TITLE: Producing and preserving fiber quality: from the seed to the bale

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Producing and preserving fiber quality: from the seed to the bale

Abstract

The future for cotton as a fiber will have many challenges with competition from synthetics as well as challenges with production costs and even competing use for land in production of grain or other uses. The opportunities are therefore to improve the product to make it more attractive in cost and feel to consumers. In this paper we review the task for cotton growers and the cotton industry in general to optimize fiber quality in all steps from strategic farm plans, cultivar choice, crop management, harvesting and ginning. Selection of the most appropriate cultivar to have good fiber quality as well as disease resistance, growth habit and yield is important. There are opportunities for cotton breeders to develop cultivars with fiber properties more appropriate for future market demands. Crop management can play an important role in determining fiber quality – we review cases for fiber length and micronaire management. Equal emphasis needs to be placed on harvesting and ginning to retain fiber properties as much as possible during processing. Only necessary treatment in the gin should be done, particularly lint cleaning. All components of the production chain have further opportunities for improvement. We introduce the Integrated Fiber Management (IFM) term to emphasize the importance of a balanced approach to managing fiber quality. New technologies, new instruments, new decision support programs and communication will facilitate IFM.

Key words: Fiber quality; crop management; ginning; Integrated Fiber management.

Introduction

Cotton is primarily grown for its fiber and its reputation and attraction are the natural feel and light weight of cotton fabrics. Heavy competition from synthetic fibers dictates that continued improvement is needed in cotton fiber properties. There is then an opportunity to exploit cotton fiber's advantage and enhance its reputation by improving and preserving its fiber qualities through the growing and processing value chain to match those properties sought by cotton spinners, who require improved fiber properties: longer, stronger, finer, more uniform and cleaner to reduce waste, allow more rapid spinning to reduce production costs and allow better fabric and garment manufacture.

Cotton fibers are naturally variable and it is a challenge to manage this variability. Our experience with variability in fiber quality shows a substantial range across seasons and irrigated sites for micronaire (35%), with lesser ranges for length and strength (<7%). Note lint yield had a 58% range across the same data set. If raingrown systems are included in such an analysis, yield and fiber length have a larger range due to moisture stress. Fiber strength is mostly affected by cultivar unless the fiber is very immature.

To ensure the best realization of fiber quality from a cotton crop, the best combination of cultivar, management, climate and processing is required. For example, if you start with a cultivar with poor fiber quality, there is nothing that can be done with management and processing to make the quality better. However, if you start with a cultivar with good fiber quality traits, there is some insurance against unfavorable conditions but careful management and processing are still required to preserve quality.

Historically there has generally been greater production problems for low micronaire (assume immature) cotton especially when grown in relatively short season production areas having a cooler and wetter finish to the season. The response by cotton breeders can be to select for a higher micronaire in parallel with high yield during cultivar development. Given a negative association between yield and fiber fineness (Price 1990), such a breeding strategy could produce cultivars with coarse and immature fibers – exactly the opposite combination required by spinners. Thus although more difficult, it is clear the breeding strategy should be to ensure selection for intermediate micronaire with fine and mature fibers. Therefore separate measurement of fineness and maturity are important. These require specialized instruments.

There are many measurements of cotton fiber quality and a corresponding range of measuring instruments. The more common instruments in commercial use and in marketing are of the high volume type and this paper will concentrate on values measured on Uster High Volume Instrumentation (HVI) or equivalent. The range of measurements include fiber length (and its components uniformity, short fiber content); fiber strength (and elongation or extension); fiber micronaire (and fineness and maturity); grade (including color, trash, neps, seed coat fragments). This paper will concentrate on fiber length, fiber strength and micronaire. All other measurements are acknowledged as being important in many circumstances, but we will use length, strength and micronaire to represent the effects that various factors such as cultivar, management, climate or processing may have on fiber quality. We aim to review opportunities for breeding, management and processing to optimize fiber quality under commercial practice.

Fiber development

The fundamentals of fiber development are well known (Balls 1915 – cited by Sethi *et al.*1960) and a good understanding of these principles helps apply farm management strategies to optimize fiber quality. Basically, as few as 10% of cells on the ovule epidermis form fibers (Ryser 1999) and growth of each fiber begins after anthesis with the cell wall expanding rapidly (>1 mm/day) for about one-third of the boll development time (Schubert *et al*. 1973; 1976). From that time the fiber wall thickens from the outside towards the center with concentric layers of cellulose when fiber strength and fiber maturity are established. About the last 10% of boll development time is drying of the seeds and fibers, the circular fiber cross section collapses as it dries to a twisted ribbon after boll opening.

Cultivar

Cultivar choice is a strong component of realizing target fiber quality levels on farm. A delicate balance needs to be resolved between yield, fiber quality, price and other important considerations such as disease resistance, insect and herbicide resistance. It is clear that cultivar fiber properties can cover for some climate or management challenges. Examples include longer fiber cultivars reducing short fiber discounts in water stress environments, or high micronaire cultivars minimizing low micronaire discounts as a result of cool or stress environments during boll maturation.

There is good genetic variation in cotton fiber properties for plant breeders to exploit. A recent review (May 1999), concluded most fiber properties had reasonable heritability, although each was under additive genetic control, with many genes for each trait and hence quantitatively inherited. Quantitative Trait Loci (QTL) studies show length, strength and fineness each being influenced by 12 to 21 QTL (Lacape *et al*. 2005; Park *et al*. 2005). HVI is adequate for measurement and selection of fiber properties in a breeding program, especially in being able to process large numbers of samples rapidly (May and Jividen 1999).

The literature shows there are negative associations between cotton yield and fiber quality traits (Miller and Rawlings 1967; Meredith and Bridge 1971; Thomson 1973; Meredith 1984; May 1999; Stiller 2000) and the breeder's challenge is to overcome these negative associations. These negative associations are evident in breeding populations as presented in the literature cited above as well as across cultivar types such as comparisons of Pima, Acala and other upland types: premium fiber types yield less than standard types, so there needs to be price incentives for premium fiber to justify their production. We would already be growing cotton with high yield and premium fiber quality if it was easy to combine these essential (yield) and desirable (quality) attributes.

It is necessary to appreciate the plant breeder's challenge in understanding slow progress. For example, our breeding program in Australia (Constable *et al.* 2001) has evidence of the negative yield quality association. One extreme example is shown in Figure 1 where fiber length in particular had a strong negative association with lint yield (r = -0.81**). This type of relationship scares breeders – although in this case the highest yielding line (subsequently released as Sicot 80 (Reid 2003)) had adequate fiber length. In recent years a large number of populations have been established to address combination of fiber quality improvement targets with high yield. Table 1 shows a summary of the association between lint yield and fiber quality in 14 F_4 breeding populations in the past three years. These correlation coefficients have been calculated for fiber length as well as a Fiber Quality Index (FQI = length * strength / micronaire) to indicate desirable combination of length, strength and micronaire. FQI was not more closely associated with yield than fiber length, somewhat surprising considering FQI would indicate combinations of three fiber traits. This would indicate fiber length associations with yield were stronger than for strength or micronaire. Many associations were not statistically significant in these populations, although a negative trend was most common, and the high yielding lines were not the best fiber quality. Given that each fiber trait is multigenic and each parent of a population can carry different genes, it should not be surprising the association between yield and fiber quality will vary. Some associations were significant: population 61220 for example was a cross between a high quality breeding line with relatively low yield and a breeding line with short and coarse fibers but with very high yield. This population had a wide spread in yield and fiber quality and a significant negative association.

It must be emphasized these were not random populations; they were F_4 populations which were the result of fiber quality selection in F_2 and F_3 as well as yield selection in F_3. The data illustrates the challenge in combining desirable characteristics.

The low statistical correlations in general, mostly not significant, should lead us to the conclusion that progress can continue on improving combination of yield and fiber quality. Our strategy as a result is to have targeted if not diverse crosses, large populations and heavy selection pressure for desired characteristic combinations. We expect to need recurrent crossing, in firstly developing parents with some desirable characteristics, and subsequently crossing those with other parents with different desirable characteristics. Genuine progress in combining high yield with fiber quality could support the hypothesis the negative association between yield and quality was genetic linkage, rather than functional. Combinations of yield and fiber quality with disease resistance and transgenic traits make the breeder's task even more challenging. Cultivar development has progressed through time to improve the combinations of yield and fiber quality – that progress is expected to continue – combining traditional breeding with biotechnology traits and tools.

Management

As opposed to the negative associations between yield and fiber quality in breeding discussed above, the majority of crop management factors which increase/optimize yield will also increase/optimize fiber quality. One exception may be instances of production of high micronaire cotton. However, agronomically fiber properties are strong yield components: everything else being equal, longer fibers mean more lint yield; likewise a greater linear density (less fine; higher micronaire) will mean more lint yield.

The literature on agronomy and climate effects on fiber quality is particularly comprehensive for fiber length and micronaire; fiber strength is more influenced by cultivar. Fiber growth and development is affected by most factors which influence plant growth. Since the fiber is primarily cellulose, any influence on plant photosynthesis and production of carbohydrate will have a similar influence on fiber growth. Cell expansion during growth is strongly driven by turgor, so plant water relations will also affect fiber elongation in the period immediately following anthesis. Thus in terms of primary (direct) responses, water status (irrigation) strongly influences fiber growth and ultimately final fiber length (Hearn 1976; Constable and Hearn 1981; Ramey 1986; Hearn 1994; Palomo-Gil *et al.* 2004). Fiber elongation and fiber thickening are also affected by temperature (Gipson and Joham 1968; Hesketh and Low 1968) and radiation (Pettigrew 1995; Wang *et al.* 2006), with large reductions in fiber thickening at lower temperatures or cloudy weather, leading to low fiber micronaire. Delayed sowing may expose more of the fiber thickening phase to lower temperatures and reduce micronaire (Constable *et al.* 1976; Davidonis *et al.* 2004; Dong *et al.* 2006). Potassium deficiency can have a significant impact on fiber length (Nelson 1949; Bennett *et al.* 1967; Hearn 1981; Read *et al.* 2006) because of the role of potassium in maintenance of cell turgor by osmotic regulation (Dhindsa *et al.* 1975). Other nutrient deficiencies can also reduce fiber length (Constable and Hearn 1981; Sawan *et al.* 2006). However where nutrient deficiencies are not the major factor in a production system, nitrogen or potassium fertilizer treatments will not necessarily improve fiber length (Pettigrew 2003; Boquet *et al.* 2004). Early crop defoliation or leaf removal can cause substantial reductions in fiber micronaire due to the cessation in carbohydrate supply for fiber thickening (Gwathmey *et al.* 2004; Siebert *et al.* 2006). Few agronomic or climatic conditions have been shown to consistently affect fiber strength.

Severe weed competition in cotton can have strong effects on fiber properties (Castner *et al.* 1989) as well as trash contamination. High density and narrow row cotton production systems have variable effects on fiber quality: from no impact (Constable 1977; Nichols *et al.* 2004; Clawson *et al.* 2006) to significant reductions (Gwathmey *et al.* 2004; Bednarz *et al.* 2006). This varied response can be explained by the specific combination of negative direct and positive indirect effects – eg negative impacts of competition on fiber quality may be balanced by positive effects of avoiding later unfavorable conditions. One aim of high density narrow row systems is to compress fruiting and fiber development to a shorter time period and avoid later cool or stress conditions – to at least achieve more uniform crop fiber properties.

Cotton’s indeterminate growth habit also leads to many secondary (indirect) impacts of climate and management on fiber properties. Any management which delays crop maturity can lead to reduced micronaire due to exposure of a greater proportion of a crop to unfavorable conditions such as cooler or cloudy weather. Early stress with subsequent recovery, or higher nitrogen fertility (Constable and Hearn 1981) and different tillage or rotation systems (Hearn 1976; Constable *et al.* 1992; Bauer and Frederick 2005; Pettigrew *et al.* 2006) and insect damage causing compensation and later fruit production (Brook *et al.* 1992) are examples.

The above results and principles assist in managing fiber quality. A proactive strategic plan combined with tactical management of a cotton crop will optimize fiber quality. The following three cases are examples.

- If fiber length is of particular concern, then cultivar choice and a general cropping system to avoid or minimize water stress should be employed to ensure more reliable fiber length. Cultivars with longer inherent fiber length will have more insurance to achieve base fiber length and avoid price discount. An irrigation strategy to avoid stress on developing fibers during flowering should be followed. For dryland production systems, soil water conservation management such as fallows; sowing date strategies to time early flowering to coincide with more reliable rainfall; and plant spacing strategies such as skip rows to reduce stress at early flowering will preserve fiber length. Dryland skip row configurations can increase fiber length by up to 0.08 inches compared with solid configurations (Bange *et al*. 2005).

- If low micronaire is of concern, then cultivar choice, and appropriate cultivar growth habit and maturity for the climate and season length are important to avoid exposure of maturing fibers to low temperature, cloudy weather and other stresses. An early maturing cultivar with inherently higher micronaire would be desirable. Management for earliness through sowing on an appropriate date for the cultivar and climate to avoid late crops in cooler areas; pest management to have uninterrupted boll setting; growth regulator application in early to mid flowering if crops become too vegetative; optimized irrigation and fertilizer management to avoid stress and to meet desired yield targets; schedule last irrigation to have soil at normal refill point at defoliation; use appropriate timing, product and rate of defoliant to minimize immature fibers. In variable climates there is a dilemma in choosing a cultivar with higher yield potential but with greater risk of encountering unfavorable conditions during boll fill compared with an early maturing cultivar which may avoid late season problems, yet yield less (up to 136 kg lint/ha for every week of earliness (Bange and Milroy 2004)). Under this situation, a mix of cultivars would spread risk.

- There is a special case for high micronaire situations. In recent years in Australia for example, a series of warm dry seasons coupled with intensive management for high yield of high retention crops such as Bollgard II® has led to many circumstances of high micronaire. The four harvests up to 2007 average 41% of the crop above micronaire of 4.6 and another 6% above micronaire 5.0 (ACSA 2007). Analysis has indicated that management, cultivar and high temperature have been significant components of that result (Kelly *et al*. 2006). The balance between boll load and crop canopy size can be significant, with high boll loads having lower micronaire (more desirable in this case), presumably from competition (Brook *et al.* 1992; Kelly *et al*. 2006). Micronaire is definitely a complex trait, but management can address the problem at least partly. A cultivar with inherently lower micronaire (preferably fine and mature) is required under these circumstances and breeders need to pay more attention to this target. Crop management to optimize agronomic inputs such as water, fertilizer and growth regulators should manage vegetative growth in balance with boll setting pattern, by using a cultivar with appropriate plant type for the region and climate; and sow on the appropriate date for the cultivar and climate to avoid boll filling of early crops in hotter periods.

In reality it is always a balancing act between what is desirable and what is achievable given the need to finish and harvest a crop. There would appear to be no evidence suggesting that high yielding crops, if managed correctly, cannot have excellent fibre quality. Many factors interact in a cropping system. Adoption of appropriate and efficient integrated pest management (IPM), irrigation, crop nutrition, disease, and weed management practices in the same way they contribute to improving yield will also contribute to improved fibre quality.

Harvest and ginning

Cutout of a cotton crop is not the end of management for fiber quality. Inappropriate harvest preparation, harvest and ginning operations can undo excellent quality inherent to cultivars nurtured with good crop management. As much effort placed in managing a crop to preserve quality should also be exercised in operations leading to cotton being baled and delivered to the spinners. However the quality of ginned cotton is most often directly related the quality of cotton delivered to the gin.

Ceasing crop growth for a timely harvest involves a number of important decisions. Late flowering and especially regrowth will cause fiber quality problems directly in fiber micronaire, often by increasing the amount of immature fibers and indirectly with grade. Practices that promote regrowth such as excess nitrogen rates or excess soil moisture at harvest should be avoided. Delayed harvests also expose clean lint to increased chances of weathering through humid conditions or rainfall increasing microbial damage reducing color grade, length and strength (Bednarz *et al*. 2004).

Mechanical harvesting of cotton generally requires leaves to be removed. Poor and untimely defoliation can have significant impact on fiber maturity as well as the amount of leaf trash. The type of defoliation product is unlikely to impact on fiber quality if timing is correct. However, early defoliation can cause a significant reduction in micronaire (Kerby *et al*. 1992; Bednarz *et al*. 2004). While growers can often seek to open late maturing bolls to improve yield or sometimes to reduce micronaire if they suspect a high micronaire problem, this practice should be generally avoided as it increases the chance of immature fibers that can lead to neps. Appropriate defoliation management that preserves quality should consider carefully timing, chemical product and rate. Research on decisions for timing defoliation has received considerable attention (eg recently by Gwatmey *et al*. 2004; Faircloth *et al*. 2004a; 2004b; Larson *et al*. 2005; Siebert *et al*. 2006; Siebert and Stewart 2006).

Poor harvesting practices will result in lower yield as well as reducing fiber quality by increasing trash levels, bark and green leaf stain. Harvesting wet cotton also increases the chance of spindle twist leading to increased neps as well as reducing grade by yellowing the cotton when it is stored in the module. For preserving quality, spindles and doffers of pickers should be maintained and checked daily, and wet crops should be allowed to dry. To avoid further weather damage and contamination, and where appropriate, growers should also follow guidelines for module placement, construction, tarping and transport.

The ginning process transforms the cotton into a marketable commodity by removing the lint from the seed and removing foreign material. Ginners are faced with often conflicting objectives: the need to maximize gin outturn to increase lint yield for growers; to minimize impact on fiber quality to meet the needs of the spinners; and optimizing gin throughput and operating efficiencies. Impacts of the ginning process on preserving fiber quality have been well researched and summarized (Anthony 1999; Mayfield *et al*. 1999). The quality of ginned cotton is most often directly related to the quality of cotton delivered to the gin. High grades will come from well defoliated and weed-free fields, harvested by properly adjusted harvesting machines.

The modern ginning process involves a number of operations in order of processing: drier, cylinder cleaner, stick machine, drier, cylinder cleaner, extractor feeder, saw-type gin stand, followed by one or two lint cleaners. As the ginning process will impact on fiber quality (Anthony 1999), any operation in the gin should be bypassed in an attempt to preserve quality if the cotton does not need specific treatment. Systems that monitor fiber quality through the ginning process would assist in ensuring only necessary handling. Fiber length can be preserved and short fiber contents decreased, by reducing the number of lint cleaner passages (Mangialardi 1991) and ensuring fiber moisture is between 5 and 7 per cent over the gin and between 5 and 6 per cent through the lint cleaners. Lower combing ratios (ratios between 19 and 23) between feed rollers and the saw of lint cleaners also reduces the amount of fiber breakage.

Ultimately, good communication between growers and ginners is a key factor in resolving contradictions of gin out turn, grade and other fiber quality parameters at the gin.

General discussion and conclusions

We have demonstrated the contributions that breeding-cultivar choice, crop management and processing can make to realizing fiber quality from the seed to the bale. Clearly all facets are important and the breeder, grower and ginner need to work together to solve challenges. Cultivar affects most fiber properties; management-stress will have influence on fiber length and micronaire in particular. Harvesting and ginning will have impacts on fiber length and grade.

This paper concentrated on fiber length, strength and micronaire, but other fiber properties are important. Two issues worthy of mention are the components of micronaire (fineness and maturity) and neps. Although it is generally conceded that micronaire is not necessarily the correct instrument to measure fiber fineness (linear density) or fiber maturity, its use continues even with considerable impact on price discounts. Despite instruments being available for measuring fineness and maturity (Fineness Maturity Tester, Advanced Fiber Instrument System, Cottonscan (Gordon and Naylor 2006)) there has been slow adoption of these more appropriate measures. May (1999) suggested breeders could use such instruments, as the need for combining fineness and maturity existed in spinning and there was genetic diversity and sufficient inheritance of those traits to utilize in breeding. Our experience is that the negative association between fineness (linear density) and yield (Price 1990) is relatively strong and limits progress in developing cultivars with fine mature fibers and high yield. Perhaps we have lost genes for fineness in traditional breeding and selection with micronaire values in the past 50 years. We believe there are gaps in knowledge of fineness and maturity that need more research, such as genetic, management and climate effects on linear density, fiber diameter and fiber maturity.

Neps are small bundles of immature fibers which decrease spinning mill processing efficiency (Hebert *et al*. 1988; Verschraege 1989). Anthony *et al*. (1988) concluded ginning (lint cleaning), was the most important phase determining neps, followed by harvesting, climate-management and cultivar. Neps are greater in fiber from cultivars which is fine, immature, weak and has high short fiber content. They have become an issue of complaint by spinners and this is an example where breeders, other scientists, growers and ginners should work together to develop packages that reduce neps and improve cotton's reputation.

Fiber has many end uses in terms of how it is spun (ring, rotor, etc), whether blending is used in spinning, intended dyeing and what type of yarn is to be produced. The suitability of each fiber lot for end use will dictate price-value. The more important fiber attributes for rotor spinning are strength, fineness and length in that order; and for ring spinning are length, strength and fineness (Deussen 1992). Thus production systems that produce particular combinations of fiber length, strength and micronaire will be marketed into a spinning method that most suits that fiber.

Crop management begins in a strategic sense with pre planting decisions on cultivar choice, fertilizer program, irrigation strategy, etc. Most production systems have a choice of cultivar to cover many possible priorities and options for yield potential, fiber quality, disease resistance, crop maturity and transgenic traits. Growers should access comparative data from sources such as Government testing and from seed companies / distributors, especially where data is available for local conditions. Likewise growers should participate / supervise / insist on resolving contradictions of gin out turn, grade and other fiber quality parameters at the gin.

There has been excellent research and extension on some aspects of fiber quality management, such as decisions on timing defoliation. There is a gap in knowledge of crop management to manage high micronaire, especially until breeders can achieve high performance cultivars with fine, mature combinations of intermediate micronaire. Extension and decision tools to assist growers in some of these complex fiber traits would be useful.

Some opportunities to preserve fiber quality at the processing level include precision agriculture monitors for yield and fiber quality (Sui *et al*. 2007) and monitoring fiber quality during ginning (Anthony 1998).

We believe the future is bright for cotton, especially if all sections of the industry work together in addressing the challenges and opportunities the industry faces in the short to medium term. Such a concerted effort could be termed Integrated Fiber Management, to be analagous with Integrated Pest Management and other subjects where a combination of approaches is required.

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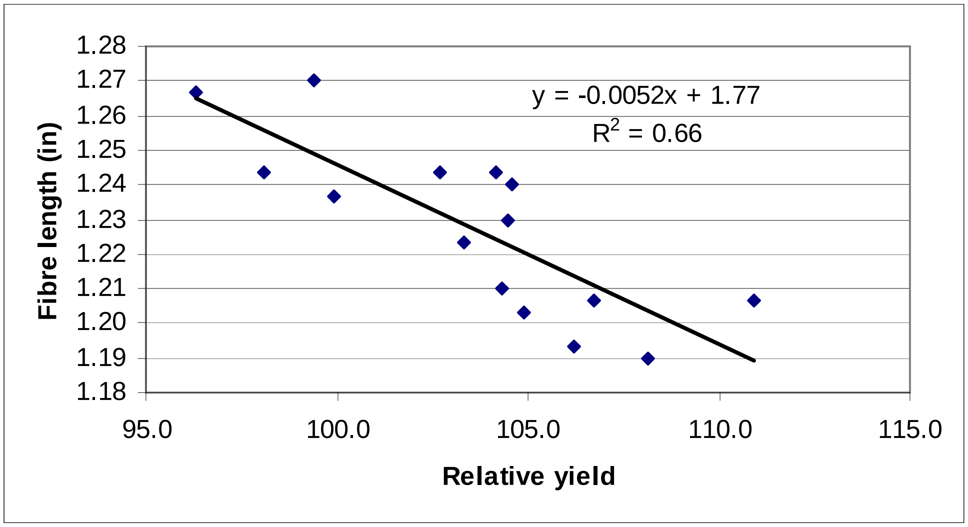
Table 1. Association between relative yield (percent of experiment mean) and fiber properties of 14 F_4 breeding populations. Fiber properties measured with HVI; FQI (Fiber Quality Index) is length x strength / micronaire. Each data set is the average from two field sites with four replications in each site. The average population size was 19.

Season	Population	Pedigree	Length	FQI
2006/7	63214	99216-467 x 97025-297	-0.49*	-0.19ns
	63225	94215-442-686 x Sicot 71	+0.13ns	-0.11ns
	62220	97219-316 x 99229-259	-0.25ns	-0.04ns
	63222	Sicala 45 x 98203-51	+0.08ns	+0.22ns
2005/6	62213	97202-284 x 99209-922	+0.05ns	+0.04ns
	62219	97219-316 x 99216-415	-0.09ns	-0.36ns
	62222	61035 x 98203-51	-0.14ns	-0.13ns
	61210	97208-576 x 94214-603	-0.30ns	-0.54*
	61214	97208-576 x 97221-303	-0.26ns	-0.45ns
	61232	99212 x Sicala 43	+0.37ns	-0.63**
	61234	Sicot 80 x 98034-180	+0.39ns	+0.19ns
2004/5	61214	97208-576 x 97221-303	-0.24ns	-0.49*
	61220	92230-348 x 97221-303	-0.44*	-0.45*
	61233	97217-210 x 97208-576	-0.46ns	-0.11ns

Figure caption

Figure 1. Association between relative yield (percent of experiment mean) and HVI fiber length of one population (94215) in 1997/98. Mean of three sites with four replications.


1.28
1.27
1.26
1.25
1.24
1.23
1.22
1.21
1.20
1.19
1.18
Fibre length (in)
95.0
100.0
105.0
110.0
115.0
Relative yield
y = -0.0052x + 1.77
R^2 = 0.66