

**MEASUREMENT OF AVERAGE MATURITY AND
MATURITY DISTRIBUTION STATISTICS BY SIROMAT IN COTTON FIBRE
SUBJECT TO DIFFERENTIAL DEFOLIATION TIMING TREATMENTS**

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Abstract

SiroMat is an automated version of the polarized light microscopy technique, which analyzes interference colors transmitted by cotton fibres when they are placed between crossed polars and a first order retardation plate. The percent areas of colors 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 SiroMat measurements are reported for blends comprising different proportions of cotton fibre picked from plants subjected to differential defoliation timing treatments. The proportion of immature fibres in each sample is correlated with measurements on the same samples of neps per gram made by the AFIS PRO. The motivation behind this study is based on the desire to manage the amount of immature fruit included in a crop, and how this relates to nep generation in the gin and spinning mill.

Introduction

A cotton fibre is a single elongated plant cell that grows from the surface of a cotton seed. How thick the cell wall becomes during its development is important because it determines how well the fibre will process from both a chemical and physical perspective. The term fibre maturity is applied to describe the degree of cell wall thickening. Immature fibres, i.e. those with little or no fibre wall thickening, are associated with the formation of small entanglements called neps, irregularities in processed fibre assemblies including finished yarns, non-uniform dyeing of fabrics and decreased processing efficiency.

Because fibres do not all develop in the same way, considerable dispersion about the mean cell wall thickening of a cotton is found. This dispersion is found in all samples of cotton, from samples sourced from baled cotton to fibres taken from one individual seed. While the importance of this dispersion is by no means certain, it has been suggested that knowledge of the spread and shape of this dispersion would be of value in managing problems associated with immature fibres.

CSIRO Textile and Fibre Technology have developed the SiroMat technology that measures fibre maturity directly and automatically. The SiroMat is based on polarized light microscopy, a technique that has long been used to investigate the crystalline structures of inorganic and inert organic materials. The technique has been used extensively in the identification of fibres that exhibit birefringent properties, i.e. fibres that behave like a uni-axial optical crystal. The optical axis in birefringent fibres is usually parallel to the fibre axis with the refractive index being dependent upon the plane of polarization of the incident light. When plane polarized light is transmitted through a birefringent object the light ray is split into two mutually perpendicular vibrating fast and slow rays, which

propagate through the object at two different speeds. Upon emerging from the object a phase difference occurs between the fast and slow rays. When recombined into a single ray by passage through a second polarizer (analyzer) the rays interfere with each other, which in turn create different interference colors that highlight the crystalline oriented aspects of the specimen.

The interference colors assumed by cotton fibres are the result of the optical phenomena described above and have been classified by Grimes [Grimes, 1945] in terms of the cotton fibre maturity they represent and incorporated into a well known ASTM Standard for determining cotton fibre maturity [ASTM, 2000]. The disadvantage of the test is that the operator must make an arbitrary assessment of the colors assumed by the fibres and the subjective decision made by the operator contributes to large discrepancies in the results from different laboratories. The Standard in fact warns against using the method for acceptance testing because of poor precision. Furthermore, the test is too slow for routine test applications both in terms of specimen preparation and test time.

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 Gordon and Phair [Gordon and Phair, 2005] has shown that specific interference colors relate directly with theta (θ) or degree of circularity, which is generally accepted as being the 'true' expression of cotton fibre maturity [Lord and Heap, 1988, ITMF, 1990]. However, on the basis of convention measurements are expressed in terms of maturity ratio (MR) according to Pierce and Lord [Pierce and Lord, 1939]. A MR value of 1.00 equates to a mean θ value of 0.577.

In this study the SiroMat is used to test a set of cotton samples from the same crop but each with a different maturity by dint of blending by weight 10% increments of seed-cotton from two defoliation treatments applied to the same crop. The objective is to demonstrate the ability of the SiroMat instrument to differentiate the samples on the basis of their mean and dispersion statistics, in this case the standard deviation and skew of the maturity distribution within each specimen tested. The SiroMat data is also correlated with Uster AFIS PRO nep results as a first step in measuring how well maturity dispersion statistics predict neps in fibre.

Materials and Methods

Cotton samples

Cotton plants (*Gossypium hirsutum* L. Sicot 71BR, CSIRO Australia) were grown under normal industry standard irrigated conditions at the Australian Cotton Research Institute (ACRI) (Narrabri, New South Wales).

Plants were sown on the 19th October 2005. Plants were subject to leaf defoliant and boll opener applications (200 mL/ha of Dropp, 3 L/ha of Prep, 2 L/ha of DC-tron) at 174 and at 187 days after sowing (DAS). To facilitate an early immature crop, a block of plants was subjected to additional early chemical treatments at 133 and 155 DAS.

Cotton from immature and mature plants was machine harvested separately (International single row spindle harvester). Four replicates of (each blend) this mature and immature seed cotton were randomly selected from the harvest and thoroughly blended together by hand at 11 different proportions based on weight (100% mature: 0% immature down to 0% mature: 100% immature, in 10% increments). Samples were saw ginned using a 20 saw gin located at the ACRI.

Instrument Testing

Test samples for the SiroMat and AFIS PRO were blended through one passage of a 'Shirley' Analyser.

Samples for the AFIS PRO were passively conditioned for at least 48 hours under standard conditions (20°C +/- 2°C and 65% relative humidity +/- 3%) before testing and then prepared according to the manufacturers instructions.

Preparation of SiroMat specimens 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 are collected and then spread in an annular pattern on a 5 cm x 7 cm glass slide using an OFDATM fibre spreader. A clean 5 cm x 7

cm slide is used to cover the specimen. Castor oil (refractive index = 1.477 – 1.481) is used as the mounting medium to enhance the contrast of the fibre snippets to their background.

Preparing the SiroMat instrument is relatively simple and involves adjusting the digital camera settings (U balance, V balance and shutter speed) and the microscope lamp intensity to match a prescribed background (magenta) color in terms of red, green and blue ratios. Background colors were also checked at regular intervals during testing to minimize drift in instrument readings.

Data Analysis

Four SiroMat and five AFIS PRO test specimens were drawn from each blend sample for testing. Table I lists the mean SiroMat and AFIS PRO values of each blend ratio along with the standard deviation and coefficient of variation of replicate measurements for each blend.

Differences in SiroMat values between 100% mature and 100% immature treatments were tested by way of a two-tailed Student t-test ($n = 16$). In order to examine the sensitivity of SiroMat data to variations in percent maturity, the mean and standard deviation of the distribution in each blend sample were regressed against the nominal percent mature fibre for each of the 11 blended ‘maturity’ portions (Figs. 2 and 3). Using percent mature fibre as the dependent variable, the standard error of estimate (SEE) was calculated to provide a measure of the SiroMat’s accuracy and precision.

The relationship between SiroMat mean and dispersion measurements were also plotted to determine the significance of any correlation (Figs. 4 and 5). A highly significant correlation between a mean and the dispersion of values about it suggests that the dispersion statistic would be of little value in describing the sample further.

Finally the SiroMat mean and standard deviation and skew of the distribution around each mean were plotted against AFIS PRO nep results (Figs. 6, 7 and 8).

Results and Discussion

Figure 1 shows the accumulated distributions (for the four blend replicates) of 100% mature and 100% immature blend samples. Noticeable is the negative skew and long immature tail of each distribution. In our experience the characteristics of these maturity distributions are common to all cottons. Despite apparent similarities in distributions mean MR values for 100% mature and 100% immature blend samples were significantly different ($p = 0.0001$). Significant levels of difference also apply to measurements of the standard deviation of maturity distribution (SDMR) ($p = 0.0085$) and the skew of maturity distributions (SKMR) ($p = 0.0340$).

The regression of mean MR (as independent variable) with percent mature fibre (Fig. 2) gave a co-efficient of determination (r^2) of 0.975 with a SEE of 5.49% for percent mature fibres in each blend. Given the narrow range examined here; mean MR ranged from 0.88 to 0.98, these data demonstrate SiroMat’s ability to distinguish small changes in fibre maturity. This predictive ability also extends to the SiroMat measure of SDMR measured in the blend samples (Fig. 3). As an independent variable SDMR produced a SEE of 7.90% for percent mature fibres in each blend. However, the high correlation, and the significant correlation observed between mean MR and SDMR (Fig. 4) suggests that at least in the case of the blend samples examined here, SDMR is of little extra value in predicting quality and processing problems in the cotton. The relationship between mean MR and SKMR shown in Fig. 5 is also significant although the correlation suffers somewhat from a higher SD between replicates of skew values. Further testing is required to determine whether or not the higher SD between reps is associated with random error or real differences between replicates.

The proposal that SiroMat data can be used to predict nep levels is examined in Figs. 6 to 8, which show scatterplots of mean MR, SDMR and SKMR versus AFIS PRO nep results. Each relationship is quite poor in terms of regression statistics, which in part is a reflection on the small amount of mechanical pressure applied to each sample; mechanical processing was limited to passages through a small laboratory gin and one passage of a ‘Shirley’ Analyser, and the narrow range of mean MR examined here. We note also that the SD between nep replicates decreased with increasing fibre maturity (Table I). We suspect the more immature fibre specimens behave differently during fibre individualization in the AFIS instrument.

In retrospect additional lint cleaning passages may have created a better illustration of the relationship between immaturity and nep creation. It is noted that more than 70% of neps measured in baled cotton are generated through two-lint cleaner passages [Draheim, 2001]. Nevertheless the relationships between SiroMat values and nep count are consistent with expected theory, i.e. that nep levels increase with increasing proportions of immature fibre in the distribution. Further study is required to take into account factors such as fineness, fibre length, variety (inc. agronomic factors) and different gin conditions before more definite judgments on the relationship between mean MR, SDMR, SKMR and nep formation can be made.

Table I – AFIS PRO and SiroMat mean and replicate data

Sample % Blend	AFIS PRO		SiroMat Mean and Replicate Data								
	Neps	SD Nep Rep	Mean MR Dist	SD MR Rep	CV% MR Rep	SD MR Dist	SD SDMR Rep	CV% SDMR Rep	Skew MR Dist	SD SKMR Rep	CV% SKMR Rep
100% Immature	269	74	0.88	0.02	2.27	0.53	0.03	5.66	-2.70	0.27	10.00
90/10	233	51	0.89	0.02	2.25	0.51	0.03	5.88	-2.78	0.19	6.83
80/20	244	45	0.89	0.02	2.25	0.52	0.02	3.85	-2.83	0.21	7.42
70/30	297	79	0.90	0.02	2.22	0.51	0.01	1.96	-2.93	0.16	5.46
60/40	229	78	0.92	0.02	2.17	0.48	0.03	6.25	-2.98	0.25	8.39
50/50	270	80	0.93	0.01	1.08	0.48	0.01	2.08	-2.98	0.13	4.36
40/60	200	38	0.94	0.02	2.13	0.47	0.03	6.38	-3.10	0.21	6.77
30/70	252	26	0.94	0.02	2.13	0.46	0.02	4.35	-3.23	0.20	6.19
20/80	179	26	0.95	0.02	2.11	0.46	0.02	4.35	-3.20	0.13	4.06
10/90	162	22	0.96	0.02	2.08	0.45	0.02	4.44	-3.20	0.13	4.06
100% Mature	179	18	0.98	0.01	1.02	0.43	0.02	4.65	-3.30	0.11	3.33

SD = standard deviation, Rep = replicate, Dist = distribution, CV% = co-efficient of variation, SK = skew

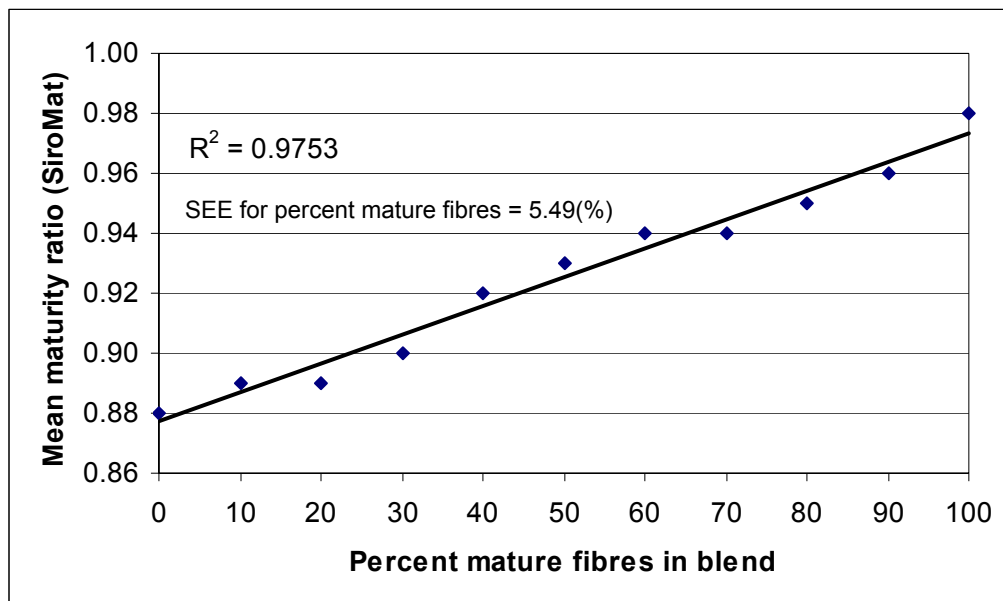


Figure 1 – Mean SiroMat maturity versus the nominal % maturity of each blend

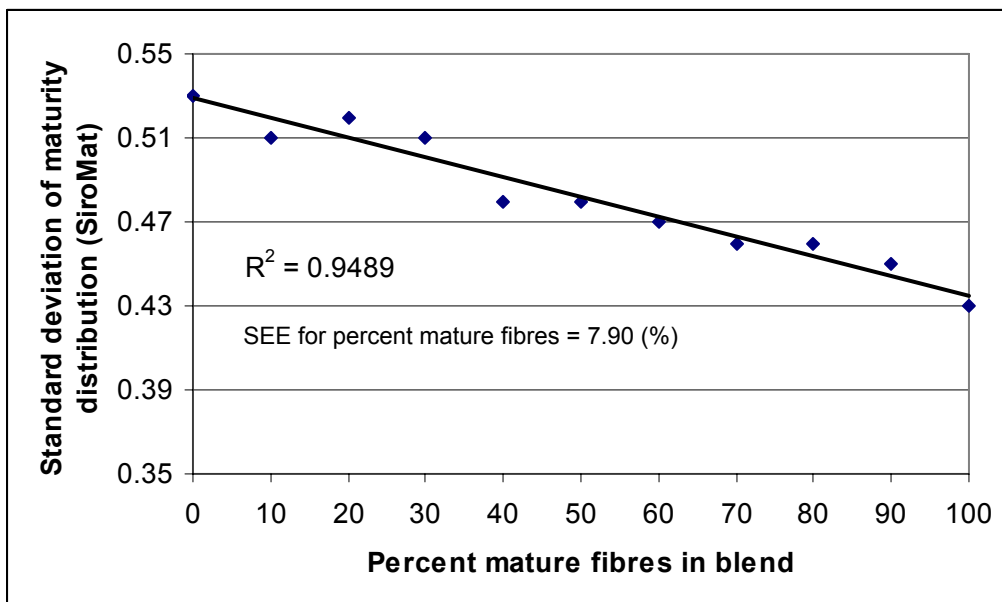


Figure 2 – Standard deviation of SiroMat maturity distribution versus the nominal % maturity of each blend

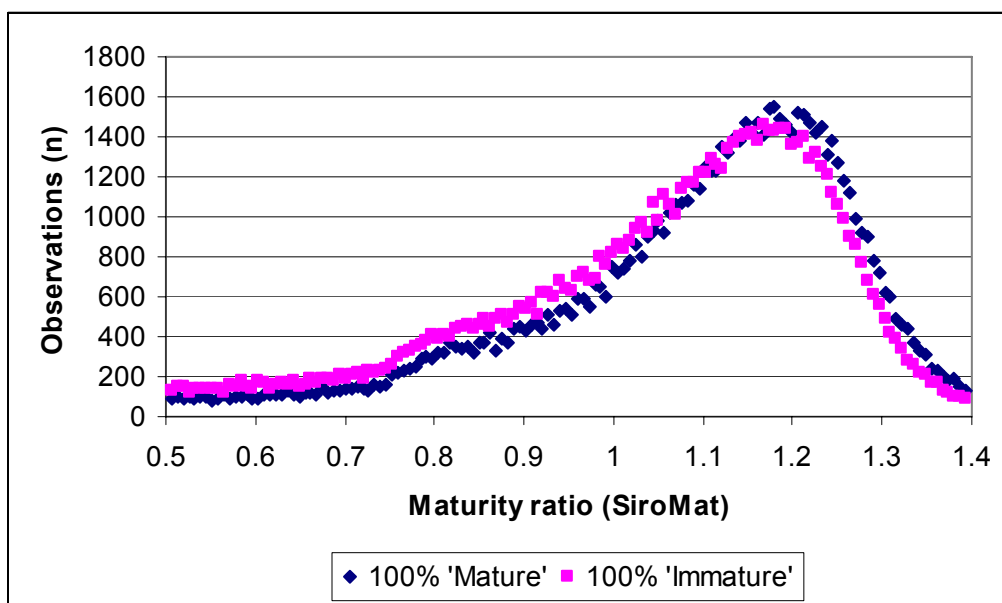


Figure 3 – SiroMat maturity distributions for 100% 'mature' and 100% 'immature' blends

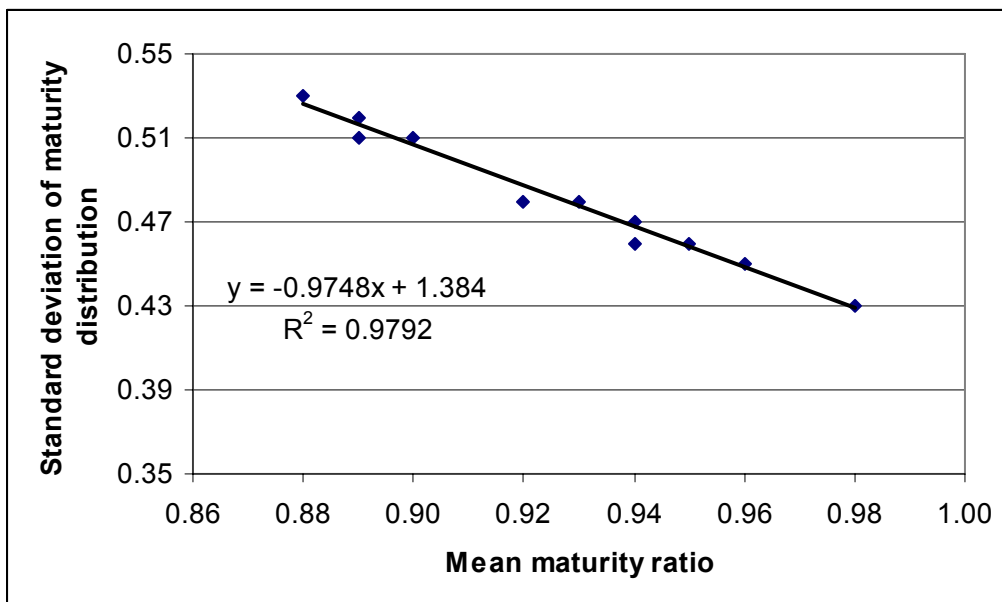


Figure 4 – Relationship between SiroMat mean maturity & the standard deviation of maturity distribution

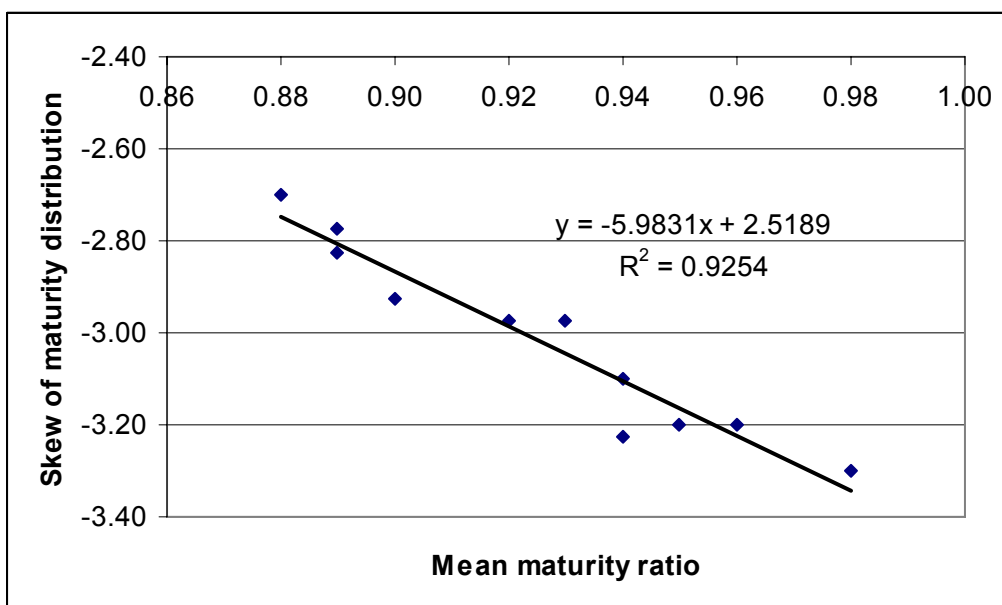


Figure 5 – Relationship between SiroMat mean maturity (ratio) & the skew of the maturity distribution

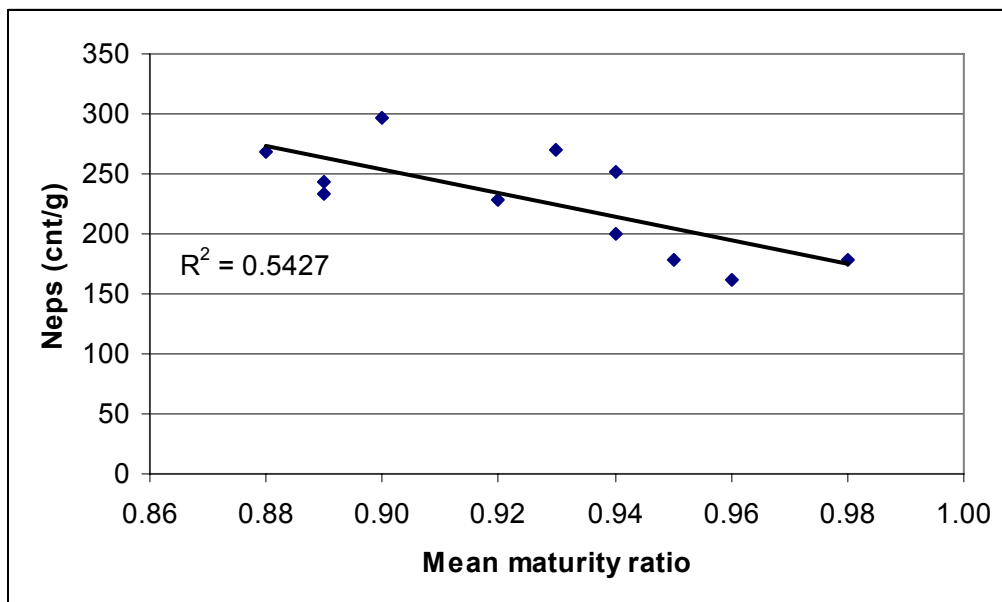


Figure 6 – Relationship between mean maturity ratio and AFIS PRO nep

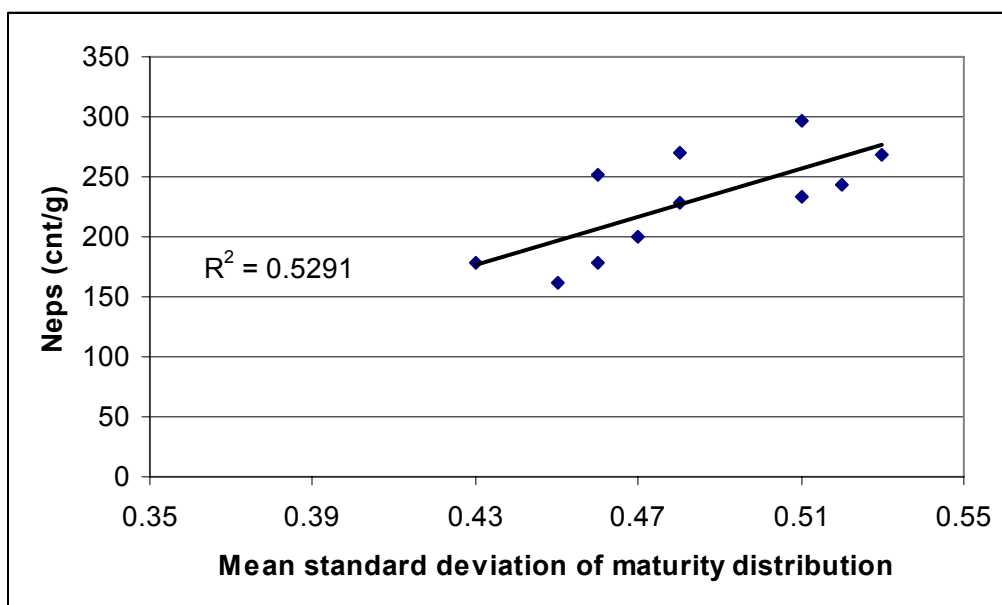


Figure 7 – Relationship between mean standard deviation of maturity (ratio) distribution & AFIS PRO nep

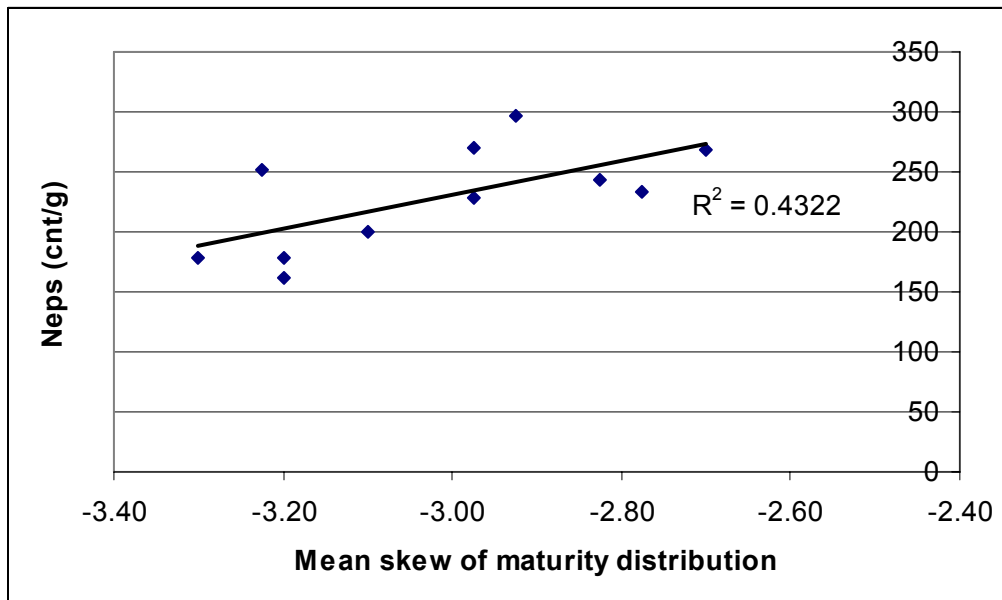


Figure 8 – Relationship between the mean skew of maturity (ratio) distribution & AFIS PRO nep

Conclusions

A set of SiroMat measurements on cotton samples that originated from two defoliation treatments shows the ability of the instrument to accurately and precisely measure the mean and the dispersion of fibre maturity in samples where the differences in mean maturity were thought to be quite small (the mean MR in this set ranged from 0.88 to 0.98). The SiroMat measurements demonstrated negative relationships exist between mean maturity and dispersion values such as standard deviation and skew. These dispersion statistics might be useful in determining nep potential or other processing problems, although it was noted that the high correlation between mean and dispersion values in this data set made the dispersion statistics redundant in terms of nep prediction. Further work is required on a sample set that includes different varieties raised and processed under different environmental, agronomic and gin conditions.

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