12.37
	Nep(+200%)	80.76	14.4	55	100	42.7	7.6	30	56
	NYT	0.414	0.039	0.351	0.485	0.39	0.019	0.359	0.421
W'shang Tianrong No. 3 Mill	YT cN/tex	19.97	0.8	18.95	21.39	19.91	0.762	17.94	21.06
	ELO%	5.68	0.74	4.18	6.48	5.11	0.71	3.53	6.62
	CV%	13.17	0.266	12.69	13.52	12.6	0.343	12.01	13.39
	Nep(+200%)	112.6	11.92	88	127.8	66.4	25.38	33	135.8
	NYT	0.613	0.015	0.595	0.643	0.625	0.028	0.562	0.664

NYT = normailised yarn tenacity

Comparison of mean values of yarn tenacity, elongation, evenness and nep count is shown in Figures 4, 5, 6 and 7. It can be seen from Table 3 and these figures that there are large variations in yarn properties between the three mills, in particular for yarn tenacity and nep count. This is not surprising given the relatively large differences in fibre quality used by the three mills to produce similar count yarns. Again the data show that on average Chongqing Sanxia No. 1 Mill had the best yarn properties of all mills, and in particular for yarn tenacity and nep count. For yarn tenacity Chongqing Sanxia No. 1 was 23% higher than Chongqing Sanxia No. 2 Mill for Ne 60 yarn and was 11% higher for Ne 50 yarn. It is of interest to note that the differences in fibre tenacity between the two mills were also very similar; being 24% for Ne 60 yarn and 15% for Ne 50 yarns. This result confirms the importance of fibre tenacity for yarn tenacity.

For yarn nep count the gaps between the three mills were even greater. Chongqing Sanxia No. 2 Mill was 47% higher than the No. 1 Mill for Ne 60 yarn and 38% higher for Ne 50 yarn. For the Wenshang Tianrong Mill, although yarn tenacity, elongation and evenness was not too bad, nep count was very poor; being 160% higher than the No. 1 Mill and 39% higher than the No. 2 Mill for Ne 60 yarn; and 150% higher than No. 1 Mill and 56% higher than the No. 2 Mill for Ne 50 yarn. These differences likely reflecting the older cleaning and carding machinery used at the No. 3 Mill.

Figure 4 – Comparison of yarn tenacity; 3G1 = Chongqing Sanxia No. 1 Mill, 3G2 = Chongqing Sanxia No. 2 Mill and TR = Tianrong No. 3 Mill

Figure 5 – Comparison of yarn elongation; 3G1 = Chongqing Sanxia No. 1 Mill, 3G2 = Chongqing Sanxia No. 2 Mill and TR = Tianrong No. 3 Mill

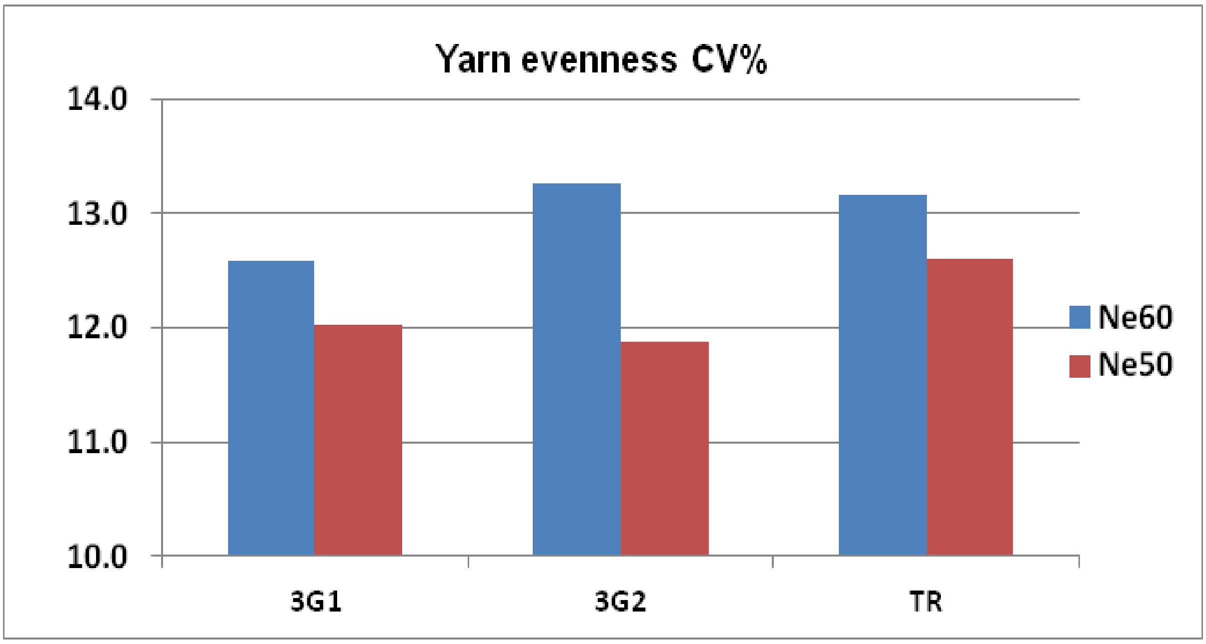


Figure 6 – Comparison of yarn evenness 3G1 = Chongqing Sanxia No. 1 Mill, 3G2 = Chongqing Sanxia No. 2 Mill and TR = Tianrong No. 3 Mill

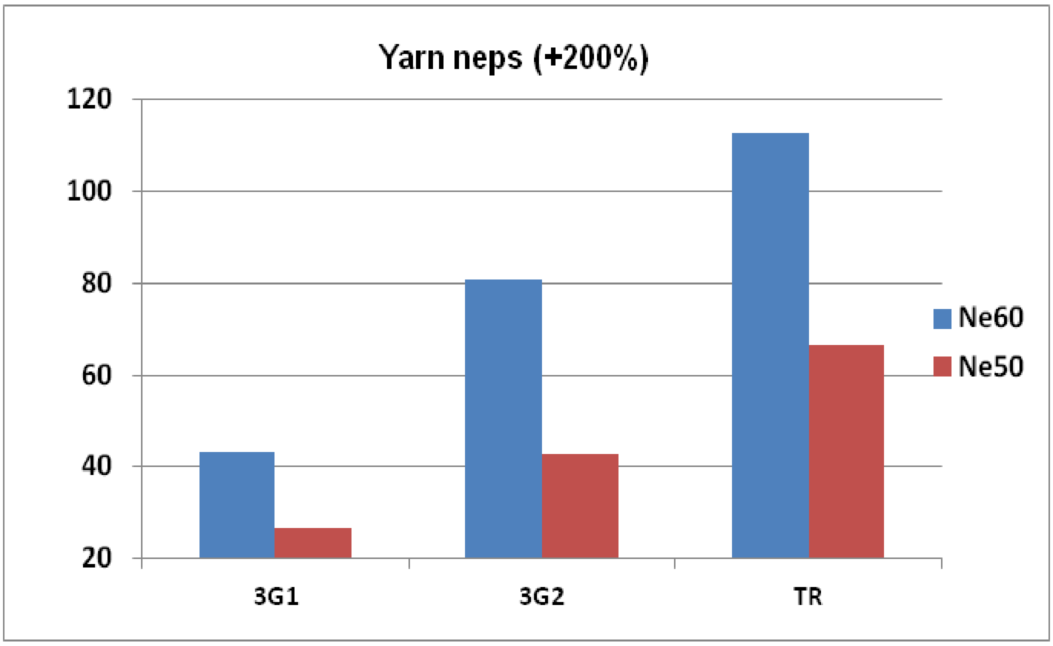


Figure 7 – Comparison of yarn nep count; 3G1 = Chongqing Sanxia No. 1 Mill, 3G2 = Chongqing Sanxia No. 2 Mill and TR = Tianrong No. 3 Mill

4.3 Upgrading Cottonspec algorithms

Spinning database

The algorithms used in the early version Cottonspec utilised in Stage 1 were developed using a small spinning database with a total of 57 lots of yarn data collected from Chongqing Sanxia No. 1 Mill. In order to develop more robust prediction algorithms larger amounts of data describing a wider range of count yarns (finer) and cotton varieties was essential.

With strong support from the three partner mills a larger database of spinning results was developed. Details of the enhanced database are shown in Table 4.

Table 4 – Cottonspec spinning database

Yarn Count Ne	Yarn type		Cotton (in laydowns)
	Compact	Ring spun	
40	/	32	CA, SJV,
50	210	87	Memphis, Pima,
60	388	94	Australia,
70	9	/	Xinjiang,
80	72	/	Egypt, Israel,
Total	679	213	Brazil, India

Prediction Models

A series of spinning prediction models for staple fibre spun yarns developed by Yang and co-workers at CSIRO for a worsted yarn spinning prediction package called Yarnspec form the basis of Cottonspec. In principal, these models are with some changes directly applicable to cotton spinning. With a large spinning database available it becomes possible to apply the physical modelling techniques to develop robust spinning prediction algorithms for fine count cotton yarns.

To illustrate the principle of the work a brief summary of yarn tenacity prediction modelling is described below. Theory and spinning trial results have shown that yarn tenacity is primarily determined by fiber tenacity (Hearle et al 1969[3]). Figure 8 shows an example of the strong correlation observed between yarn tenacity and cotton fibre tenacity for a set of samples from the spinning database.

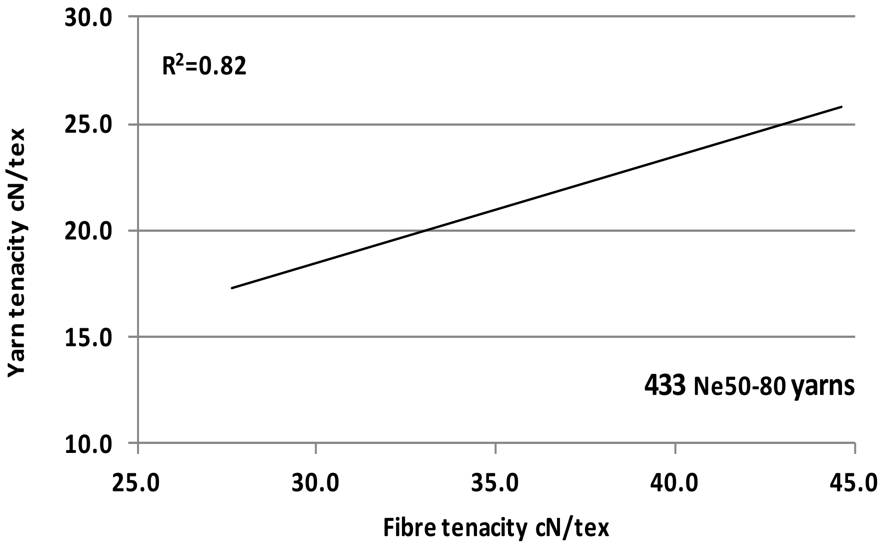


Figure 8 – Correlation of yarn tenacity with cotton fiber tenacity for a range of Ne 50 to 80 ring spun yarns

[3] Hearle, J. W. S., Grosberg, P. and Backer, S., (1969) Structural mechanics of fibers, yarns and fabrics, Vol 1, 469 pp, Wiley-Interscience

To achieve better results in yarn tenacity prediction the concept of Normalised Yarn Tenacity (NYT) was introduced – see the ratio in (1):

$$NYT = \frac{Yarn\ Tenacity}{Fibre\ Tenacity} \quad (1)$$

Normalised Yarn Tenacity indicates the proportion of fibre tenacity that is realised in the yarn tenacity result. For staple fibre spun yarn NYT is also a function of other fiber properties, e.g. fineness, elongation, length and SFC. NYT is also affected by the level of twist inserted into the yarn.

To determine the effect of twist on yarn tenacity a comprehensive yarn twist curve trial was conducted at tye No. 1 Mill. Three cotton types were represented in the trial including Acala cotton from the San Joaquim Valley (SJV), US Pima and Brazilian Upland cotton. For each cotton three yarn counts were used; Ne 23, Ne 32 and Ne 40 for the shorter Brazilian cotton, Ne 40, Ne 50 and Ne 60 for the SJV cotton and Ne 50, Ne 60 and Ne 70 for the US Pima cotton. For each yarn count seven (metric) twist levels were used ranging from 95 to 132. In total 63 yarns were spun giving nine experimental twist curves to show (model) the dependence of yarn tenacity on twist level.

Due to the limited number of twist levels used in the trial not all curves showed a tenacity maxima. The shape of the twist curve was largely dependent on cotton growth reflecting fibre length differences and yarn count. For simplicity, an average of the Ne 50 and Ne 60 yarn twist curves were used to develop a theoretical yarn twist model. Experimental data fitted to this theoretical twist curve showed good agreement.

The averaged theoretical yarn twist model is shown in Figure 9. It shows that yarn tenacity increases with increasing yarn twist level and reaches a maxima at a twist factor of around 120. After this point yarn tenacity reduces as a result of the oblique of twisted fibres to the yarn (vertical) axis. The yarn tenacity plotted on the vertical axis of this Figure is the measured yarn tenacity normalised to the average yarn tenacity at each twist level. This normalised yarn tenacity for each twist level is called the yarn tenacity twist correction factor (TCF).

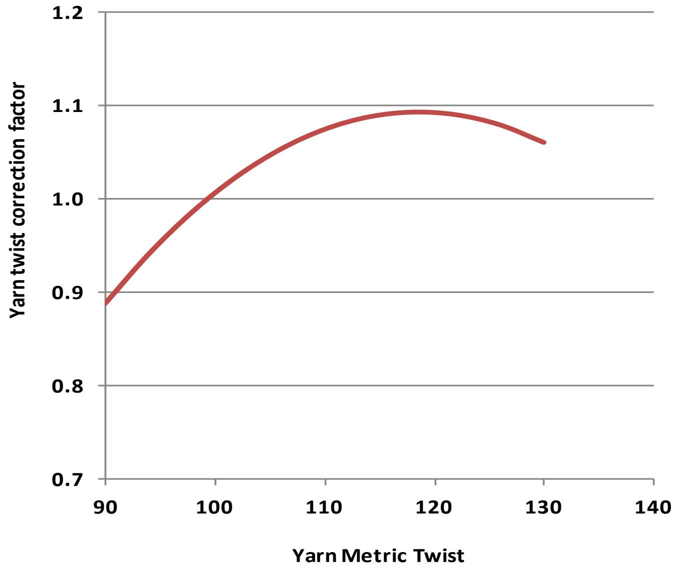


Figure 9 – Cotton spinning yarn twist model

To exclude the effect of yarn twist on yarn tenacity the concept of Twist Corrected Normalised Yarn Tenacity (TCNYT) is introduced and defined as the ratio in (2):

$$TCNYT = \frac{NYT}{Twist\ Correction\ Factor\ (TCF)} \qquad (2)$$

Theoretically, TCNYT is independent of fibre tenacity and yarn twist. However, experimental results show that fibre tenacity has a secondary effect on observed yarn tenacity. This is a result of the fibre length changing as a result of fiber breakage during processing. Fibre breakage depends on the fiber work-to-break value, which in turn is the product of fibre tenacity and elongation.

Utilising the now larger spinning database, a spinning prediction model for TCNYT was developed, containing the independent variables of predicted yarn evenness, Micronaire, SFC, length and tenacity; the fibre properties selected on the basis of a competative stepwise regression. The predicted yarn evenness model was developed based on theoretical yarn evenness prediction model (Yang *et al* 1998) and fitted with the data from the large size spinning database. Using these variables, predicted yarn tenacity can be expressed by Equation (3):

$$PYT = TCNYT(predicted\ CV\%, Mic, SFC, UHML, FT)\ x\ FT\ x\ TCF \qquad (3)$$

To facilitate wide application of Cottonspec by industry the upgraded Cottonspec prediction algorithms now require only five HVI test results: tenacity, elongation, length, SFC and Micronaire; although there is a room for improved prediction accuracy if faster, widespread tests for other fiber property values become more widely available, e.g. fibre fineness, maturity and nep count. Indeed analysis of model performance using these additional variables shows improved prediction, particularly in the use of fineness over Micronaire

Mill Correction Factors

The quality of a spun yarn is predominantly affected by the quality of the cotton used to spin the yarn. However, other factors, e.g. the quality of textile machinery, maintenance schedules, settings and quality control regimes play a role in determining the measured yarn quality. To make Cottonspec a useful quality control tool for a range of spinning mills it is necessary to introduce Mill Correction Factors (MCFs) to correct for these differences. For example, predicted yarn tenacity (PYT) for Ne 60 yarn is expressed as:

$$PYT = TCNYT(Pred.CV\%, Mic, SFC, UHML, FT)\ x\ FT\ x\ TCF\ x\ MCF(YT\ Ne60) \quad (4)$$

In the standard version of Cottonspec the default value for all MCFs is one. For a particular mill, MCFs may be adjusted after a certain period of time when additional processing data is accumulated. For a particular yarn property of a given yarn count, the MCF is one minus the average variations between predicted and measured yarn property – see (5):

$$MCF = 1 - \frac{\sum(Predicted - Measured)/Measured}{n} \quad (5)$$

where, n = the number of yarn lots. In the majority of cases MCF is expected to be yarn count dependent.

With the prediction models developed as described, algorithms were derived using the spinning database mentioned earlier. The power of their prediction is demonstrated using a set of 362 Ne 50 to 80 compact spun yarns from the No. 1 Mill in Figure 10. It can be seen that calculated yarn evenness and tenacity are highly correlated to measured values with the square of the correlation coefficients (R^2) being 0.84 for yarn evenness and 0.94 for yarn tenacity.

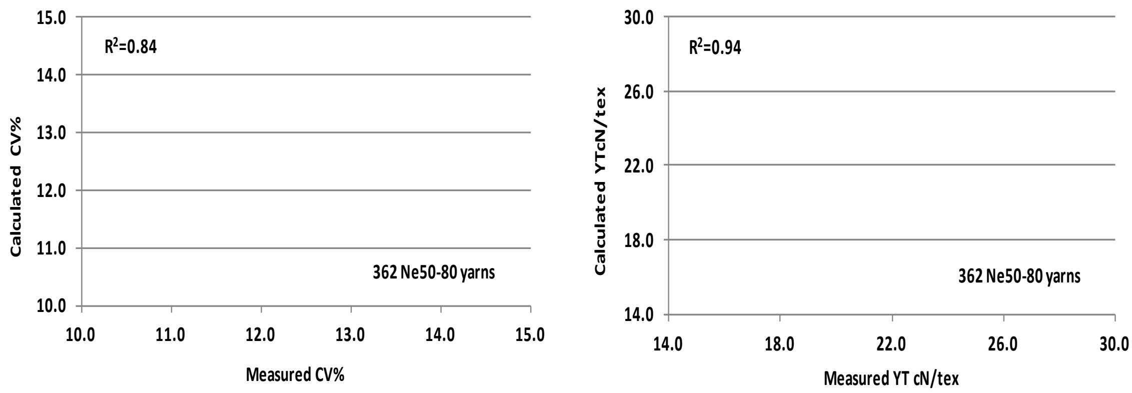


Figure 10 – Calculated vs. measured values for (left) yarn evenness and (right) yarn tenacity, for 362 Ne 50 to 80 yarns produced in the No. 1 Mill.

4.4 Validation of algorithms and determination of Mill Correction Factors

Cottonspec is aimed at fine count yarns of Ne 50 and above. In this report the focus was concentrated on compact spinning Ne 50 and 60 yarns, although the models used support predictions of standard ring spun yarn. Since the amount of data from Demian was small and not statistically significant it was not included in this part of the study.

Chongqing Sanxia No. 1 Mill

Predicted yarn evenness and tenacity values from applying standard Cottonspec algorithms, i.e. with MCF = 1, to a validation set of 123 lots of Ne 50 to 80 yarn data collected from the No. 1 Mill are shown plotted against measured values in Figure 11. Error of prediction values are listed in Table 5.

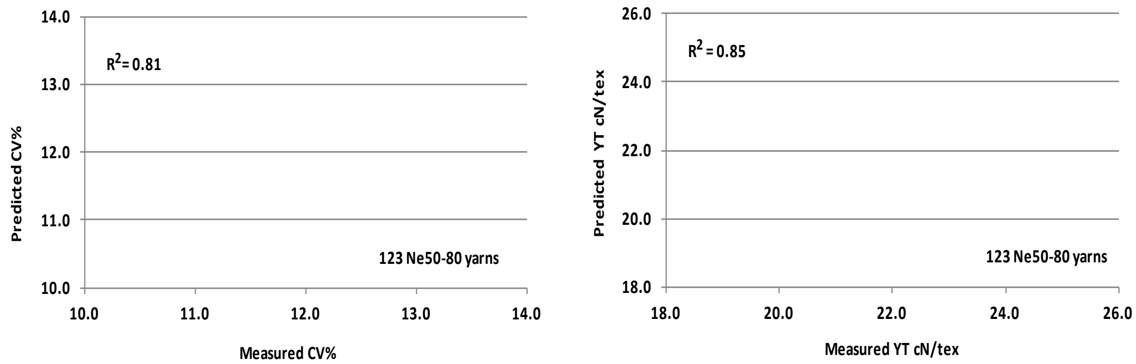


Figure 11 – Predicted vs. measured values for (left) yarn evenness and (right) yarn tenacity values for 123 Ne 50 to 80 validation yarn results for No. 1 Mill

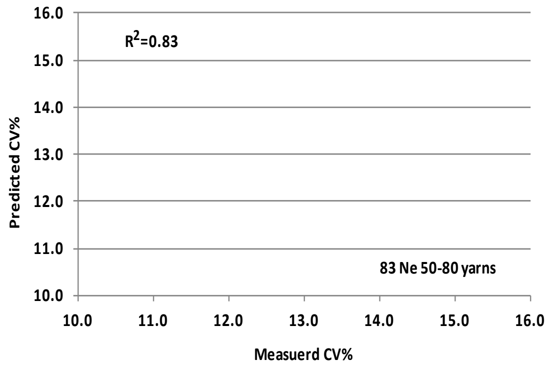
Table 5 – Errors for predicted values for the 123 Ne 50 to 80 yarns for No. 1 Mill

Standard Errors		**Relative Standard Errors %**	
CV%	YT cN/tex	CV%	YT cN/tex
0.42	0.84	3.28	3.73

It is seen that measured yarn evenness and tenacity are highly correlated to the predicted values with the R^2 being 0.81 for yarn evenness and 0.85 for yarn tenacity and prediction errors being relatively small. These results demonstrate the prediction algorithms work well for the No. 1 Mill.

Chongqing Sanxia No. 2 Mill

Applying standard Cottonspec (MCF = 1) to 83 lots Ne 50 to 80 yarn data collected from No. 2 Mill predicted yarn evenness and tenacity against the measured are shown in Figure 12. Prediction errors are given in Table 6.



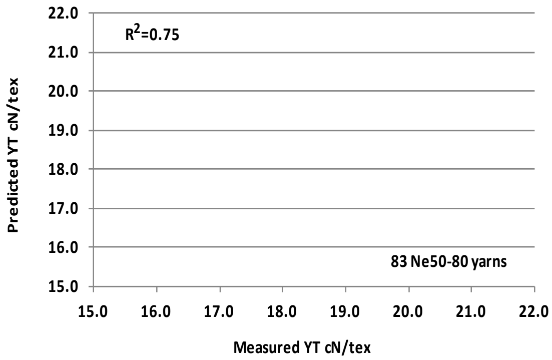


Figure 12 – Predicted vs. measured values for (left) yarn evenness and (right) yarn tenacity values for 83 Ne 50 to 80 validation yarn results for No. 2 Mill

Table 6 – Errors for predicted values for the 83 Ne 50 to 80 yarns for No. 2 Mill

MCF	**Standard Errors**		**Relative Standard Errors %**	
	CV%	YT cN/tex	CV%	YT cN/tex
no	0.68	0.85	5.01	4.80
yes	0.46	0.61	3.43	3.41

It is seen that the prediction accuracy for the No. 2 Mill is reasonably good with R^2 values of 0.83 for yarn evenness and 0.75 for yarn tenacity. The prediction errors are similar to that for the No. 1 Mill for yarn tenacity and slightly greater for yarn evenness. This indicates Cottonspec yarn evenness and tenacity prediction models work reasonably well for modern mills like the No. 1 and No. 2 Mills.

To further improve the prediction accuracy MCFs for yarn evenness and tenacity for various No. 2 Mill yarn counts were worked out and are detailed in Table 7.

Table 7 – MCFs for yarn evenness and tenacity for No. 2 Mill

Yarn count Ne	**Yarn Evenness**	**Yarn Tenacity**
80	1.053	1.047
70	1.050	0.990
60	1.021	1.010
50	0.980	1.043

It is seen the MCFs for both yarn evenness and tenacity are close to one for all yarn counts. This illustrates that the prediction models work reasonably well across a range of yarn counts and varieties of cottons of different qualities. Using the MCFs shown in Table 7 predicted yarn evenness and tenacity versus the measured for 83 lots Ne 50 to 80 yarns are shown in Figure 13.

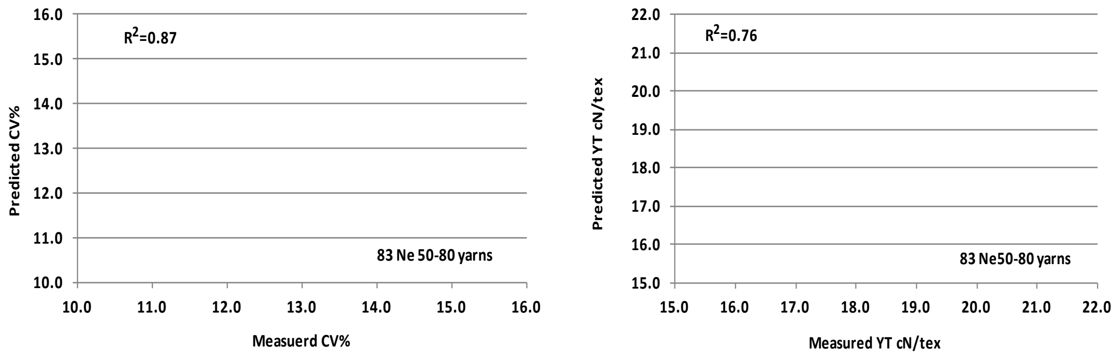


Figure 13 – Predicted vs. measured values for (left) yarn evenness and (right) yarn tenacity values for 83 Ne 50 to 80 validation yarn results for No. 2 Mill using MCFs

The prediction errors for yarn evenness and tenacity for the model using MCFs are shown in Table 6. The results show the prediction accuracy is significantly improved with MCFs. This exercise demonstrates that while Cottonspec works reasonably well for a good modern mill without MCFs, introducing MCFs can enhance its prediction power.

Wenshang Tianrong No. 3 Mill

Figure 14 shows predicted yarn evenness and tenacity values against measured values from the No. 3 Mill. Prediction errors are given in Table 8.

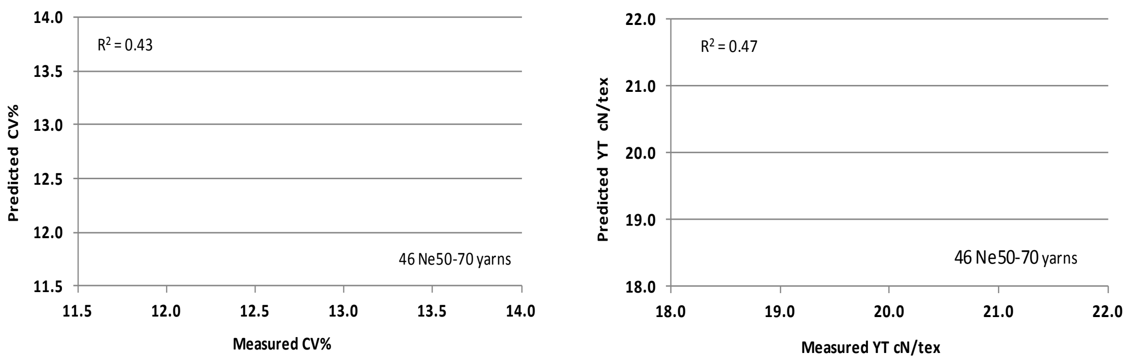


Figure 14 – Predicted vs. measured values for (left) yarn evenness and (right) yarn tenacity values for 46 Ne 50 to 70 validation yarn results for No. 3 Mill.

Table 8 – Prediction errors for 46 Ne 50 to 70 yarns for No. 3 Mill

MCF	**Standard Errors**		**Relative Standard Errors %**	
	CV%	YT cN/tex	CV%	YT cN/tex
no	0.63	0.70	5.12	3.84
yes	0.30	0.49	2.40	2.47

These validation trials show the situation for No. 3 Mill is rather different from the No. 1 and No. 2 Mills. On average, measured yarn evenness was significantly higher than predicted while the measured yarn tenacity was lower than predicted. The correlations between the predicted and the measured yarn quality were significantly lower than for No. 1 and No. 2 Mills. This indicates that the quality control status at the No. 3 Mill is not as good as that at the No. 1 and No. 2 Mills. In this context Cottonspec works like a ruler that can tell a mill's quality control status. If measured yarn quality is close to predicted values the conclusion can be drawn that the mill is a good mill. For a mill with poor quality control the main purpose of Cottonspec is to benchmark the mill's performance against the best commercial practice rather than trying to achieve accurate predictions. Actually, the large scatter observed for No. 3 Mill are mainly caused by poor quality control procedures, e.g. improper sampling, non-standard testing conditions, human error and poor machine maintenance. As the quality control status improves the scatter will reduce and better prediction accuracy will be achieved.

To improve the prediction accuracy mill correction factors for yarn evenness and tenacity for various yarn counts have been worked out as detailed in Table 9. Using the MCFs the predicted yarn tenacity and evenness versus the measured for 46 lots Ne 50 to 70 yarns are shown in Figure 15.

Table 9 – MCFs for yarn evenness and tenacity for No. 3 Mill

Yarn count Ne	Yarn Evenness	Yarn Tenacity
70	1.001	0.977
60	1.017	1.012
50	1.046	0.981

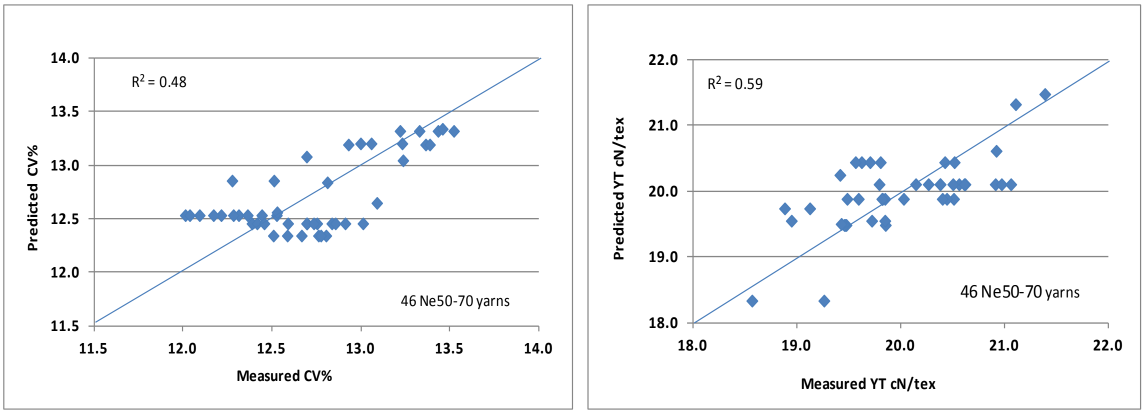


Figure 15 – Predicted vs. measured values for (left) yarn evenness and (right) yarn tenacity values for 46 Ne50 to 70 validation yarn results for No. 3 Mill.

It is seen that the prediction accuracies are greatly improved with MCFs although a large scatter was still obvious. It has to be emphasised that it is of critical importance to improve the mill's quality control procedures before expecting good prediction accuracy with Cottonspec.

For the purpose of comparison the correlation coefficient between the measured and the predicted yarn evenness and tenacity values as well as the prediction errors for the three mills are summarized in Table 10.

Table 10 – R^2 and prediction errors with and without MCFs for partner mills

Mill No.	MCF	R^2		Standard Errors		Relative Errors %	
		CV%	YT cN/tex	CV%	YT cN/tex	CV%	YT cN/tex
1	no	0.81	0.85	0.42	0.84	3.28	3.73
2	no	0.83	0.75	0.68	0.85	5.01	4.80
	yes	0.87	0.76	0.46	0.61	3.43	3.41
3	no	0.43	0.47	0.63	0.70	5.12	3.84
	yes	0.48	0.59	0.30	0.49	2.40	2.47

4.5 Effect of cotton fibre properties on yarn quality

Yarn evenness

Multiple linear regression (MLR) is used to measure the effect of fibre properties on yarn properties. Using the new large database a yarn evenness prediction model was developed from Stage 2 using stepwise MLR – see Equation 6:

CV% = 13.6 + 0.0323 SFC16 + 1.24 Mic - 0.370 Tex - 0.0954 UHML (6)

The relative importance of the four contributing factors (SFC, Mic, Tex and UHML) are illustrated in Figure 16. It is seen that when different yarn counts are mixed together yarn linear density is the most important factor affecting yarn evenness, accounting for about 43% of the observed variations in yarn evenness. This is in line with the Martindale theory (Martindale, 1945)[4], which states yarn evenness is determined primarily by the number of fibres in the yarn cross section.

As far as fibre properties are concerned, SFC less than 16 mm is the most important factor contributing to yarn evenness, adding an additional 25% to the observed variation in yarn evenness. This is supported by theory around fibre drafting; that yarn unevenness above the ideal evenness determined by the Martindale theory is caused by fibres that float between the rollers of a draft zone. The higher the SFC, the more floating fibres there will be and the more uneven (in terms of mass variation per unit length) the resulting yarn will be.

Following SFC, Micronaire is the second most important fibre character that affects yarn evenness, adding another 12% to the observed variations in yarn evenness. Again this is in line with the Martindale theory that yarn evenness is primarily determined by the number of fibres in the yarn cross section. For a given yarn count the number of fibres in the yarn cross-section is determined by mean fibre linear density and its variations.

[4] Martindale, J. G., (1945) Theory of random fibre arrangements in worsted yarns, J. Textile Inst., 1945, 36, T33.

Mean fibre length adds another 4%, bringing the total variation explained by fibre properties to 84% of the total observed variation in yarn evenness.

It is believed that improved measurements of fibre fineness and other fibre properties will improve the accountability of observed variations in yarn evenness. Since the database was provided by the partner mill Micronaire is the only option for fibre fineness in yarn evenness model. Besides, in the database fibre elongation is not available (available only for a small portion of the total database) and its effect on yarn evenness could not be analysed. Cotton neps also has an influence on yarn evenness and its effect is not included because there is no widely adopted measurement technique for cotton neps count.

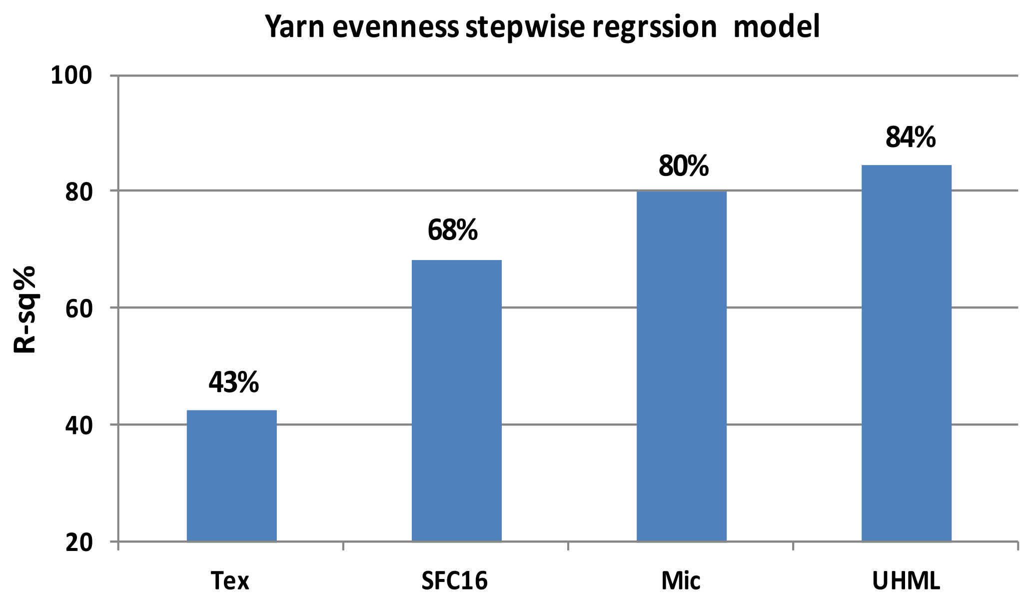


Figure 16 – Yarn evenness stepwise regression model showing contribution of each (fibre) factor to yarn evenness.

Yarn tenacity

The yarn tenacity (YT) MLR model is given by Equation 7:

$$YT = 14.0 - 1.35\ Mic + 0.414\ FT + 0.171\ UHML - 0.0343\ SFC - 0.555\ Pred.CV\% \qquad (7)$$

Again, the relative importance of the five contributing factors were analysed using a stepwise regression technique; the results of which are shown in Figure 17. It is seen that fibre tenacity is the dominant factor affecting yarn tenacity, accounting for almost 87% of the observed variation in yarn tenacity. This is not surprising because theory and experimental results have confirmed that for yarns made from staple fibre, yarn tenacity varies proportionally with fibre tenacity.

It has to be pointed out that cotton fibre properties are strongly inter-correlated. For example, fibre tenacity is strongly positively correlated to mean fibre length, as shown in Figure 18. Therefore, the observed contribution of fibre tenacity to yarn tenacity is also, to some extent, attributable to fibre length effect and it is difficult to separate their effect using the multiple regression technique. In the yarn tenacity prediction model predicted yarn evenness is used as a predictor for yarn tenacity based on the weak-link theory and its effect ranks second following fibre tenacity, adding about 5% to observed variations in yarn tenacity. Micronaire, mean fibre length and SFC make additional small contribution of about 1.3% to observed variations in yarn tenacity, on top of their effects on yarn evenness.

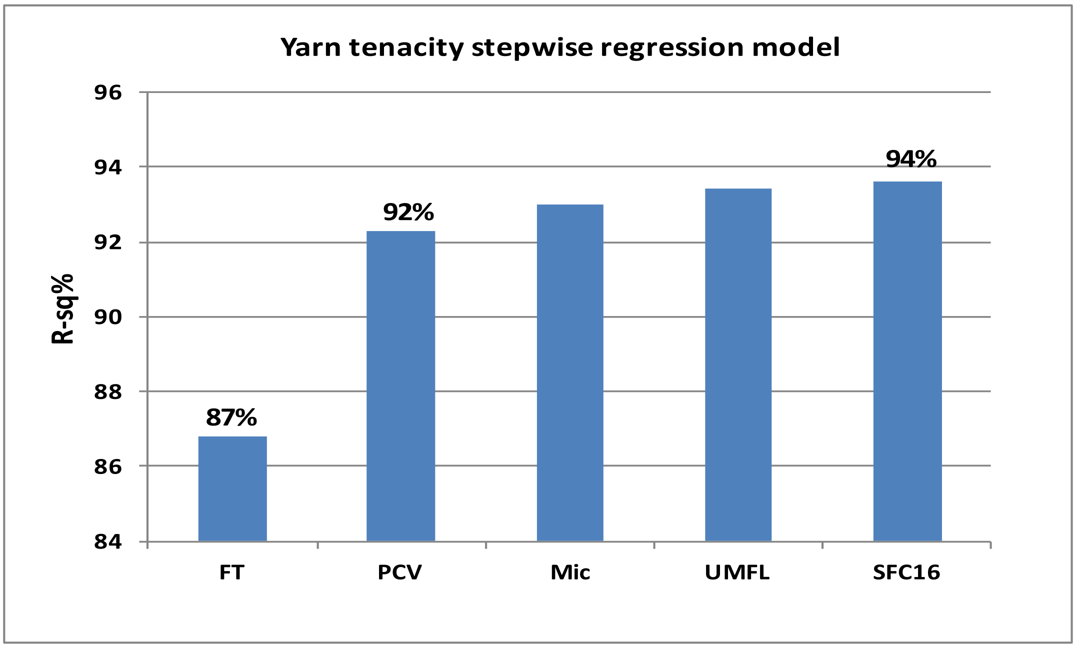


Figure 17 – Yarn tenacity stepwise regression model showing contribution of each (fibre) factor to yarn evenness.

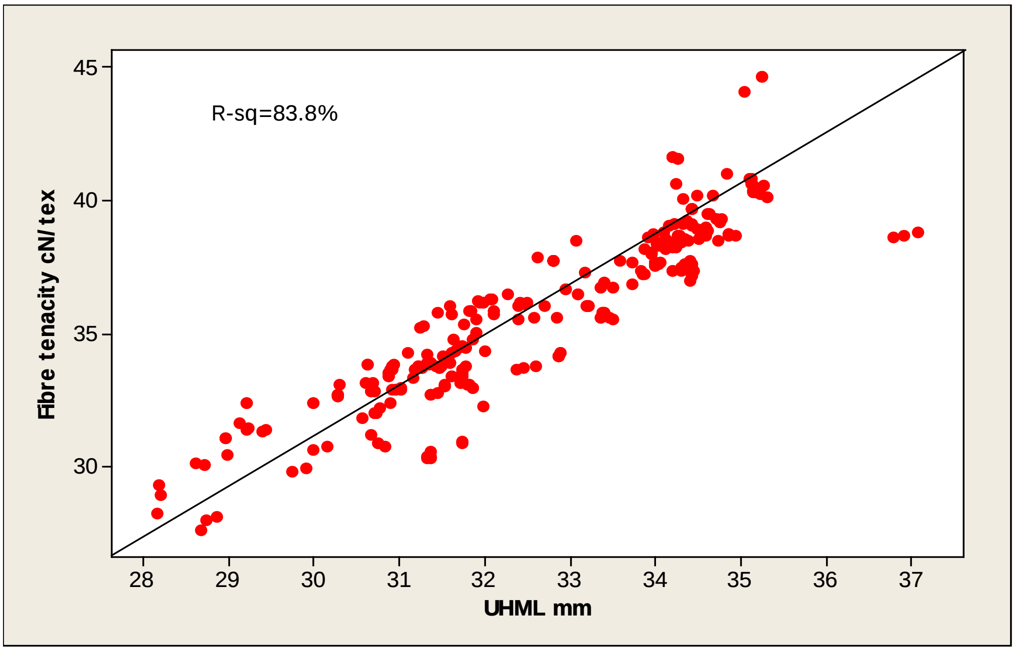


Figure 18 – Correlations between fibre tenacity and mean fibre length

Regression models for other yarn properties, e.g. yarn elongation, neps, thin and thick places are still being developed. Regressions of fibre properties against these yarn characteristics show some strong effects, e.g. fibre elongation has a strong effect on yarn elongation (83%), however most are affected by large outside errors, e.g. small numbers of data and yarn CV% affects.

5. Outcomes

Expected Outputs

This project has delivered a robust cotton spinning prediction software package with significantly improved prediction models utilising spinning database developed through international validation trials. The package will enable spinning mills to choose the most suitable cottons to meet customers' demands for the end products. The package could be particularly useful to merchants as a tool to demonstrate to spinners the advantages of utilising high quality Australian cotton. An industry seminar will be held in China (in Sep/Oct 2012) to promote Cottonspec and the associated know-how throughout the Chinese cotton spinning industry.

The expected outputs have been delivered. Through the validation trials Cottonspec has proven a useful management tool, giving spinners immediate feedback on the fibre they use in terms of yarn quality. The program gives excellent predictions of yarn tenacity and evenness from HVI properties.

Cottonspec has also been used to demonstrate the value of new varieties of long staple cotton produced by Australian growers. Cottonspec will be launched in China later this year at a technical seminar to be held jointly by CSIRO, ACSA and the China Cotton Textile Association (CCTA).

Expected Outcomes:

The science outcomes for the project are associated with the testing and improvement of the Cottonspec yarn quality prediction model, particularly with the incorporation of CMSE's new fibre fineness and maturity test method values and the use of Dr Yang's models on yarn mass variation.

From an industry perspective, Cottonspec could enhance the cotton industry's current drive towards the production of high quality (ALS) fibre that is differentiated by its inherent quality and information around its quality. The software can be used to enhance understanding amongst the growing, ginning and merchant sectors of the importance of fibre quality. The combination of industry understanding and demand pull from spinners will help fulfil the industry's ambitions to develop a high quality product.

Cottonspec's prediction algorithms favour fine, long, strong cotton, i.e. play on Australian cotton fibre characteristics. The package can be used by spinners to select the most suitable cottons, which best meet the spinner's needs, or as a quality control tool to benchmark performance against "best commercial practice". Cottonspec can also be used as a trading tool for merchants to promote the value of a particular growth, or used by cotton researchers and grower collectives to assess and promote new cotton varieties.

The impacts of Cottonspec on mill performance are demonstrated by the example of the Chongqing Sanxia No. 1 Mill, a key partner mill in the project. Established in 2005 this mill is currently one of the most modern mills in China. Through collaboration with the Cottonspec project the quality of yarn produced by this mill has lifted dramatically. Now the mill is among the top five mills in China in terms of quality. All of the yarn this mill produces is exported to Europe and Japan. Moreover, before the project this mill had never used Australian cotton. In 2010-2011 this mill used 3350 tons of Australian cotton, making up about 20% of its lay-downs and its management has made plans to increase this proportion in the next few years.

6. a) Technical advances achieved

For the last sixty years or so researchers around the world have been working on spinning prediction models without great success in the sense that the work has never been accepted by the industry. Cottonspec is the first cotton spinning prediction package in the world that has good commercial potential. Its development involves sophisticated theoretical modeling, experimental design and large-scale industrial spinning trials in collaboration with a number of leading Chinese cotton spinning mills.

b) Other information developed from research

c) Required changes to the Intellectual Property register

Copyright for Cottonspec is owned by CCC CRC and CSIRO.

7. Conclusion

Cottonspec software version 1.0 Beta has been successfully developed with recently upgraded prediction algorithms. Validation trial results showed that for a good modern spinning mill Cottonspec works well with predicted yarn evenness and tenacity closely correlated to the measured yarn quality. Prediction accuracy is further improved by introducing MCFs.

To facilitate wide applications of Cottonspec by the industry the upgraded Cottonspec algorithms require only five HVI test data: tenacity, elongation, length (UHML), SFC and Micronaire. To further improve prediction accuracy some other fibre properties may be included in the future, e.g. fibre fineness, maturity and nep count.

Cottonspec has already produced significant impacts on partner mills. For example, Chongqing Sanxia No. 1 Mill, a key partner mill in this project, has claimed significant benefit through collaboration with the Cottonspec project. Established in 2005 this mill is one of the most modern mills in China. Through collaboration with the Cottonspec project the quality of yarn produced by this mill has lifted dramatically. Now the mill is among the top five mills in China in terms of quality. All of the yarn this mill produces is exported to Europe and Japan. Moreover, before the project this mill had never used Australian cotton. In 2010-2011 this mill used 3350 tons of Australian cotton, making up about 20% of its lay-downs and its management has made plans to increase this proportion in the next few years. Cottonspec project has lifted the demand for high quality Australian cotton through its partner mills and this impact will be further strengthened through the commercialization of the software package in China.

8. Extension Opportunities

See Cottonspec Business Plan

Detail a plan for the activities or other steps that may be taken:
(a) to further develop or to exploit the project technology.
(b) for the future presentation and dissemination of the project outcomes.
(c) for future research.

See FRP to CRDC 'Commercial Ready Cottonspec' for 2012/123 and 2013/14

9. Publications

<u>Non-peered reviewed articles</u>

Yang S., Wu L. and Gordon S., Cottonspec – A Cotton Fibre and Yarn Quality Management Tool, Procedings Beltwide Cotton Conferences, Atlanta, US, Jan. 2011.

Yang S. and Gordon S., Cottonspec – Preliminary Results of Cottonspec Validation Trials, Procedings Beltwide Cotton Conferences, Orlando, Florida, US, Jan. 2012.

<u>Presentations (conference, field days, workshops etc)</u>

Yang S. and Gordon S., CottonSpec – Predicting –Yarn Quality from Cotton Fibre Property, Poster, Australian Cotton Conference, Goldcoast, August, 2010

Yang S. and Gordon S., Strategic relationships with the Chinese Cotton Spinning Industry, Poster, Australian Cotton Conference, Goldcoast, August, 2010

Yang S. and Gordon S., Promote Australian Cotton to International Spinners, Presentation, CRC Science Forum, Narrabri, October, 2010

Yang S. and Gordon S., Cottonspec - a tool for cotton fibre and yarn quality management, Presentation to ACSA Board, March 2011

Yang S. Cottonspec, Presentation, PI Fibre Workshop, Narrabri July, 2011

Yang S. and Gordon S., Promoting Australian Cotton to International Spinners - Update of the Latest Development of Cottonspec, CRC Science Forum, Narrabri, March, 2012

B. All other publications by project team during this period.

Gui, L., Yang Y. Wang M., Yang S. Yu W., Comprehensive Characterization Model of Integrated Cotton Fiber Quality Index, J. Donghua University (Eng. Ed.), Vol 28, No. 4, 2011

C. Have you developed any online resources and what is the website address?

See Cottonspec Business Plan

Part 4 – Final Report Executive Summary

Cottonspec is a yarn quality prediction software developed by CSIRO with support from the CCC CRC, CRDC and Chinese partner mills. Validation trials conducted as part of this project showed Cottonspec was a useful mill management tool, giving spinners immediate feedback on the fibre they use in terms of yarn quality. The software program gives excellent predictions of yarn tenacity and evenness from (five) HVI properties.

Cottonspec will be launched in China later this year at a technical seminar to be held jointly by CSIRO, ACSA and the China Cotton Textile Association (CCTA).

Cottonspec has the capacity to improve the classification of Australian cotton by linking cotton fibre quality with yarn quality with theoretical modelling. The prediction algorithms favour fine, long, strong cotton, i.e. play on Australian cotton fibre characteristics. The package can be used by spinners to select the most suitable cottons that best meet the spinner's needs, or as a quality control tool to benchmark performance against "best commercial practice". Cottonspec can also be used as a trading tool for merchants to promote the value of a particular growth, or used by cotton researchers and grower collectives to assess and promote new cotton varieties.

Cottonspec could prove to be an invaluable tool to promote Australian Long Staple (ALS) cotton to mills for production of high quality yarns. Cottonspec has excellent potential to help create demand pull from high-end mills for ALS cotton. The commercialisation of Cottonspec through an extension project will create stronger partnership with quality mills to enable feedbacks on future fibre quality demands and yarn and fabric trends; and to create demand for ALS cotton.

The impacts of Cottonspec on mill performance are demonstrated by the example of the Chongqing Sanxia No. 1 Mill, a key partner mill in the project. Established in 2005 this mill is one of the most modern mills in China. Through collaboration with the Cottonspec project the quality of yarn produced by this mill has lifted dramatically. Now the mill is among the top five mills in China in terms of quality. All of the yarn this mill produces is exported to Europe and Japan. Moreover, before the project this mill had never used Australian cotton. In 2010-2011 this mill used 3350 tons of Australian cotton, making up about 20% of its lay-downs and its management has made plans to increase this proportion in the next few years.

The successful commercialisation through the extension project 'Commercial Ready Cottonspec' will enhance the cotton industry's current drive towards the production of high quality fibre that is differentiated by its inherent quality and the information around its quality. The combination of industry understanding and demand pull from stragegic partner mills in China for high quality Australian cotton will help fulfil the industry's ambitions to develop a high quality product.

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