FIBREpak

from seeds to good shirts

2nd Edition

A Guide to Improving Australian Cotton Fibre Quality

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Australian Government
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1. Introduction

The cotton fibre is unique in generating a host of products that sustain and make life for humans more comfortable and atheistically appealing. Australian cotton is viewed worldwide as an excellent fibre. It is usually purchased with the intention of producing high quality combed, ring-spun yarns for use in the woven and knitted apparel sector primarily in the Asia-Pacific region. China is a significant market. Australian cotton is purchased for a premium as it meets many of the spinner's requirements on the basis of quality and consistency.

Fibre quality is affected by a large number of interacting factors; variety, seasonal conditions, crop and harvest management, and ginning. These can all determine whether or not the spinner's requirements are met. While some of these factors cannot be controlled, there are many that can. Through better understanding of the nature of fibre and the factors that affect its quality, improved varieties, management for each region's climate, and processing to minimise damage to fibre are all opportunities to improve the quality of fibre delivered to mills.

The task for industry is to optimise fibre quality in all steps from strategic farm plans, variety choice, crop management, harvesting, and ginning. We have termed this 'Integrated Fibre Management' (IFM) to emphasize the importance of a balanced and complimentary approach to managing fibre quality across the whole production chain (see Figure 1.1). The industry's *myBMP* program seeks to improve quality by providing guidance and assurances in production, classing and ginning. Along with *myBMP*, new technologies, instruments, research and extension programs and communication will all help together to facilitate IFM.

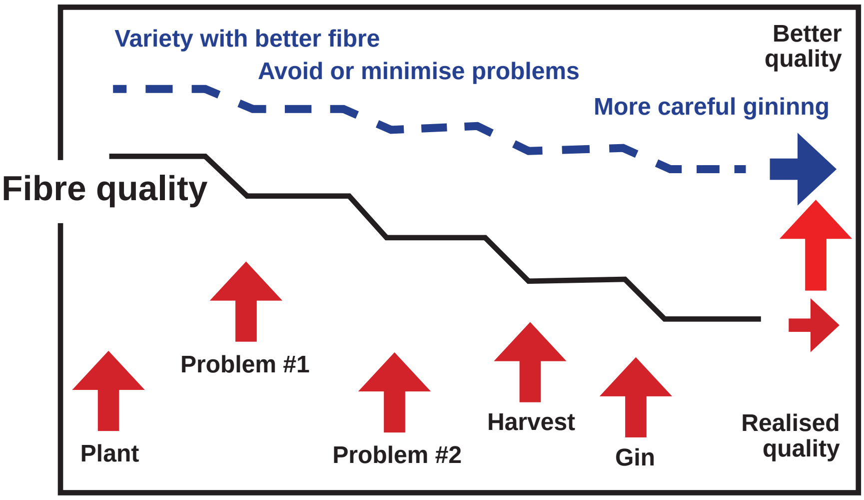

Figure 1.1: Concept of 'Integrated Fibre Management' (IFM) to improve industry fibre quality. The aim is to raise quality by minimising the damage to fibre quality along the whole production chain. Note in comparing the dotted line with the solid line how starting with better fibre properties and avoiding or minimising problems through the production and processing chain can substantially improve fibre quality outcomes.

FIBREpak contains information for managing fibre quality at every step, from pre-planting to processing. The aim is to provide all those involved in producing and delivering fibre — the grower, manager, agronomist, consultant, harvester, ginner, classer, merchant, shipper and retailer — with:

- Knowledge of what aspects of fibre quality they can influence;
- Options for managing those aspects;
- An understanding of the needs and constraints of the other participants in the fibre supply chain.

Coarse (high Micronaire) fibre, high nep counts, excessive short fibre content, and increasing contamination are aspects of Australian cotton that spinners would like to see improved. Some key fibre quality challenges addressed by FIBREpak include:

- Maintaining and improving fibre length through better variety choice; management during hot, dry seasons; and preservation through harvest and ginning.
- Producing fibre within the optimum Micronaire range through hot sunny seasons; high yield management strategies; and appropriate defoliation and harvest preparation.
- Reducing nep content through effective defoliation and harvest preparation; better management of fibre moisture in the field at harvest and through the gin; and reduced requirement for cleaning in the gin.
- Minimising contamination found in bales (Figure 1.2).
- Ensuring fibre quality uniformity and consistency within and between years.

Figure 1.2: Some spinning mills invest significantly to remove contamination. This shows manual decontaminating cotton before processing at an Indian Spinning Mill. (Photo: Rene van der Sluijs, CSIRO).

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2. History of Cotton Fibre Use

There are four distinct species of cotton. Two of these, *Gossypium arboreum* and *Gossypium herbaceum* are called Old World cottons as they originated in Africa and the Sub continent. They have been used by man for thousands of years for clothing but are now only grown in very limited areas of India, Pakistan and China – they have good drought tolerance but low yield and fibre quality. The other two species, *Gossypium barbadense* and *Gossypium hirsutum* are called New World cottons and originated in Central America. *G. hirsutum* (called Upland) represents more than 90% of world's cotton production as it is most productive and has suitable fibre properties for modern textile production. *G. barbadense* (ELS - Extra Long Staple) cottons have a number of names – Pima, Egyptian, Peruvian, Sea Island. These cottons have very good fibre properties demanding a significant price premium from spinners for manufacture of fine garments. They have lower yield and narrower climatic requirements – requiring specific management. In Australia, Pima production has been limited to western NSW locations such as Bourke, Hillston and Tandou.

The industrial revolution in England during the 18th and 19th centuries encouraged cropping and export of cotton from the US and other colonies. Cotton, at the beginning of this period, was relatively expensive (about US$100/lb) compared to today (less than US$1/lb). The reductions in the cost of fibre reflect the improvements made in agricultural production, mechanisation of harvesting and ginning, particularly after the Second World War, and the rise of man-made fibres (MMF). Running parallel with the developments in agricultural production were comparable improvements in textile machinery production, which have improved by a factor of 100 from since the start of the 20th century.

Queensland had been identified as a possible production area of cotton for English cotton spinning mills from the time of Cook's mapping of eastern Australian in 1770. Cotton was bought to Australia with the First Fleet in 1788 with seed sourced by Governor Phillip from Rio de Janiero. These plants were most likely *Gossypium barbadense* tree cottons and were better suited to Queensland than to NSW coastal regions. The US Civil War provided an opportunity to provide cotton into England and there was a small cotton industry in Queensland from 1862 to 1871, with a peak of 5,200 (227 kg) bales produced in 1871 from about 10,000 ha.

In 1884, a Dr David Thomatis moved to Cairns and established a tree cotton plantation. Thomatis Creek to the north of Cairns is named after him. The cotton cultivar he developed is now also a Cairns suburb name, *Caravonica*, was named after his wife and/or home town in Italy. There are still volunteers of that cotton growing in the district.

A small cotton industry existed in Queensland through the 1920s and 1930s but it was not until better crop mechanisation and new irrigation dams were developed that the modern cotton industry

Gossypium hirsutum

Gossypium barbadence

Gossypium arboreum

Photos: Warwick Stiller (CSIRO)

was established in the early 1960s, firstly in the Namoi Valley and then followed by a number of other regions. It is interesting that the start of the modern cotton industry was encouraged by a Federal Government subsidy to reduce costs of imports for local spinning mills. Now Australia has virtually no cotton spinning and so nearly 100% of today's production is exported to markets largely in South East Asia. In this market, the need for continually improved fibre properties are key. In recent years China has become the biggest customer of Australian cotton.

Upland cotton varieties (*G. hirsutum*) have staple lengths typically ranging from 1.00 to 1.125 inches (see Table 2.1 for length conversion). Fibre lengths of Upland cotton have increased over the last 20 to 30 years with new Upland varieties extending this range currently to 1.250 inches. Pima (*G. barbadense*) long staple (LS) and extra-long staple (ELS) type cotton are longer and finer than Upland cotton. The staple length of *G. barbadense* cottons typically range from 1.25 to nearly 2.00 inches. Fibre from *G. arboreum* and *G. herbaceum* typically have very short, coarse fibre with staple lengths ranging only to 1.00 inch.

Today cotton is grown in more than 60 countries on about 2.5% of the world's arable land, making it one of the most significant crops in terms of land use after food grains and soybeans.

Table 2.1: Conversion of fibre length measurements.

Imperial		Metric
Decimal inches	**32nds inch**	**(mm)**
1.000	32	25.40
1.031	33	26.19
1.063	34	26.99
1.094	35	27.78
1.125	36	28.58
1.156	37	29.37
1.188	38	30.16
1.219	39	30.96
1.250	40	31.75
1.406	45	35.72

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3. Fibre Biology (How Fibre Properties are Determined)

This chapter outlines the properties of cotton fibre, its development, and key factors that influence the development of the fibre.

The Cotton Fibre

Cotton fibres form from single cells that begin their development on the seed coat of unfertilised seeds (ovules) just prior to flowering. A mature or fully ripened cotton fibre consists of about 96% pure cellulose (a naturally occurring crystalline carbohydrate polymer). In nature, the function of cotton fibres on the seed in wild species may be related to seed dispersal to new locations by floating on water, and protection against herbivores and extreme climate conditions. The fibre itself consists of a primary and secondary cell wall. The primary wall is covered with a cuticle consisting of mainly wax and consists of fibrils (very small fibres) placed on a wide angle to the axis (approximately horizontal) which adds little to fibre strength. The secondary wall which makes up 90% of fibre weight consists of cellulose fibrils arranged in a layered helical structure. This layer contributes greatly to the tensile (e.g. strength and elongation) properties of the cotton fibre.

Cotton Fibre Development

Cotton fibre development can be divided into four phases: initiation, elongation, secondary wall thickening, and maturation. These phases will be discussed in more detail below.

Fibre Initiation

Fibre initiation on an ovule starts one to two days before flowering, beginning at the chalazal (round) end of the seed and moving towards the micropylar (pointy) end of the seed (see Figure 3.1). The time for initiation sometimes takes up to three days from one end to of the seed to the other. On the day of flowering most of the fibre cells on the seed coat have swelled into small balloons (Figure 3.1), although some fibres can still be initiated four to five days later. This ballooning stage is considered critical to determining fibre perimeter. Following this initial burst of fibre initiation a second set of fibres are initiated on the seed. These develop into the fuzz left on cotton seed following ginning. The majority of fibres that initiate remain as fuzz (up to 80%).

The number of fibres initiated can vary between 12,000 and 20,000 per seed and is also variety dependant. There is little understanding of the effects of plant stress on fibre initiation although stress is known to reduce the number of fruit, ovules per fruit and seeds per ovule.

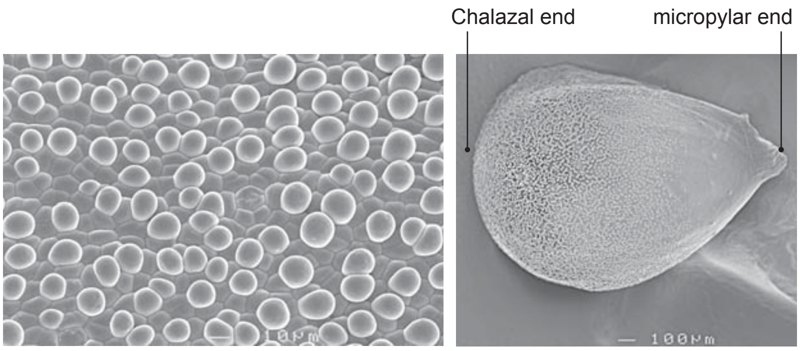

Figure 3.1: Fibres initiating on a seed. Note that fibres at the chalazal (round) end of the seed are initiated first. (Photos: Rosemary White, CSIRO). Units are micrometres.

Fibre Elongation

Fibre elongation (Figure 3.2) does not start until flowering despite some fibres having been initiated a few days before this. From flowering fibres elongate for up to 25 days, reaching variable lengths. The elongation period and the rate of fibre elongation in this period determine the final length of fibres (the reason for differences between varieties). This is well illustrated by Pima which has a longer fibre elongation period and long fibre length. Across the seed, average fibre length decreases from the chazal (round) end of the seed to the micropyle (pointy) end.

Elongation is the onset of a process in which fibre length increases 1000 to 3000 times the diameter of the cell. The tubular hair cells that form consist of a very thin cuticle, a thin primary wall (only about 30% cellulose), a cytoplasmic layer and a large vacuole (lumen) (Figure 3.3). The rapid expansion of the fibre cell is controlled by internal water pressure (turgor), which stretches the primary wall like an inflating balloon. To enable this massive extension, the cell must be able to incorporate both expansion and new growth of cell wall material. New growth occurs especially at the fibre tip but diffuse growth occurs over its entire surface. This prodigious growth of the fibre cell can only result from: considerable metabolic activity; a fast and consistent uptake of large amount of substrate into the cell; and formation of a strong primary wall.

The large and vigorous demand on the plant during fibre lengthening makes this process very sensitive to stress. The environment therefore plays an important role in whether fibre length reaches the genetic potential (determined by variety). Firstly, to maintain turgor, the cell must have ready access to potassium, solutes and water to regulate osmosis into the vacuole, and produce the turgor pressure essential for fibre elongation. Severe water stress or potassium deficiency will reduce turgor pressure and result in shorter fibres. Temperature also plays an important role in regulating the rate of fibre elongation and influencing the duration of fibre elongation. Cool temperatures may reduce the rate of elongation but this effect will often be compensated by having a longer fibre elongation period.

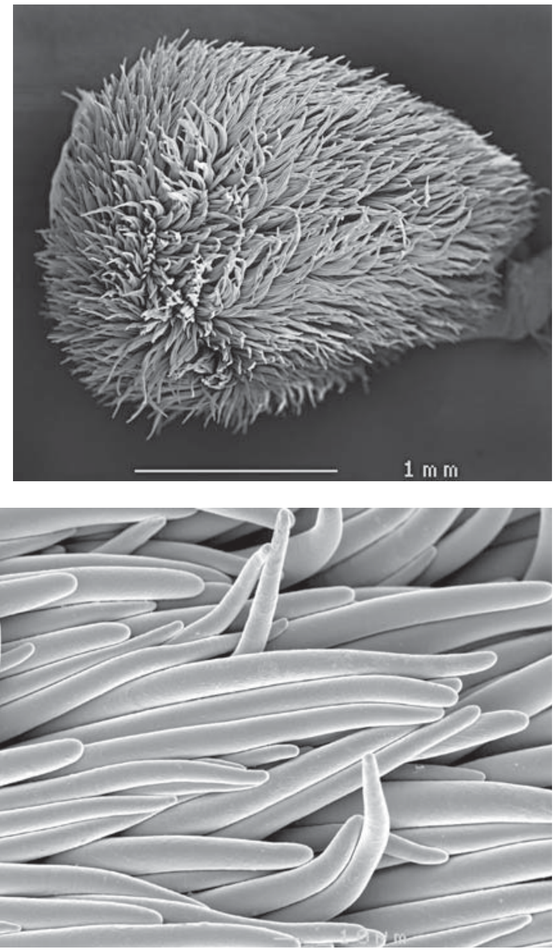

Figure 3.2: Fibres beginning their elongation. (Photos: Rosemary White, CSIRO). Units are millimetres (mm) and micrometres.

High temperatures and stress however, may reduce fibre length as the elongation period is shortened and access to substrates can be limited.

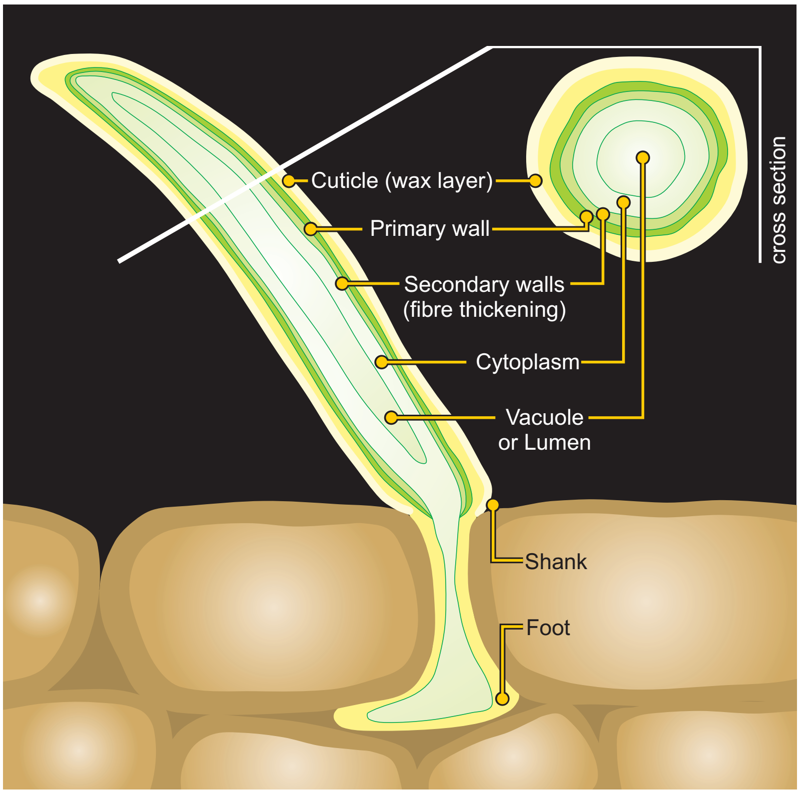

Figure 3.3: A diagrammatic representation of the internal structure of an individual fibre attached to the wall of a seed.

Fibre Thickening

Fibre thickening is sometimes referred to as the secondary wall formation phase. It is the phase where cellulose is laid down in winding sheets on the inner surface of the primary wall of the fibre cell. As a result the cytoplasm is pushed towards the interior of the cell and the vacuole (lumen) is reduced in size. More than 90% of the fibre weight is made up of the secondary wall. Fibre thickening occurs over a period of approximately 40 days but this can vary depending on cotton species, variety and environment. Some overlap of up to 5 to 10 days occurs between the end of the fibre elongation and the start of the fibre thickening phases.

Photosynthesis is the process by which plants convert carbon dioxide and water using light of the day and chlorophyll present in the leaves to produce carbohydrates for energy needed by the plant (e.g. glucose), and cellulose used for the formation of structural components contained within the plant. A further by-product is oxygen. Hence the degree of deposition of cellulose in the fibre cell is significantly affected by factors that affect photosynthesis. As cotton plants are subjected to fluctuations in the levels of photosynthesis and growth on a daily basis, the production of secondary wall in the fibre forms growth rings like a tree (Figure 3.4). However, unlike a tree where growth rings are deposited on outside of last year's growth, a cotton fibre's growth rings are deposited on the inside of the previous day's growth. A fibre growth ring is made up of two layers: the compact layer that is laid down during the day; a porous layer that is laid down at night. Improved photosynthesis during the day will mean that there is a greater chance that the fibre growth ring for that day will be also thicker.

Cotton growth rings

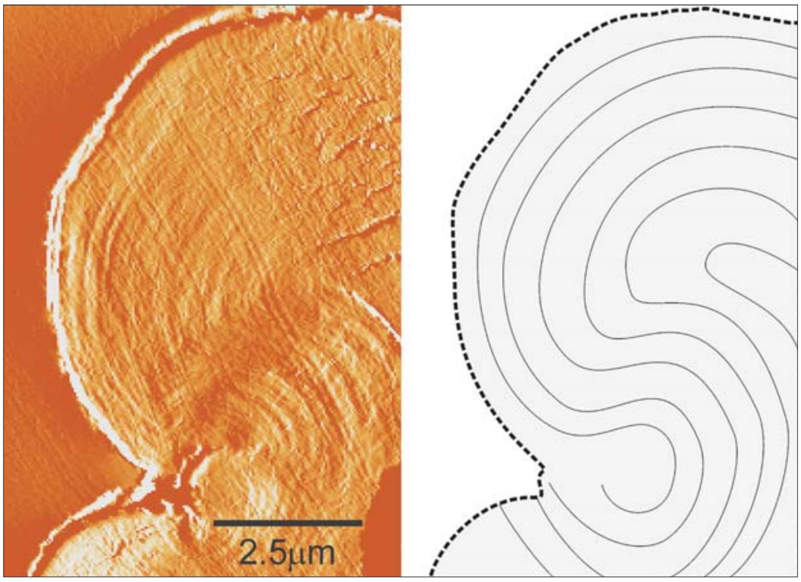

Figure 3.4: A cross section of a fibre showing concentric rings (reproduced with permission from Maxwell et al. (2003). Units are micrometres.

Fibre maturity is a term that is used to refer to the degree of development or thickening of a fibre (which contributes to the Micronaire measurement incorporated in HVI (High Volume Instrument) testing. The thicker the layers of cellulose during fibre thickening the more mature the fibre. Insufficient supplies of carbohydrate for cellulose production will cause fibres to be more immature. Fibre maturity is an important property for both the physical and chemical processing properties of cotton fibres. Immature fibres are more prone to nep formation and do not take up as much dye as mature fibres. A nep is an entanglement of fibres resulting from mechanical processing (see chapter on importance of quality).

HVI (High Volume Instrument)

HVI™ (High Volume Instrument) lines are assembled and automatically linked fibre testing instruments that enable quick, objective measurement of fibre quality characteristics of cotton. HVI lines currently measure reflectance and yellowness, length, Micronaire, strength, length uniformity index, short fibre index (SFI) and elongation. Manual classers still largely determine the colour, leaf, extraneous matter and preparation grades of cotton.

Immature fibre results from effects on photosynthesis during secondary wall thickening. Some reasons for this include:

- Early termination of leaf function (e.g. early defoliation or frost).
- Excessive internal competition within the plant for carbohydrates from photosynthesis needed for boll growth. This is often associated with high boll loads.
- Late season cloudy and/or cool temperatures reducing photosynthesis.
- Water stress causing reductions in leaf area or direct reductions as a result of leaf stomates closing reducing transpiration and then photosynthesis.
- Premature senescence caused by nutrient deficiency (such as potassium, phosphorus, nitrogen, etc.) as a result of high boll load. This loss of leaf area can reduce photosynthesis.

The strength of cotton fibres is related to the degree of wall thickening. Importantly however, substantial differences in strength of fibres will depend on the chemical structure or the cellulose being laid down in the secondary wall. The longer the cellulose molecule chains that are laid down the stronger the fibre. It is analogous to the length of fibres needed for yarn strength (longer fibres mean stronger yarn (see yarn production chapter). The different fibre strength in varieties is related to composition of the cellulose.

Micronaire, Fineness, Fibre Maturity, Linear Density and Fibre Perimeter?

When these terms are used in FIBREpak they will use these following definitions (also see Figure 3.5).

Fibre Linear Density or Fibre Fineness – Cotton fineness is described in terms of linear density or weight per unit length of fibre, the unit for which is usually milligrams per kilometre (mtex) or µg/m (micrograms/metre). FIBREpak will use the term linear density.

Fibre Maturity – The degree of wall thickening increases as the fibre matures. Historically maturity ratio was assessed under the light microscope by counting the proportions of mature and 'immature' fibres in a sample swollen in concentrated caustic soda. The scale for this ratio has a theoretical range between 0.2 and 1.2, where cotton samples with a value greater than 0.85 are regarded as mature, and samples with a value less than 0.85 are immature. More recently with the advent of fibre cross-section and image analysis techniques the degree of wall thickening (denoted θ - theta) has been used as reference measure of fibre maturity. The degree of thickening is defined as the ratio of the cell wall area to the area of a circle with the same perimeter as the fibre cross-section (Figure 3.5). The value has a theoretical range of between 0.0 and 1.0. An empirical scaling factor is used to convert theta values to maturity ratio values.

Fibre Perimeter – Refers to the perimeter of the cross-section of a fibre. The perimeter is often considered to be genetically determined. It is an important property that contributes to differences in fibre linear density and the number of fibres that exist in the yarn cross section.

Micronaire – Airflow measurement based on the pressure difference obtained when air is passed through an accurately weighed plug of cotton fibres. The method measures specific surface area (surface area per unit mass) and reflects a combination of the sample's linear density and fibre maturity. Reducing fibre linear density or fibre maturity (e.g. by reducing cell wall thickness) results in more fibres in the plug increasing airflow resistance lowering Micronaire. FIBREpak will not use the term Micronaire when fibre linear density or fibre maturity are discussed specifically.

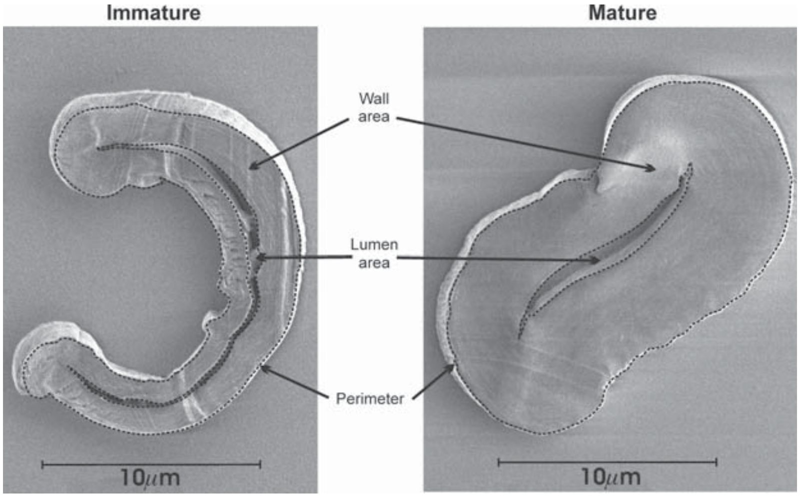

Figure 3.5: Fibre cross sections showing fibre perimeter and differences in wall area that lead to differences in fibre maturity. Units are micrometres. (Photos: CSIRO).

Fibre Maturation

As a boll matures the seed coat oxidises (turns black) and the lint cells (fibres) lose water causing the vacuole (lumen) to collapse and the fibre to die. The fibres are no longer cylindrical or tubular in structure, rather they become twisted ribbon-like (crimped) structures (Figure 3.6) with a kidney (bean) shaped cross section (Figure 3.5).

Fibres can have few to many twists that can change direction at frequent intervals along their length. Twist in a fibre is influenced by fibre maturity (secondary wall thickness), the size of vacuole (lumen) remaining, as well as the perimeter of the fibre. The direction of the twist in the fibre reflects the orientation of the microfibrils laid down during secondary wall thickening.

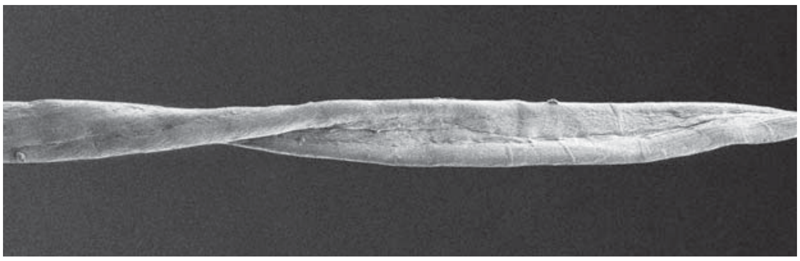

Figure 3.6: A mature cotton fibre showing fibre twists (convolutions). (Photo: Margaret Pate, CSIRO).

Mature fibres are easily detached from the seed and only fuzz remains. The presence of fuzz is genetically controlled, and in some instances no fuzz is present and the seed is naked (e.g. Pima). During fibre development the fibre base spreads out broadly into a flattened foot into the surrounding cells on the surface of the seed to anchor the fibre to the seed (Figure 3.3). However, the diameter of the fibre at the base near the seed is less. This allows the fibres to break close to the seed coat and be easily removed during ginning. This point, where the secondary wall is thinnest is sometimes referred to as the shank and is where most fibres break during ginning. Varieties can differ in the force required to separate the fibre from the seed at this point of attachment and this can be a significant factor in determining the quality of fibre resulting from the ginning process.

Figure 3.7 shows the timing of fibre elongation and fibre thickening. Fibre length is determined and finalised in the first one-third of boll development time (250 day degrees or about 20 days at normal temperature). Fibre thickening which effects Micronaire is then determined in the last two-thirds of boll development (from 250 to 750 day degrees, or about days 20 to 60 from flowering). Fibre maturing and drying occurs between about 650 and 750 day degrees from flowering.

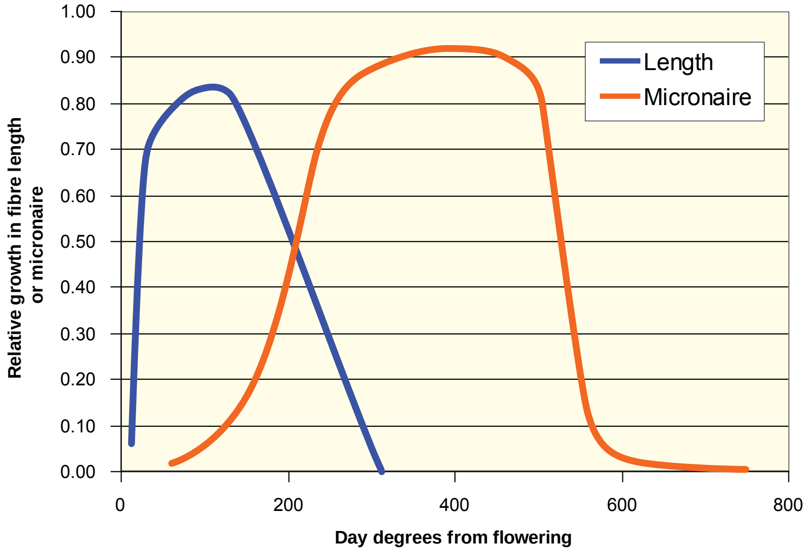

Figure 3.7: Stages and duration of fibre development within a single boll.

Cotton Fibre Quality and its Relationship to Yield

Fibre properties can be strong yield components. It stands to reason that if a plant has more, longer or heavier fibres then it should have a higher yield. We see in the example given in Table 3.1 that longer and more mature or coarse fibres (those with greater linear density) contribute to higher yields even when boll number and seeds/boll remain equal. So it may appear that achieving high yields and quality together seems straightforward. However, the problems breeders face is that improved fibre quality attributes are often genetically associated with lower yield. This is especially the case when breeders select for long, strong and fine fibres. The cause of this negative association is not well understood. It could be genetic, or simply related to how the fibre develops and grows relative to the rest of the plant.

Table 3.1: Fibre quality attributes are strong yield components. Note that changes in fibre length (A to B), fibre linear density (often referred to as fineness) (B to C) and fibres/seed (C to D) can lead to changes in yield even when boll size and number remain similar.

Component	A	B	C	D
bolls/m (no)	100	100	100	100
seeds/boll	30	30	30	30
fibres/seed (no)	15,000	15,000	15,000	**18,000**
length (inch)	1.15	**1.20**	1.20	1.25
uniformity (%)	82	82	82	82
linear density (ug/m)	170	170	**190**	**160**
yield (kg lint/ha)	1645	1716	1918	2019

Breeders continue to scan large populations of cotton in order to identify instances where the negative relationship between quality and yield is less evident. This provides opportunities for progress on improving combinations of high yield and improved fibre quality. Understanding the linkages between yield and fibre quality is a subject of current intensive research. With these efforts breeders will continue to progress improved yield and fibre quality combining traditional breeding with biotechnology traits and tools.

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4. Textile Production

The reason for attributing value to cotton through quality assessments is to gain premiums (or discounts) from the market on the basis of that cotton's suitability for particular end-uses. In the production of traditional textiles, conversion of fibre to textiles starts with the spinner, for whom price and quality are key attributes of the product they purchase. Price and quality are highly related; higher quality means higher price. Higher quality fibre means higher quality yarns and fabrics (finer, lighter, stronger, more even, cleaner) and generally better productivity in the mill (better machine efficiency, less waste, fewer quality rejections). Here, we use the spun yarn attributes that generate differences between the fabric that is made into a pair of jeans and the fabric that is made into a light summer shirt to illustrate.

Fabric Quality

Leaving aside the important issues of price, colour and fashion, what are key characteristics we expect from these two different garments? For jeans it is durability, strength and abrasion resistance. As a result denim fabric for jeans is relatively thick and heavy. By comparison, for summer shirts, comfort and 'breathability' are paramount and so the fabric is much lighter. These examples illustrate the general point that within the textile industry fabric mass is an important technical specification. Garment manufacturers will specify to the fabric manufacturer what a fabric must weigh in terms of mass per unit area. A typical value for a denim-weight fabric is 400 grams per square metre (gsm), with a light to heavy range from 340 to 500 gsm, whereas light summer shirting fabric has a range between 70 to 140 gsm. In this example, the denim fabric is woven using a thick, coarse yarn and the summer shirting fabric is woven (or knitted) from a finer yarn.

Yarn Count

Actual yarn thickness is difficult to measure accurately and so the textile industry refers to yarn in terms of its mass per unit length, which is called the yarn linear density or more commonly yarn count. Yarn count is typically measured as the mass in grams of one kilometre of yarn. The unit, grams per kilometre, is called tex. An older system of measurement called English cotton count (notated Ne) is used within the cotton spinning industry. This system measures the number of yarn hanks, each of which is 840 yards long, per pound of yarn. In this system a big number implies a fine yarn and a small number implies a coarse yarn. This is the inverse of the tex system. The systems can be inter-converted by dividing 590.5 by the other number. Both systems are used in trade and commonly appear side-by-side in yarn descriptions.

Table 4.1 lists typical yarn counts used in a range of garments and fabrics. In our example above, denim yarns range in count between 60 to 100 tex (grams per kilometre) or Ne 10 to 6 (10 to 6 x 840 yard hanks per pound of yarn), whereas the shirting yarn will range in count between 30 and 15 tex or Ne 20 to 40.

Table 4.1: Typical fabric mass and yarn requirements to manufacture specific garments (gsm is grams per square metre).

Garment	Fabric Mass (gsm)	Yarn Linear Density or Count Tex	Ne
Jeans (woven)	200 - 400	60 - 100	10 - 6
Business shirt (woven)	< 100	5 - 15	120 - 40
T-shirts and hosiery (knit)	120 - 180	15 - 30	40 - 20
Bed sheets (woven)	150 - 250	20 - 35	30 - 17
Towels (woven)	> 500	40 - 80	15 - 7

The most common yarns produced from Australian Upland type cottons are 20 tex (Ne 30) to 10 tex (Ne 60) count yarns, produced on the ringspun system of which at least 80% are combed (see the next chapter on yarn production). These yarns are used to construct a wide range of reasonably high-end woven and knitted fabrics. For comparison, the most common yarns produced from extra long staple (ELS – see definition in previous chapter on cotton history) cottons are in the range of 12 tex (Ne 50) to 7.5 tex (Ne 80) or even finer, which are used for fine knit, and woven fabrics. These yarns can be spun using 100 % ELS cotton or in blends with standard Upland cotton. In recent years there has been a move to coarser Pima yarns, up to 20 tex (Ne 30) and coarser yarns for fabrics such as denim.

Niche Textile Markets

Within traditional textile markets there are niches for organic and environmentally sustainable cotton, coloured cotton, high quality (long and fine) cotton and high-end cotton blends (with other natural staple and man-made fibres). Organic cotton, however, should not be confused with naturally coloured cotton, although coloured cotton can be grown organically. Natural coloured cotton occurs in wild cotton plants and breeders have been able to select through cross breeding to improve these cottons. Currently coloured cotton is available in various shades of brown and green (Figure 4.1).

White

Green

Shade of brown

Figure 4.1: There are many natural colours in cotton lint. This photo shows the various shades of green and red-brown compared with white (called ecru). (Photo: CSIRO).

Whilst the volume of fibre in these niches is relatively small, it is notable that strong growth is predicted in nearly all of them and particularly for organic and high quality cotton. For coloured cotton, prices obtained for the lint, coupled with low yields, inferior fibre quality, danger of contamination with conventional cotton, and the stability of fabric colour has resulted in low production.

Recent market pushes by the Australian cotton industry into the ELS premium cotton market follows these trends although work remains to properly define the premium that candidate varieties would bring to these markets.

Whilst the bulk of world cotton is sold into traditional textile markets for staple yarn there are a range of non-textile end-uses where cotton fibres are used. These include: dissolving fibres for pulp from which cellulose intermediates and synthetic fibres and casings can be made; the production of felts for cushions, pads, automotive upholstery and furniture upholstery; the production of absorbent medical grade cotton for cotton balls and swabs; and fibre pulp for specialised papers including fine writing paper, filter paper, currency, sanitary products and battery separators. The markets for these products are typically small in volume and dominated by man-made fibres (MMF) and their intermediates.

5. Yarn Production

In today's highly competitive and incredibly global textile market, a spinning mill cannot remain competitive and survive if it does not produce a quality yarn in a cost-effective way. In order to achieve this a spinner needs to know the important fibre properties of the cotton lint and how they will influence processing performance, cost and quality of the yarn, and ultimately the fabric.

Why this is important to a spinner is that the purchase of the cotton lint alone accounts for 50-70% of the mill's operating costs. It is also vital that the spinner purchases cotton which is the most suitable to process on their spinning machines and achieve the quality standards desired. Most spinning mills operate continuously, which means the fibre properties of the cotton used in the first week of the operating year must be not be significantly different from the fibre properties of the cotton used in the last week. Traditionally, the most desirable cotton is said to be 'as white as snow, as strong as steel, as fine as silk and as long as wool'. As well as this, spinners would also ask that the fibre be inexpensive.

This chapter will describe how yarn is produced and introduces fibre quality attributes desired by spinners that contribute to differences in yarn quality, and are necessary for efficient operation of their spinning machines.

Yarn - The Magic of Spinning

Have you ever wondered how all the fibres in a yarn are able to 'stick together' to produce a strong and useful yarn? Spinning utilises the power of friction between fibres to achieve this.

This 'magic' can be demonstrated and explained as follows: Hold one end of a ruler between the palms of your hands, and then ask a friend to pull on the other end of the ruler in a horizontal direction in an attempt to slide the ruler out from between your hands. The experiment is really a 'tug of war' between the frictional forces, at your end of the ruler and the force your friend can apply at the other end. As you increase the vertical pressure between your hands and the ruler, the frictional force increases and is eventually large enough to match the strength of your friend in the tug of war game.

Now let's look closely at the arrangement of the fibres in a yarn. After spinning each fibre forms a roughly spiral or helical shape as visible in the close up photo of cotton yarn (Figure 5.1). This helical shape is the key to the yarn's ability to harness the power of friction. When tension is applied to the yarn, the force tries to stretch or extend each fibre spiral within the yarn. Look closely at what happens to the helical shape of a single fibre when this happens. Figure 5.1, (A) illustrates the fibre before it is stretched and (B) after stretching. As the helical shape elongates the diameter or thickness of the helix naturally decreases. In the yarn, the diameter or thickness of the helix formed by a particular fibre is not hollow but is filled with other fibres so the particular fibre cannot move very much when tension is applied to the yarn. However the 'desire' of helical shape to decrease its diameter or thickness will cause the fibre to press inwards on the neighbouring fibres, and just like pressing our hands together with the ruler, the pressure enables frictional forces to develop and hinder slippage of fibres relative to one another. The 'magic' of the twisted/helical structure is such that as the external forces applied to the yarn increase, the inwards pressure each fibre exerts on the structure also increases and so the friction increases to resist the slippage. Indeed normally in yarn failure, the fibres themselves actually break rather than any fibre slippage occurring. A twisted yarn is indeed a very clever structure.

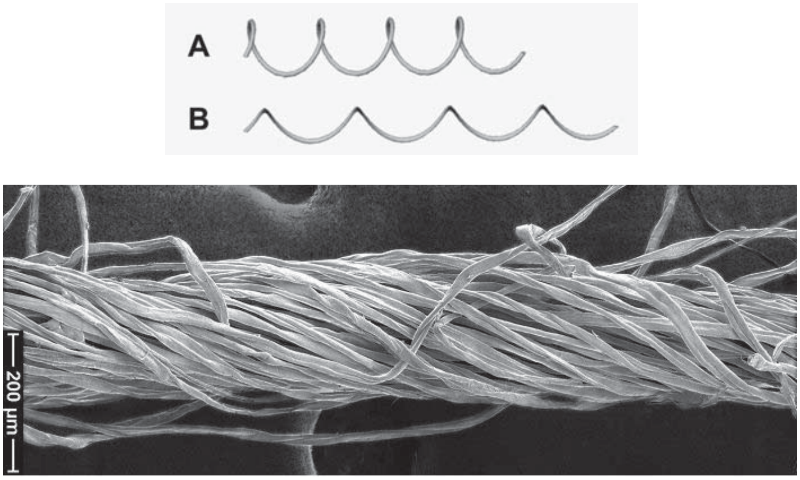


Figure 5.1: After spinning each fibre forms a roughly spiral or helical shape. It is this helical shape is the key to the yarn's ability to harness the power of friction. (Photo: CSIRO). Units are micrometres.

Spinning Yarns

The process of converting cotton fibres from ginned lint into a yarn involves a number of processes clean, remove short fibres, align fibres and ultimately spin the yarn and prepare it for delivery (Figure 5.2). Depending on the setup and machinery present in a spinning mill and the desired quality of the yarn needed to be produced will determine which processes are undertaken (Figures 5.3 and 5.4).

Figure 5.2: The evolution of cotton through a spinning mill (Photo CSIRO).

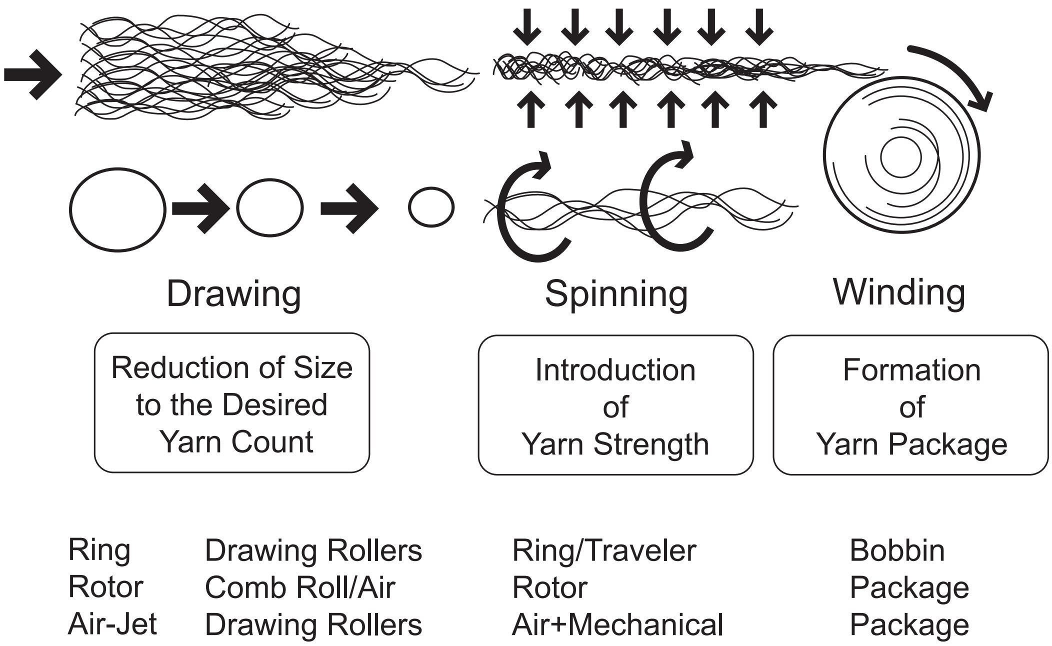


Figure 5.3: The results of various spinning mill processes that help to clean, remove short fibres, align fibres and ultimately produce yarn. (Illustration: CSIRO).

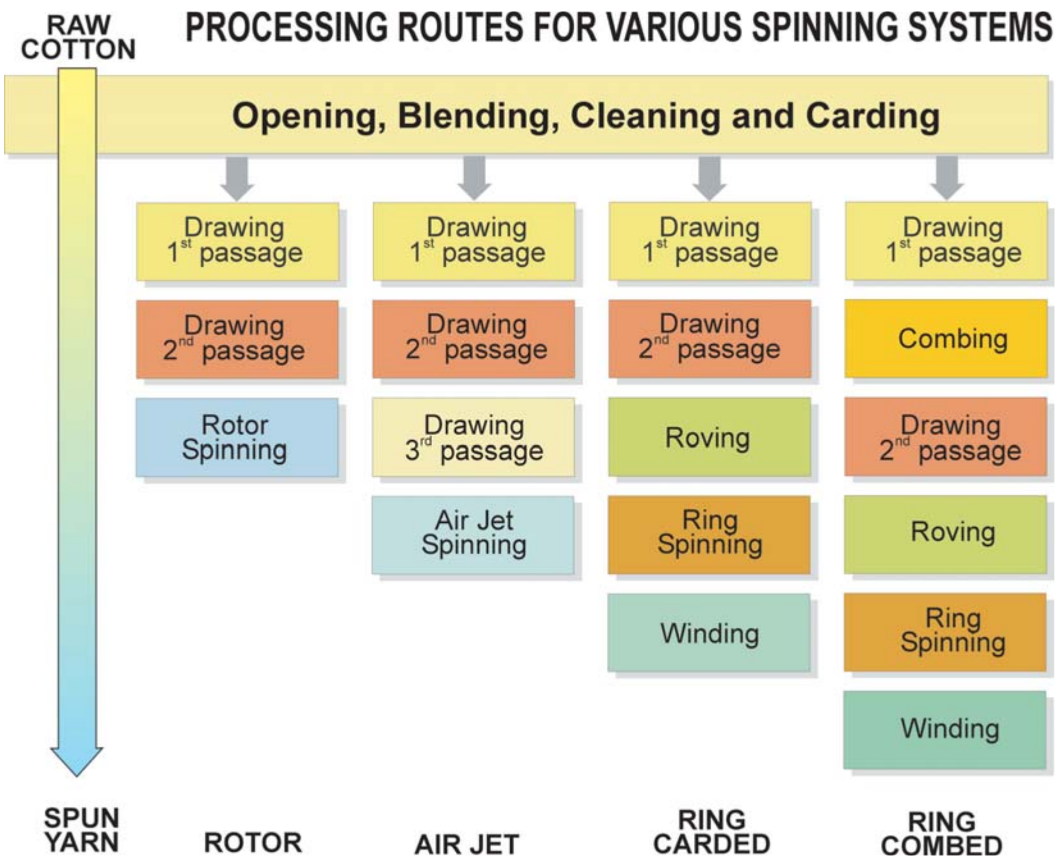


Figure 5.4: Flow chart showing processing routes for various spinning systems (Illistration CSIRO).

Figure 5.5: A 'laydown' takes the cotton from opened bales of differing quality. (Photo: Rene van der Sluijs, CSIRO).

Opening, Blending and Cleaning

Opening, blending and cleaning of the fibre are the first processes in the spinning mill. In the mill, bales are selected to satisfy the requirements of a particular end use and then laid down in a row (called a laydown) to be opened and blended through a range of machines (Figure 5.5). The opening and blending processes ensure a consistent and homogeneous blend of fibres. Blended fibre is then passed through more machines to further open (loosen) the fibre tufts and to clean and remove plant-based contaminants such as leaf, sticks, boll parts, bark and seed fragments. In high-end mills contamination dectection devices are also used to identify and remove contaminants such as fabric, plastic, polypropylene and other non-plant material, which create serious quality issues if contained within the cotton to the final product.

Carding

Once the fibre has been opened, blended and cleaned it is fed to the carding machine which is often referred to as the 'heart of the spinning mill' (Figure 5.6A). This is for good reason as the carding machine individualises, aligns and further cleans the fibres, before condensing them into a single continuous strand of overlapping fibres called a 'sliver'. Importantly, a large proportion of short fibres and neps are also removed during carding. The quality of the sliver assembly from the card determines both the quality and processing efficiency of products further up the processing chain.

Figure 5.6: Carding (A) and Drawing (B) produces a sliver a single continuous strand of overlapping fibres. (Photos: CSIRO).

Drawing

Drawing is the process where the fibres are blended, straightened and the number of fibres in the sliver reduced in order to achieve the desired linear density in the spinning process. The drawing process also improves the uniformity or evenness of the sliver. The number of drawing passages utilised depends on the spinning system used and the end products (Figure 5.6B).

Combing

Combing is the process that removes the final proportion of short fibre, neps and other impurities such as vegetable matter and seed coat fragments in cotton that has already been carded. The waste material, which is predominantly made up of short fibre, is referred to as noil or comber waste and commonly makes up between 15 and 20% by weight of the fibre into the comber. Combed yarns are superior in quality when compared to carded yarns as they are generally finer, stronger, smoother and more uniform due to the removal of short fibres and the alignment of fibres (Figure 5.7). Combed yarns are however more expensive than carded yarns (approximately 10%) as combing involves additional processing stages and produces more waste.

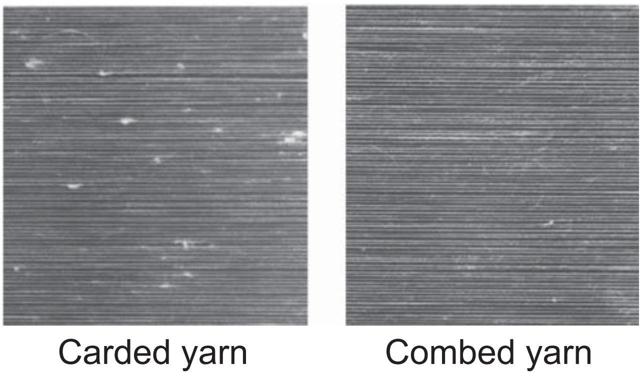


Figure 5.7: Combed yarns are generally finer, stronger, smoother and more uniform, due to the removal of short fibres and the alignment of fibres. (Photos: CSIRO).

Roving

In preparation for ring spinning, the sliver needs to be condensed into a finer strand known as a roving before it can be spun into a yarn (Figure 5.8). The roving frame draws out the sliver to a thickness of a few millimetres and inserts a small amount of twist to keep the fibres together. The drafted twisted strand is wound onto a bobbin which is then transported to the ring frame and used as the feed package for spinning yarn.

Figure 5.8: Roving bobbins on the creel of a ring spinning machine. The formation of roving reduces the sliver into a finer strand with the addition of twist. (Photo: CSIRO).

Spinning

There are three main spinning systems used commercially to produce cotton and other short staple yarns, i.e. yarns produced from fibres typically with lengths up to 50 mm.

1. Ring spinning
2. Rotor spinning (also known as open-end spinning)
3. Air-jet spinning (including Vortex spinning)

Ring spinning (Figure 5.9) was perfected as a process by the end of the 19th century. There are currently over 261 million ring spindles installed world-wide that account for about 60% of all short-staple yarn production. Its prominence reflects its versatility in terms of productivity, the range of yarn counts that can be spun on it and the fibre types that can be used. Ring spun yarns are also superior in terms of yarn strength and character in terms of fabric handle and comfort. The majority of Australian cotton is spun into yarn using this system.

Rotor spinning was introduced as a new short-staple spinning system in the mid 1960's and achieved its greatest uptake during the 1980s when production speed and versatility were improved. Today, there are over 9.2 million rotor positions installed world-wide which account for about 30% of all short-staple yarn production.

Air-jet spinning was developed in the 1960s but was not successful commercially until the early 1980's when it was introduced by the Murata Company of Japan. Initially suited to longer staple polyester rich fibre blends, air-jet spun yarn could be delivered at speeds significantly higher than that of ring spinning. Later versions of air-jet spinning were adapted to 100% cotton fibres, e.g. Vortex spinning, and with delivery speed increased by nearly a factor of two over the original air-jet machines. It is estimated that there are around one million air-jet spinning positions installed world-wide.

The advantages of rotor and air-jet spinning over ring spinning are chiefly based around their superior productivity in the delivery of medium to coarse count yarns. Furthermore, both systems use drawn sliver as their feed stock and both are able to build (wind) a yarn package that can be used directly by fabric manufacturers. Hence both systems avoid two processes required in ring spinning, i.e. the roving and winding processes.

Detailed descriptions of the different spinning systems are contained in Appendix 1.

Winding

The winding process is a necessity in the case of ring spun yarn in order to transfer the yarn from small bobbins (Figure 5.9), which hold short lengths of yarn, to larger packages (Figure 5.10). These packages hold longer lengths of yarn suitable for subsequent processes such as warping, weaving, yarn dyeing, and knitting. Yarn faults or defects such as slubs (slub yarn is a yarn containing varying thicknesses), thin, thick and weak places as well as contaminants can be removed during winding by special fault clearing devices. The yarn can also be lubricated for knitting during winding.

Figure 5.10: Winding produces a yarn package. (Photos: CSIRO)

Plying, doubling, or folding is the process of twisting two or more yarns together. The process is normally used to improve yarn evenness, strength, elongation, abrasion resistance, to reduce hairiness and fibre shedding (fly), and to produce speciality (fancy and/or bulky) yarns. An assembly winder is used to assemble the ends of yarn on one package in preparation for twisting. A lubricant can also be applied at this stage. Yarns are generally twisted together on a two for one twisting machine where two turns of twist are inserted per spindle revolution.

Figure 5.9: Ring Spinning produces the yarn which is wound onto bobbins. (Photos: CSIRO).

Further Reading

Lord PR (2003) 'Handbook of Yarn Production – Technology, Science and Economics'(The Textile Institute and Woodhead Publishing).

Ratnam TV, Doraiswamy I, Chellamani KP (2005) 'Quantitative requirements of cotton by 2010'. Asian Textile Journal. 14(10):88-92.

McCreight DJ, Feil RW, Booterbaugh JH, Backe EE (1997) 'Short Staple Manufacturing' (Carolina Academic Press).

Duessen H (1993) 'Rotor Spinning Technology' (Schlafhorst Inc.).

6. Importance of Quality Fibre

This section outlines and discusses the importance of specific fibre quality attributes, and how changes in these attributes affect textile production. Textile production in this context refers to spinners, who spin yarn and the fabric manufacturers; knitters and weavers, who make and finish the fabric. Finishing the fabric refers to scouring, bleaching, dyeing, and the addition of any functional finishes to the fabric, e.g. stain resistance, permanent press finishes. Many fibre properties are considered and measured where possible by the spinner and fabric manufacturer in order to control product quality. For the spinner the following properties are considered important:

- Length, Length Uniformity, Short Fibre Content
- Micronaire (Linear Density/Fibre Maturity)
- Strength
- Trash (including the type of trash)
- Moisture
- Fibre entanglements known as neps (fibre and seed coat fragments)
- Stickiness
- Colour
- Contamination

These fibre properties however, vary in importance according to the spinning system used and the product to be made. Table 6.1 lists the most important fibre properties required by each spinning system to process high quality yarns.

Table 6.1: Importance of fibre properties for different spinning processes

Importance rank	Ring Spinning	Rotor Spinning	Air-Jet Spinning
1	Length	Strength	Length
2	Strength	Linear Density	Low Trash
3	Linear Density	Length	Linear Density
4	-	Trash	Strength

For the fabric manufacturer the quality of the fibre is largely characterised by the quality of yarn they buy or are provided with; where good quality fibre translates to good quality yarn. However, the following fibre properties also have significance when appraising the finished fabric quality. These include:

- Micronaire (maturity)
- Trash
- Contamination
- Short Fibre Content (SFC)
- Neps
- Colour and grade

The above properties contribute to knowledge of the general ‘spinning ability’ and ‘dyeing ability’ properties. Indeed indices and equations incorporating various fibre properties are commonly used to predict spinning and dyeing ability. However, there are fibre properties not yet routinely measured, which could contribute to a more accurate prediction of the spinning and dyeing properties of cotton fibres. These properties include fibre elongation, fibre cross-sectional shape, fibre surface and inter-fibre friction, the make up of a cotton fibre's surface wax, the crystalline structure of cotton's cellulose, and the level of microbial infection (known as 'Cavitoma').

Consequences of poor fibre quality are presented in Table 6.2 and are discussed in more detail following. In subsequent chapters practices to reduce poor fibre quality are discussed.

(Warwick Stiller: CSIRO)

Table 6.2: Consequences of poor fibre quality.

Fibre Trait	Trait Description	Ideal Range	Consequences of poor fibre quality – cotton price	Consequences of poor fibre quality – spinning
Length	Fibre length varies with variety. Length and length distribution are also affected by stress during fibre development, and mechanical processes at and after harvest.	UHML (Upper Half Mean Length) in excess of 1.125 inch or 36/32nds. For premium fibre 1.250 or 40/32nds. See table 2.1 for conversions.	Significant price discounts below 33/32nds.	Fibre length determines the settings of spinning machines. Longer fibres can be spun at higher processing speeds and allow for lower twist levels and increased yarn strength.
Short fibre content	Short fibre content (SFC) is the proportion by weight of fibre shorter than 0.5 inch or 12.7 mm.	< 8%	No premiums or discounts apply.	The presence of short fibre in cotton causes increases in processing waste, fly generation and uneven and weaker yarns.
Uniformity	Length uniformity or uniformity index (UI), is the ratio between the mean length and the UHML expressed as a percentage.	> 80%	Small price discounts at values less than 78. No premiums apply.	Variations in length can lead to an increase in waste, deterioration in processing performance and yarn quality.
Micronaire	Micronaire is a combination of fibre linear density and fibre maturity. The test measures the resistance offered by a weighed plug of fibres in a chamber of fixed volume to a metered airflow.	Micronaire values between 3.8 and 4.5 are desirable. Maturity ratio >0.85 and linear density < 220 mtex Premium range is considered to be 3.8 to 4.2 with a linear density < 180 mtex.	Significant price discounts below 3.5 and above 5.0.	Linear density determines the number of fibres needed in a yarn cross-section, and hence the yarn count that can be spun. Cotton with a low Micronaire may have immature fibre. High Micronaire is considered coarse (high linear density) and provides fewer fibres in cross section.
Strength	The strength of cotton fibres is usually defined as the breaking force required for a bundle of fibres of a given weight and fineness.	> 29 grams/tex, small premiums for values above 29 /tex. For premium fibre > 34 grams/tex.	Discounts appear for values below 27 g/tex.	The ability of cotton to withstand tensile force is fundamentally important in weaving. Yarn and fabric strength correlates with fibre strength.
Colour Grade	Grade describes the colour and 'preparation' of cotton. Under this system colour has traditionally been related to physical cotton standards although it is now measured with a colorimeter.	> MID 31, small premiums for good grades.	Significant discounts for poor grades.	Aside from cases of severe staining the colour of cotton and the level of 'preparation' have no direct bearing on processing ability. Significant differences in colour can lead to dyeing problems.
Trash / dust (Leaf Grade)	Trash refers to plant parts incorporated during harvests, which are then broken down into smaller pieces during ginning.	Low trash levels of < 5% Less than or equal to leaf grade 3	High levels of trash and the occurrence of grass and bark incur large price discounts.	Whilst large trash particles are easily removed in the spinning mill too much trash results in increased waste. High dust levels affect open end spinning efficiency and product quality. Bark and grass are difficult to separate from cotton fibre in the mill because of their fibrous nature.
Stickiness	Contamination of cotton from the exudates of the silverleaf whitefly and the cotton aphid.	Low / none	High levels of contamination incur significant price discounts and can lead to rejection by the buyer.	Sugar contamination leads to the build-up of sticky residues on textile machinery, which affects yarn evenness and results in process stoppages.
Seed - coat fragments	In dry crop conditions seed-coat fragments may contribute to the formation of a (seed-coat) nep.	Low / none	Moderate price discounts.	Seed coat fragments are difficult to remove as they are attached to the fibre and do not absorb dye and appear as brown 'flecks' on finished fabrics.
Neps	Neps are fibre entanglements that have a hard central knot. Harvesting and ginning affect the amount of nep.	< 250 neps/gram. For premium fibre < 200	Moderate price discounts.	Neps typically absorb less dye and reflect light differently and appear as light coloured 'flecks' on finished fabrics.
Contamination	Contamination of cotton by foreign materials such as woven plastic, plastic film, jute / hessian, leaves, feathers, paper leather, sand, dust, rust, metal, grease and oil, rubber and tar.	Low / none	A reputation for contamination has a negative impact on sales and future exports.	Contamination can lead to the downgrading of yarn, fabric or garments to second quality or even the total rejection of an entire batch.

Fibre length, Length Uniformity, and Short Fibre Content (SFC)

Longer fibres allow finer and stronger yarn to be spun at higher production speeds as the twist inserted into longer fibres traverses and entwines over a longer length of yarn. Fibre length determines the draft settings of machines in a spinning mill. Longer fibres also mean that less twist needs to be inserted into yarn, which in turn means production speeds can be increased. Spinning production is determined by the spinning speed of the spindle, rotor and air current, yarn count, and the amount of twist required in the yarn. Hence longer fibre allows lower twist levels to be used, increases yarn strength, improves yarn regularity and allows finer yarn counts to be spun. Fibre length must stay consistent as variations in length can cause severe problems and lead to an increase in waste, deterioration in processing performance and yarn quality.

Fibre length is a genetic trait that varies considerably across different cotton species and varieties. Length and length distribution are also affected by agronomic and environmental factors during fibre development, and mechanical processes at and after harvest. Gin damage to fibre length is known to be dependent upon variety, seed moisture, temperature (applied in gin) and the condition of fibre delivered to the gin (e.g. weathered fibre). The distribution pattern of fibre length in hand-harvested and hand-ginned samples is markedly different from samples that have been mechanically harvested and ginned; two processes that result in the breakage of fibres.

Fibre length can be determined using fibre arrays or fibre staple length diagrams (Figure 6.1a) produced using a comb-sorter apparatus. These diagrams can be used to define upper fibre staple lengths such as the upper-quartile length (UQL), which is the length of the shortest fibre in the upper one-fourth of the length distribution, and other fibre length parameters such as mean length and SFC. Comb-sorter apparatus use a series of hinged combs separated at 1/8 inch intervals, to align, separate and allow the withdrawal and description of weight-length or number-length groups from a sample.

Whilst in theory comb-sorter methods are accurate they are unacceptably expensive in terms of operator cost and give results that are too imprecise for routine testing for commercial trading purposes. To rectify this issue a Fibrograph instrument was developed and later incorporated into HVI lines. Test specimens for this instrument are fibre beards prepared manually or automatically. Fibre length from HVI is usually defined as the upper-half mean length (UHML) or 2.5% span length (2.5% SL) from a Fibrogram beard. Both measures roughly coincide with the manual classer's assessment of staple length.

The HVI test fibre beard sample is held in a comb that is inserted into the instrument and scanned by a light source. The variation in fibre density (related to light intensity) of the different lengths of fibre is recorded and reproduced in the form of a length-frequency curve called the Fibrogram (Figure 6.1b). Interpretation of the Fibrogram takes into account the comb gauge length i.e., the depth of the comb at which fibres are held (0.25 inch).

Two different kinds of fibre length measurement can be generated from a Fibrogram; mean lengths and span lengths. Mean lengths, e.g. the upper half mean length (UHML), which is the mean length of the longer half (50%) of the fibre by weight, and the mean length (ML) are more commonly used since they describe the mean of all or a set portion of fibres represented in the Fibrogram. Span lengths (SL), which came about as a result of a technical shortcoming in the ability of the first digital Fibrograph to graphically run a tangent to the Fibrogram, represent fibre extension distances, e.g. the 2.5%SL represents the distance the longest 2.5% of fibres extended from the comb.

Fibre length is typically reported as 100ths of an inch or 32nds of an inch. Length reported in 100ths of an inch can be converted to 32nds by multiplying the value by 32 and rounding to the nearest whole number (conversion table in Fibre History Chapter). Length Uniformity is expressed either as the uniformity index or uniformity ratio. Both terms are ratios of measurements from the Fibrogram, where uniformity index refers to the ratio between the mean length and the upper half-mean length and the uniformity ratio refers to the ratio of the 50% span length to the 2.5% span length (see Figure 6.1b).

Excessive short fibre increases waste in the mill, lowers yarn strength and can cause yarn imperfections. The most common definition of SFC is the proportion by mass of fibre shorter than one half inch (12.7mm). Short fibre content is not measured directly by any instrument employed in HVI lines. Instead SFC or short fibre index (SFI) is estimated indirectly using the Fibrogram measurements of UHML and ML or 2.5% span length and 50% span length as the main variables in prediction equations.

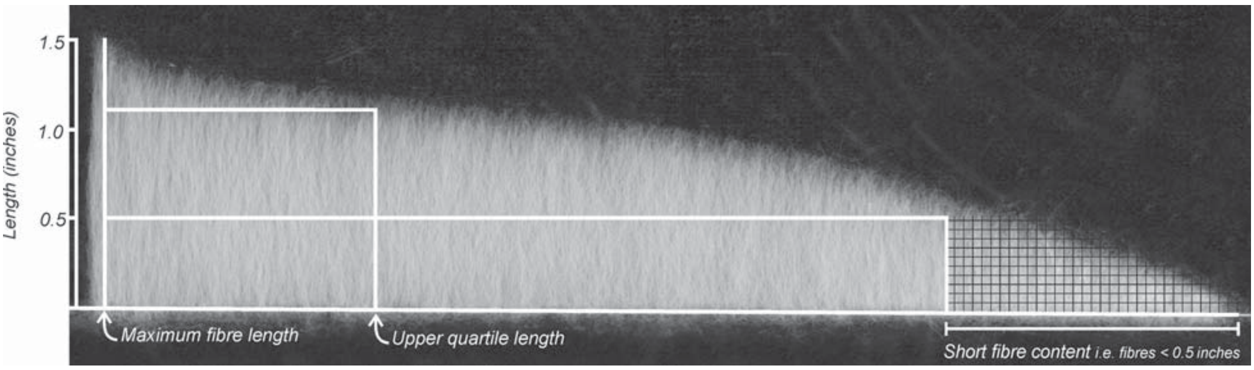


Figure 6.1a: – Comb-sorter fibre array for a roller ginned extra long staple fibre sample. Note long maximum length and proportion of short fibre. (Photo: CSIRO).

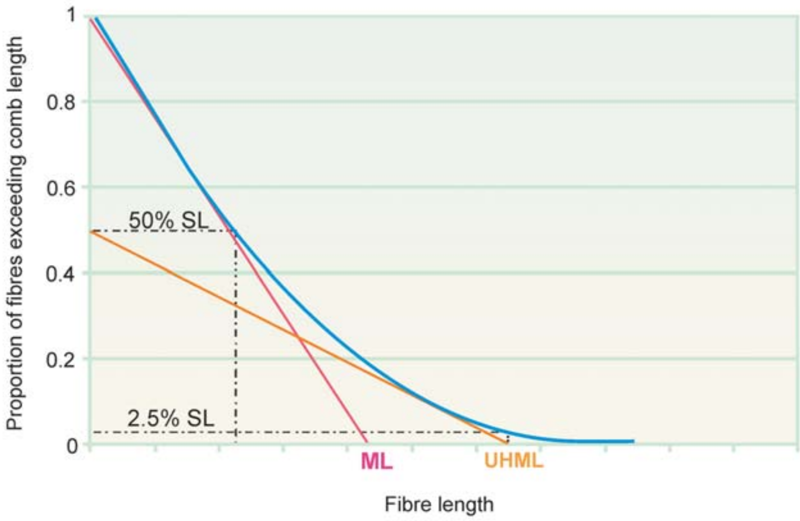


Figure 6.1b: – Typical Fibrogram showing length measurement locations on the fibre length diagram produced by the Fibrograph (ML - mean length, UHML - upper half mean length, SL - span lengths).

Fibre Strength

Yarn strength is directly related to fibre strength, particularly in rotor spun yarns (see Table 6.1). Cottons with good strength can be spun faster and usually result in fewer problems during processing than weaker cottons. In turn strong yarn improves fabric strength and durability.

Fibre and yarn strength represent the maximum resistance to stretching forces developed during a tensile test in which a fibre, fibre bundle or yarn is broken. The maximum resistance to these forces is called the breaking load and is measured in terms of grams (or pounds) force. To account for differences of fibres with different linear densities and for the number of fibres present in a bundle, the breaking load is adjusted by the number of fibres in the bundle, which is determined by the linear density of the fibre and the weight of fibre in the bundle. This adjustment produces the value of tenacity, which is measured in terms of grams force/tex (tex - grams/kilometre) and allows direct comparison of the strength of different fibres and yarns.

There are also other issues that need consideration when measuring the strength of fibre bundles (Figure 6.2). One issue relates to the length, known as the gauge length, between the jaw clamps that hold the fibre bundle. A sample with a high number of short fibres (high SFC) means that many of the fibres may not reach across the gauge length (typically 1/8 inch) to be clamped, resulting in a lower bundle strength measurement. Another important issue relates to the moisture content of the fibres in the bundle. It is well known that fibre with high moisture content has a higher strength than 'dry' fibre. It is for this reason that fibre moisture is equilibrated to standard conditions (20°C and 65% relative humidity) for up to 24 hours before testing. Fibre tenacity can be increased in excess of 10% by increasing fibre moisture from 5% to 6.5%.

The effect of fibre maturity or immaturity on fibre bundle strength tests is also sometimes a point of contention. Whilst a single mature fibre is inherently stronger than a single immature fibre by virtue of its crystalline cellulose structure, this relativity is often not clearly seen in HVI bundle strength tests. Research has shown that reasonably immature fibre can still produce good fibre bundle tenacity values and corresponding yarn tenacity values. The effects seen in this circumstance can probably be attributed to one or a combination of the following factors. One is inaccurate assessment of fibre linear density and bundle weight by the HVI and therefore improper adjustment of the fibre bundle/yarn strength value, and the other is the positive effect of immature fibre having more fibre ends and surface area contributing to the bundle strength result.

Figure 6.2: Photo of a fibre array comb for the HVI Fibrograph (length) and strength tester. (Photo: Warwick Stiller, CSIRO).

Elongation

Cotton fibre is flexible and can be stretched. The increase in length or deformation of the fibre before it breaks as a result of stretching is called elongation. Expressed as a % increase over its original length.

Neps

Neps occur in all ginned cotton but hardly in unpicked seed-cotton. Neps are fibre entanglements that have a hard central knot that is detectable (Figure 6.3). Harvesting (Figure 6.4), ginning (particularly lint cleaning), opening, cleaning, carding and combing in the mill are mechanical processes that affect the amount of nep found in cotton. The propensity for cotton to nep is dependent upon its fibre properties, particularly its linear density and fibre maturity, and the level of biological contamination, e.g. seed coat fragments, bark and stickiness. Studies have shown generally that over 90% of fibres in a nep are immature.

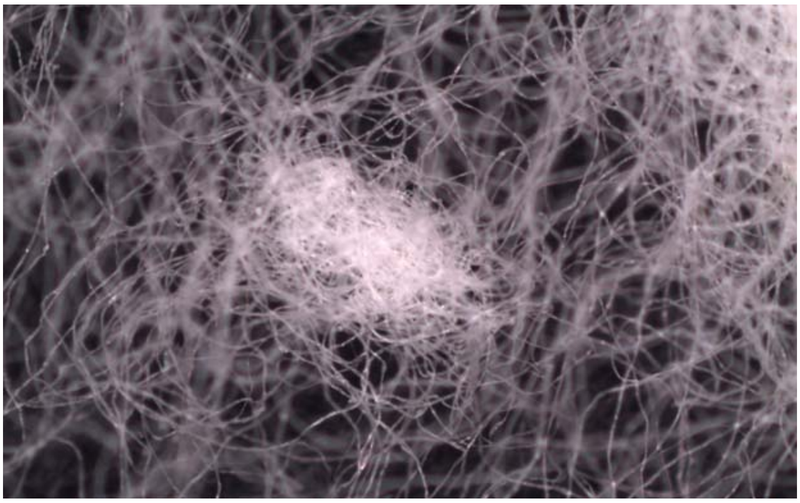


Figure 6.3: A nep is an entanglement of fibres resulting from mechanical processing. More neps can occur if cotton is immature as they entangle more easily. (Photo: CSIRO).

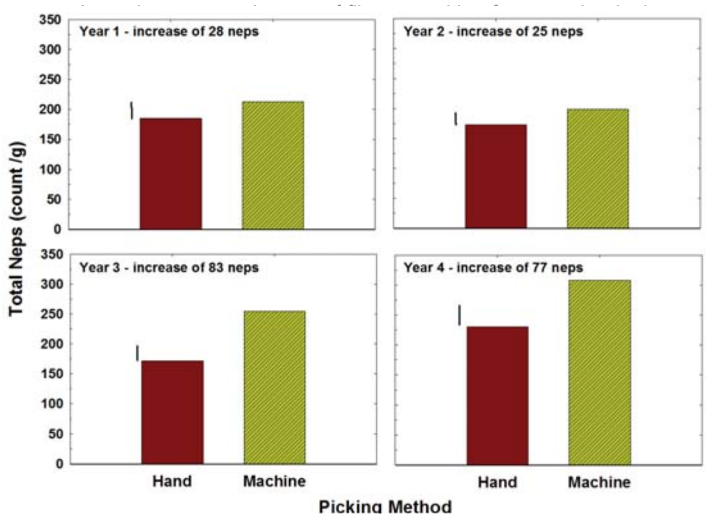


Figure 6.4: Neps are created following mechanical handling of the fibre, such as machine picking. These graphs show the effect of picking on the level of neps compared to hand-picked cotton over four seasons (Bange and Long, 2013).

Trash

Trash in seed-cotton is a grower and ginner problem, whilst trash in baled lint is a spinner problem however, the solutions for the grower and ginner are not always the best solutions for the spinner. In the gin more cleaning can result in more fibre breakages leading to increased short fibre content, and more neps. With an increasing number of impurities (i.e. trash), such as husk, leaf, stalk and seed-coat fragments, the tendency towards inferior yarn quality can increase if the installed opening and cleaning line in a mill is unable to cope with it. Removing trash is a cost to a spinning mill and can cause deterioration in spinning performance and yarn quality. It is imperative for a spinning mill to know what the cleaning efficiency of its cleaning line is to ensure that it can cope with the trash content in the cotton lint, especially for rotor and air jet spinning.

Stickiness

Sticky cotton is a major concern for spinning mills. Physiological plant sugars in immature fibres, contaminants from crushed seed and seed coat fragments, grease, oil and pesticide residues are all potential sources of stickiness. However, these are insignificant compared with contamination of cotton from the exudates of the silverleaf whitefly (*Bemisia tabaci* B-biotype) and the cotton aphid (*Aphis gossypii*). The sugar exudates from these insects lead to significant problems in the spinning mill including a build-up of residues on textile machinery, which results in irregularities and stoppages in sliver and yarn production. Even at low to moderately contaminated levels, sugar residues build up, decreasing productivity and quality, and forcing the spinner to increase the frequency of cleaning schedules. A reputation for stickiness has a negative impact on sales and price for cotton from regions suspected of having stickiness (more details in the chapter 'Open Boll to Harvest').

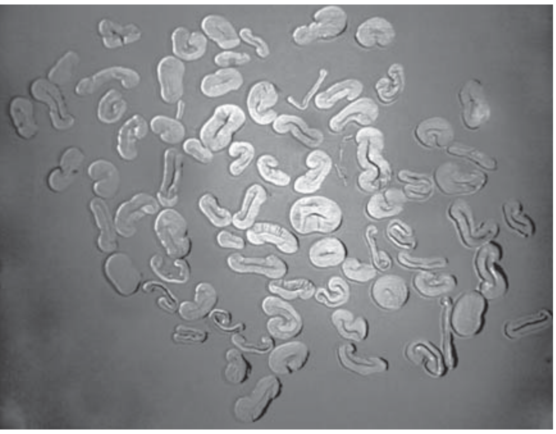


Figure 6.5: The cross section of a cotton yarn showing the packing and interaction of individual fibres. In this yarn cross-section seventy eight individual fibres are distinguishable. (Photo: CSIRO).

Colour Grade

Colour is a primary indicator of grade. Discolouration is due a to range of influences including trash and dust content, rain damage, insect secretions, UV radiation exposure, heat and microbial decay. Colour in cotton is defined in terms of its reflectance (Rd) and yellowness (+b), which are measured by a photoelectric cell. Historically grade is a subjective interpretation of fibre colour, preparation and trash content against 'official' standards.

Fibre Linear Density

Fibre linear density (often referred to as fineness) determines the minimum yarn linear density or yarn count that can be spun from fibre. This is based on the minimum number of fibres required to physically hold a twisted yarn assembly together. The linear density of fibres increases with both larger fibre perimeter and greater fibre maturity. This 'spin-limit' minimum will depend on different spinning systems and the level of twist inserted into the fibre assembly. In general, for ring spinning the minimum number of cotton fibres required in the yarn cross-section is around 80 (Figure 6.5), for rotor spinning the number is 100 fibres and for air-jet spinning the number is 75 fibres.

The linear density of raw cotton used to manufacture a yarn can therefore have a big impact on yarn evenness. For coarser fibres with higher linear densities there is a higher probability of there not being enough fibres in a yarn cross section to support the yarn structure (a thin place) as illustrated below (Figure 6.6). A thin place in a yarn is a weak place, which has potential to break during either the spinning process itself or later during fabric manufacture. This can have a significant impact on the efficiency of the spinning process and the effect of uneven yarn can sometimes be observed in light weight tee shirts or vests where close examination highlights a slightly uneven appearance of the knit structure. So there is considerable pressure on the spinner to ensure that the yarn manufactured and supplied is as even as possible so breakages do not occur.

Figure 6.6: Simple schematic representations of the arrangement of fibres within a yarn. (a) a yarn made with fine fibres (lower linear density) (b) a yarn with a similar linear density made from coarser fibres (higher linear density). The red line indicates less fibres in the cross section leading to a thin/weak spot.

In the example, illustrated in Figure 6.6, imagine if the spinner chose to make the same yarn from a coarser cotton fibre. In this case, fewer rows of the heavier fibres are required to make up the required mass for the yarn as shown schematically in Figure 6.6b. With coarse fibres along with the natural variation in the number of fibres in the yarn cross-section there are opportunities for more 'thin' places in the yarn cross section (see vertical line in Figure 6.6b).

These effects are well known to the spinner and hence chooses fibre quality with some care. The linear density of synthetic fibres is routinely available and fibre diameter (micron) is used by the wool industry. Spinners carefully use this data to choose appropriate raw materials for spinning either synthetic or wool yarns. In the case of cotton, unfortunately fibre linear density is not available to the trade, which instead relies on the Micronaire value as a proxy for fibre linear density. The Micronaire has limitations as it is unable to properly distinguish premium fine mature cotton from immature, coarser cotton (smaller fibre perimeters and lower linear density).

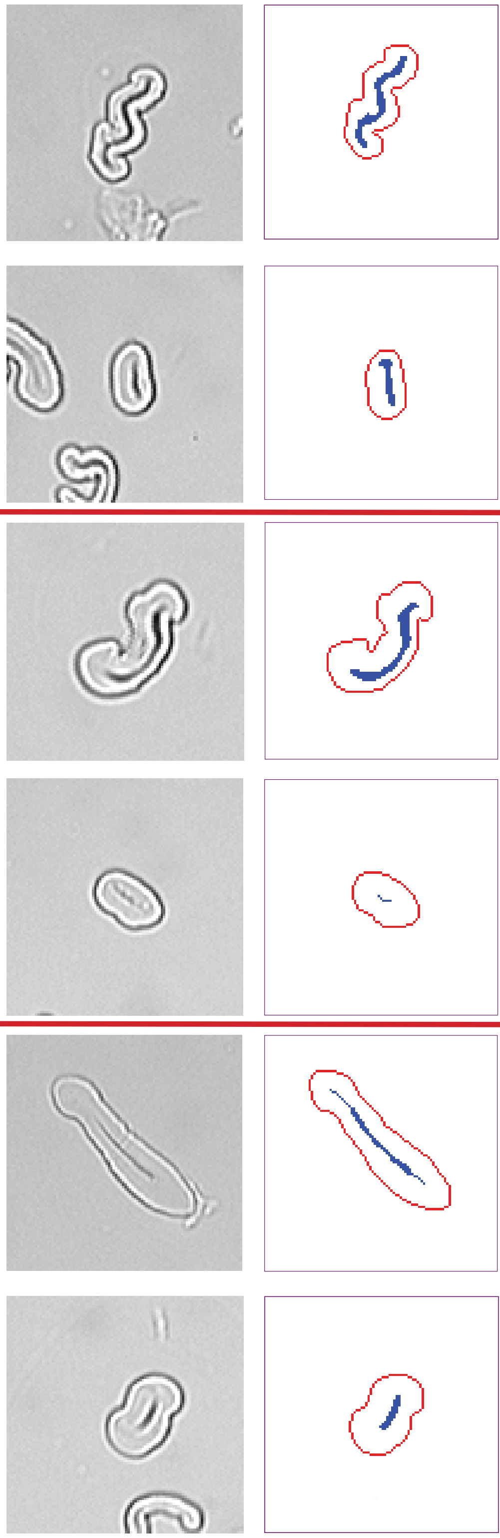
Limitations of the Micronaire measurement

Micronaire is a measure of the rate at which air flows under pressure through a plug of lint of known weight compressed into a chamber of fixed volume. The rate of air flow depends on the resistance offered by the total surface area of the fibres which is related to the linear density as well as the thickness of the fibre walls. A reduction in linear density, wall thickness or fibre perimeter decreases the Micronaire reading as there is more fibres in a plug of cotton that is tested increasing air resistance.

It is important to remember that both yarn count (how fine) and yarn quality (how even and strong) are the main reasons why fibre linear density is so important, and thus why spinners prefer to purchase fibres with a specified linear density (see chapter on textile production). Currently, the commercial trade relies on Micronaire readings to indicate the linear density of cotton, despite it being well known that the Micronaire readings represent a combination of fibre linear density and fibre maturity, and as a result is not a particularly accurate measure of either important parameter.

For the spinner there are two potential problems in managing quality using the Micronaire value. Low Micronaire may indicate the presence of immature fibre and high Micronaire values may indicate that the cotton is coarse. Instances can occur where Micronaire readings are similar and fibre traits of fibre maturity and linear density (and wall thickness) can be entirely different (see Figure 6.7) leading to differences in yarn properties (Figure 6.8). All situations are problematic for the spinner.

Microscope image | **Analysed image**



Micronaire: **3.1**
Linear density: 150 mtex
Theta: 0.41
Perimeter: 56 µm
Wall area: 102 µm²

Micronaire: **3.1**
Linear density: 81 mtex
Theta: 0.76
Perimeter: 30 µm
Wall area: 56 µm²

Micronaire: **4.3**
Linear density: 216 mtex
Theta: 0.43
Perimeter: 65 µm
Wall area: 145 µm²

Micronaire: **4.3**
Linear density: 108 mtex
Theta: 0.86
Perimeter: 33 µm
Wall area: 73 µm²

Micronaire: **5.3**
Linear density: 279 mtex
Theta: 0.45
Perimeter: 72 µm
Wall area: 187 µm²

Micronaire: **5.3**
Linear density: 160 mtex
Theta: 0.78
Perimeter: 42 µm
Wall area: 107 µm²

Figure 6.7: Cross section of fibres that have similar Micronaire values (same surface area to weight ratios). For instance, one fibre type achieves a Micronaire of 4.2 because it has a smaller fibre perimeter (meaning more fibres are present in the plug used for sampling) and has more fibre wall thickening (fibre maturity), overall resulting in a smaller fibre linear density. The other fibre achieves the same Micronaire as it has a larger fibre perimeter but has poorer fibre wall thickening (immature) resulting in a larger fibre linear density. (Photo: CSIRO).

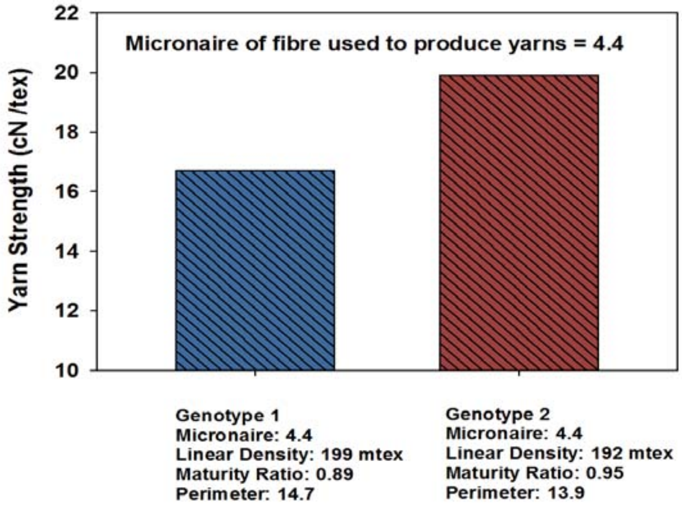


Figure 6.8: Impact of changes of the fibre properties of fibre fineness, maturity and perimeter on yarn strength from cotton measured with the HVI having similiar micronaire. Yarn was 20 tex ring spun yarn following both carding and combing processes (Long et al. 2010).

Figure 6.9 shows the relationship between the fibre quality attributes of Micronaire, fibre linear density and fibre maturity. Note that it is not possible to accurately estimate fibre linear density from the Micronaire value alone. However, without an accurate measure of fibre linear density the spinning industry is forced to adopt a risk minimisation strategy by choosing cottons within a relatively narrow Micronaire band. Within these bands the spinner can be reasonably assured that the linear density and fibre maturity of the fibre will translate into good quality yarn. Micronaire values less than 3.4 and greater than 5.0 are considered to be in the 'Discount Range'; the range 3.5 to 4.9 is regarded as 'Base Grade' whilst 3.7 to 4.2 is considered to be the 'Premium Range'.

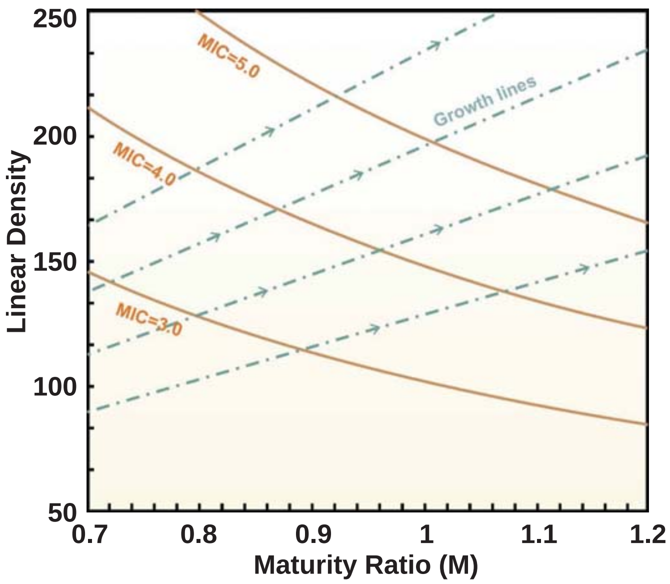


Figure 6.9: The relationship between fibre linear density, maturity ratio, and Micronaire (MIC). Note that during growth a fibre will progress diagonally across this graph as illustrated schematically by the dotted lines, with the increasing wall thickening resulting in fibre linear density, fibre maturity ratio and MIC ire all increasing. The different growth lines can represent varietal differences. (Adapted from Thibodeaux 1998).

Whilst there are a number of methods for measuring fibre maturity and linear density until recently no one method has been able to do so accurately and with the speed requirement for classing purposes. The development of the Cottonscope™ instrument by the CSIRO measures both fibre linear density and maturity, and is aimed at creating fast and accurate instrument test methods for breeders, merchants and spinners alike (Figure 6.10).

Figure 6.10: Instrumentation has been developed that offers significant opportunities to measure fibre linear density and fibre maturity ratio (Cottonscope™) directly and quickly as an alternative to the indirect measurement of these properties using Micronaire. (Photo: CSIRO).

Further Reading

ASTM D4604, Standard Test Method for Measurement of Cotton Fibers by High Volume Instruments (HVI)

Bange MP, Long RL (2013) Impact of harvest aid timing and machine spindle harvesting on neps in upland cotton. Textile Research Journal 83(6):651-658.

Gordon SG, Naylor GRN (2006) New research and development work from Australia in cotton fineness and maturity assessment. ICAC Recorder June 2006. 24(2), 13-18.

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Gordon SG (2007) Cotton fiber quality. In' Cotton: Science and technology'. Gordon SG, Hsieh Y-L. (eds), (Woodhead Publishing Ltd., Cambridge, England) pp. 68-100.

Hertel KL (1940) A Method of Fiber Length Analysis Using the Fibrogram. Textile Research Journal 10(12): 510 – 524.

Long RL, Bange MP, Gordon SG, van der Sluijs MHJ, Naylor GRS, Constable GA (2010) Fibre quality and textile performance of some Australian cotton genotypes. Crop Science 50(4):1509-1518.

Montalvo, JG (2005) Relationships between microniare, fineness, and maturity. Part I. Fundamentals. The Journal of Cotton Science. 9(2): 81-88.

Thibodeaux DP (1998) Development of calibration cottons for fibre maturity. In Proc. 24th International Cotton Conference Bremen. H. Harig, SA Heap, JC Stevens (eds) (Faserinstitut Bremen e.V. & Bremer Baumwollbourse) pp. 99-107.

Suh MW, Cui X, Sasser PE (1994) New Understanding of HVI Tensile Data based on mantis single fiber test results. Proceeding Beltwide Cotton Conference pp. 1400-1403.

van der Sluijs MHJ, Gordon SG, Long RL (2008) A spinners perspective on fibre fineness and maturity. Part 1: Current practice based on Micronaire. The Australian Cottongrower 29(1): 30-32.

7. Crop Management for Improved Fibre Quality

Fortunately the majority of crop management factors which increase/optimise yield will also increase/optimise fibre quality. One exception may be instances of production of high Micronaire cotton. As discussed previously in the chapter on 'Fibre Biology', fibre properties can be strong yield components and influence yield: everything else being equal, longer fibres mean more lint yield. Likewise a greater linear density (and maybe higher Micronaire) will mean more lint yield

The literature on agronomy and climate effects on fibre quality is particularly comprehensive for fibre length and Micronaire; fibre strength is more influenced by variety. Fibre growth and development is affected by most factors which influence plant growth. Since the fibre is primarily cellulose, any influence on plant photosynthesis and production of carbohydrate will have a similar influence on fibre growth. Cell expansion during fibre growth is strongly driven by turgor, so plant water relations will affect fibre elongation in the period immediately following flowering. Thus in terms of **primary (direct)** responses, water status (irrigation) strongly influences fibre growth and ultimately final fibre length. Fibre elongation will also be affected temperature and carboydrate limitations, with high temperatures shortening the time for fibres to elongate.

Fibre thickening is also affected by temperature and radiation effects on photosynthesis with large reductions in fibre thickening leading to low fibre Micronaire following long periods of low temperatures or cloudy weather. Delayed sowing may expose more of the fibre thickening phase to lower temperatures and reduce Micronaire. Early crop defoliation or leaf removal can cause substantial reductions in fibre Micronaire due to the cessation in carbohydrate supply for fibre thickening.

Potassium deficiency can have a significant impact on fibre length because of the role of potassium in maintenance of cell turgor by osmotic regulation. Other nutrient deficiencies can also reduce fibre length. However where nutrient deficiencies are not the major factor in a production system, nitrogen or potassium fertilizer treatments will not necessarily improve fibre length.

Few agronomic or climatic conditions have been shown to consistently affect fibre bundle strength. As mentioned previously fibre strength is primarily controlled by variety. Research has shown that varities with stronger fibre are those that have larger cellulose molecules laid down.

Cotton's indeterminate growth habit also leads to many **secondary (indirect)** impacts of climate and management on fibre 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 and different tillage or rotation systems and insect damage causing compensation and later fruit production are examples. Microbial damage to the fibre can change the surface properties of the fibre reducing airflow when using HVI, causing Micronaire to be lower. Severe fibre weathering has also been known to reduce strength.

Increased trash and contamination in fibre samples can be caused by weeds or poor harvest aid management. Weeds when severe can compete with crops and also have strong effects on fibre properties through resouce limiations to the crop.

Therefore adoption of appropriate and efficient management (both strategic and tactical) for improving yield will also contribute to improved fibre quality. The issues to consider for each crop management phase are summarised in Table 7.1 and will be discussed in more detail in the following chapters.

Table 7.1: Key in-field management considerations for optimising fibre quality.

Objectives	Pre planting	Sowing to first flower	First flower to open boll	Open boll to harvest	Harvest to gin
Realising the genetic potential for fibre length	Variety selection. Strategic planning for irrigation availability. Consider skip row for dryland.	Monitor soil moisture and schedule irrigation to optimise plant vegetative size.	Monitor soil moisture schedule irrigation to optimise plant vegetative size and to avoid stress on developing fibres.		Avoid delays in harvest where rainfall can reduce grade
Maintaining fibre strength	Variety selection.		Maintain healthy crop.		
Producing fibre with mid range Micronaire to avoid fibres that have too high linear density or are immature	Variety selection.	Monitor soil moisture and schedule irrigation to optimise plant vegetative size. Sow at appropriate date for the region to avoid early crops in hot areas or late crops in cool areas.	Management of plant vegetative size, structure and balance with boll setting pattern. Uniform boll set is achieved by having the appropriate plant type for the variety, region and climate. Optimise agronomic management such as water, fertliser and growth regulators. Adopt IPM to protect fruit, and leaves.	Timely harvest to avoid bad weather. Use appropriate nitrogen fertilizer rates to match crop and fertilizer cut out. Schedule last irrigation to leave soil at refill point at defoliation. Use appropriate timing, product and rate. Refer to Cotton pest management guielines for aphid and whitefly management. Apply harvest aids at 60% bools open.	
Reducing the incidence of neps	Variety selection.				Spindles and doffers maintained daily. Reduce spindle twist by not picking too wet.
Delivering clean white cotton with no stickiness	Weed management. Optimum crop nutrition to avoid excessive growth at the end of the season.	Weed management.	Optimise timing of cutout to match season length		Picker setup – avoid pin trash and bark. Follow guidelines for module placement, construction, tarping and transport. Keep good module records.
Preventing contamination	Farm hygiene to avoid contamination during harvest. Weed management.	Weed management.			Farm hygiene. Picking height. Hydraulics on pickers and builders checked and maintained.

Fibre Quality Management and Climate – Scenarios

FIBREpak has highlighted many principles to assist in managing fibre quality. A proactive strategic plan combined with tactical management of a cotton crop will optimise fibre quality. The following three cases are examples.

Fibre Length

If fibre length is of particular concern, then variety choice and a general cropping system to avoid or minimise water stress should be employed to ensure more reliable fibre length. Cultivars with longer inherent fibre length will have more insurance to achieve base fibre length and avoid price discount. An irrigation strategy to avoid stress on developing fibres 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 fibre length. Dryland skip row configurations can increase fibre length by up to 0.08 inches compared with solid configurations.

Low Micronaire

If low Micronaire is of concern, then cultivar choice and appropriate cultivar growth habit and crop maturity for the climate and season length are important to avoid exposure of maturing fibres 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; optimised 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 minimise immature fibres. 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 0.6 b/ha for every week of earliness). In this situation, a mix of cultivars may spread risk.

High Micronaire

There is a special case for high Micronaire situations. In warm dry seasons coupled with intensive management for high yield of high retention crops such as Bt cotton has sometimes led to circumstances of high Micronaire. Analysis has indicated that management, cultivar and high temperature have been significant components of these results. 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. Micronaire is definitely a complex trait but management can address the problem at least partially. A variety with inherently lower Micronaire (preferably lower linear density and mature) is required under these circumstances. Crop management to optimise 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.

8. Pre Sowing

Pre sowing decisions for fibre quality are mainly concerned with variety selection and preparation of fields to ensure effective weed control early in crop growth to enable early crop vigour and reduce potential contamination in later stages of growth. The choice of which variety to sow is a major decision each grower must make.

Management considerations prior to sowing include:
- *Variety selection*
- *Appropriate weed control*
- *Crop nutrition management*
- *Optimising sowing date for yield and quality*
- *Establishing uniform crops at optimum plant density*
- *Skip rows in dryland production*

Variety Selection

If you start with a variety with poor fibre quality, there is nothing that can be done with management and processing to make the quality better. However, if you start with a variety with good fibre quality traits, there is some insurance against unfavorable conditions, but careful management and processing are still required to preserve quality.

Growers should use published seed company data to evaluate relative fibre properties of candidate varieties to ensure they will be optimising yield and fibre properties to avoid discounts and even attract a premium price. Discussion with seed companies on COMPARATIVE data (not only absolute values) of fibre properties for varieties and standards grown in your region will assist with these decisions.

Specific considerations for variety selection include:
- Strategic planning for irrigation water availability (including dryland) – crops with limited water availability may be more likely to encounter stress during fibre elongation, so a variety with inherently longer fibre to lessen the likelihood of fibre length discounts should be considered.

- Selecting premium fibre types – Varieties that have premium fibre attributes sometimes yield less. Growers should ensure that market premiums are negotiated and are in place to offset any potential yield reductions.

- Crop maturity – Selecting a variety with a long growing period in a cooler shorter season region is likely to create delayed crop maturity and lower Micronaire because there is a chance of immature bolls being harvested. In some instances this may be desirable to lower the overall Micronaire of a crop but this is not advisable as it may increase the level of neps. Late maturing crops may be exposed to increased chances of cotton being downgraded from weathering. Choice of variety can impact time of sowing decision. In short season regions varieties that

Photo: Adam Kay

are earlier maturing should be chosen. This offers as added insurance in ensuring the crop will mature and be harvested before the onset of cold wet conditions. In long season regions there is more flexibility. If a variety is earlier maturing (or more determinate) there is more opportunity to sow later in long season regions.

- Achieving optimum Micronaire – If crops in your region are susceptible to producing higher Micronaire, consider varieties that have inherently lower Micronaire. Similarly for short season areas, higher Micronaire varieties help to minimize low Micronaire discounts as a result of cool, cloudy, or stressed environments during boll maturation.

- In variable climates there is a dilemma in choosing a variety with higher yield potential but with greater risk of encountering unfavourable conditions during boll fill compared with an early maturing variety which may avoid late season problems, yet yield less (up to 1.8 to 2.2 bales/ha every week of earliness). Under this situation, a mix of varieties would spread risk.

Other issues to consider in variety choice that can impact fibre quality include:

- Disease that will affect healthy growth and reduce fibre maturity (lower Micronaire).
- Insect tolerant varieties (e.g. Bt Cotton) under high Helicoverpa pressure or environmentally sensitive areas. In some regions Bt cotton may be predisposed to higher Micronaire as a result of the earlier and higher fruit retention leading to more fibres thickening in warmer conditions. In addition there is less fruit maturing in cooler conditions at the end of the season thus lowering the fibre maturity of fibres which would lower (dilute) crop Micronaire.
- Herbicide tolerant varieties in weedy fields.
- Okra leaf versus normal leaf types - Okra leaf varieties are known to cause an increase in trash content as the leaf shape stops the leaf from falling easily to the ground. Approximately half a grade decrease can result. Okra leaf varieties are also more resistant to silver leaf whitefly and may have less risk of honeydew contamination (see open boll to harvest chapter).

Delayed Crop Maturity

Throughout FIBREpak reference is made to the fibre quality consequences of delayed crop maturity. This box summarises those effects:

There can be severe consequences of delayed crop maturity on fibre quality. These will include:

- A delay may mean more of the crop will be developing and maturing during cooler weather. The slower fibre thickening will result in reduced fibre maturity and risk of discount for low Micronaire. Immature fibre may be more prone to neps and is inferior for dyeing.
- The crop will be more attractive to late season pests such as aphids and whitefly which may produce honeydew, a serious contamination problem for fibre quality at the ginning and spinning stages.
- The crop may be more difficult to defoliate. This delay increases the risk of weather damage to fibre and grade reductions.
- Later maturing crops may be at increased risk of Verticillium and Fusarium Wilts, and Alternaria leaf spot if they are present. These diseases may affect yield and quality. See disease management guidelines.

Figure 8.1: Strong fibres resulting from appropriate variety selection and by avoiding situations which delay crop maturity (which may result in more immature fibre that weakens the fibre) will avoid broken fibres which lower yarn and fabric quality. (Photos: CSIRO).

Weed control

Effective control of weeds at this time and throughout the season is important as competition from weeds for water and nutrition will reduce both yield and quality, and there is also little that can be done at harvest time to reduce the consequences of poor weed control. Weeds at harvest have the potential to:

- Reduce harvest efficiency by clogging or damaging picker heads. Vines, large weeds and bulky weeds in the picker-head zone can particularly cause problems. Vines can wrap around picker spindles and bulky weeds can reduce harvest efficiency by up to 31%. Large weeds, such as large sesbania, thornapples or noogoora burrs can damage picker spindles, requiring expensive repairs and down-time
- Contaminate lint with their leaves, stems, bark and bracts, lowering grades and returns to growers. This can increase the amount of (lint) cleaning in the gin, again exposing the lint to further damage. One large mature grass plant every 6m can reduce cotton by one leaf grade.
- Reduce the effectiveness of leaf desiccant applications which may lead to increases in boll rot and a reduction in the rate of boll opening.
- When weeds are still actively growing there are increased chances of the lint being stained. These weeds can also harbour insects that contaminate or stain the lint (e.g. aphids, pale cotton stainer and whitefly).

Controlling grass species is especially important as some grass parts when crushed have similar characteristics to cotton fibres and are difficult to separate, which in turn affects the spinning quality of the fibre. Some grasses also have dark seed coats that cannot be bleached and cause disfigurements in fabric.

Figure 8.2: Herbicide damage can result in the loss of most early bolls. The crop can then be very late and have reduced fibre quality. Parrot-beaking (malformed bolls) is another common consequence of herbicide damage. (Photo: Graham Charles).

Another aspect of weed control is the potential for the weed control inputs themselves to damage the crop, affect boll retention, and delay maturity (Figure 8.2). Ideally, weeds should be well managed throughout the season. However, aggressive early season weed control with residual herbicides and inter-row cultivation can damage cotton plants and may thin the plant stand and delay crop maturity. Later in the season, many of the residual herbicides still have the potential to damage cotton plants if poorly or too aggressively applied. Herbicide damage can cause square and boll loss. The crop will normally compensate for this damage by setting additional late bolls, but there will be a delay in crop maturity and fibre quality may be reduced.

See cotton pest management guidelines for detailed information on appropriate weed control strategies and the possible consequences of herbicide damage to the crop.

Figure 8.3: Lint harvested from weedy crops can have significant impact on classing grade which affects discounts to growers and can lead to imperfections in yarn and fabric appearance. (Photos: CSIRO).

Crop Nutritional Management

Meeting the nutritional requirements of the crop is important before flowering as it is very difficult to correct nutritional deficiencies later. Nitrogen and potassium nutrition can have a significant effect on fibre quality. Excessive nitrogen affects fibre quality indirectly by causing crops to produce excessive vegetative growth, which can shed fruit or promote late fruit, delaying crops leading to more immature bolls at the time of harvest. These crops are also prone to reduced chemical penetration and are more attractive to insects (e.g. aphids and whitefly), and can be difficult to defoliate. Fibre quality of crops with nitrogen deficient conditions will be less affected as the crop compensates to support the growth of fibre on only those fruit that are present. Crops that have less leaf area, have less fruit overall.

Potassium deficiency can have a significant and direct impact on fibre length because of the role of potassium in maintenance of cell turgor pressure needed to expand the fibre. Low potassium can also cause premature senescence of leaves especially in crops with high boll loads. Leaves photosynthesise and provide carbohydrate for fibre secondary wall thickening so if they are senesced or lost, fibre maturity and thus Micronaire, may be reduced. Where nutrient deficiencies are not the major factor in a production system, potassium fertilizer treatments will not necessarily improve fibre length. Potassium deficiencies can also be exaggerated by water stress.

The best approaches to meeting the nutritional needs of a cotton crop to maintain quality are similar to that to optimise yield which include:

- Making soil nutrient applications the foundation of meeting the crop needs. This particularly relates to nitrogen, phosphorus and potassium.
- Determine residual soil nutrients from pre-season soil tests (or in the case of nitrogen estimate what has been provided by a legume crop).
- Monitoring crops using petiole and leaf analyses to peak flowering (approximately 1000 day degrees) to determine if crops are deficient or adequate in nutrition.
- Minimise pre sowing applications of nitrogen prior to May to avoid denitrification losses from the soil.
- Splitting applications of nutrients prior to flowering based on crop needs, especially when high fertilizer rates are required. Avoid high rates of nitrogen during late flowering as this may promote late season growth, delaying boll opening and inhibiting the effect of defoliation. For potassium, supplemental applications of potassium nitrate (KNO_3) can be applied as a foliar spray prior to cutout.
- Ideally completing all fertilizer applications before peak flowering.
- Considering past experience in the particular field with either rank or insufficient growth and adjust rates accordingly.

Optimising sowing date for yield and quality

Choosing the optimal sowing date for a particular region is important for both yield and fibre quality. Sowing too early can affect crop establishment during cold weather and expose the crop to disease, reducing early crop vigour. Sowing too late can mean that yields are reduced as the length of season to grow cotton is reduced as well as delaying crop maturity.

Considerations for establishing the optimum sowing date for your region include a number of factors:

- Season length - This should be considered as it helps to determine how long a crop can be grown and whether there is flexibility in changing sowing date. Short growing seasons such as those experienced in southern and eastern growing regions should consider sowing as early as feasibly possible to avoid crops maturing and being harvested in cold wet conditions. Current recommendation for sowing a crop that avoids emergence and establishment problems is to aim to have soil minimum temperatures above 15°C at 10cm depth for three consecutive days prior to planting and no cool weather predicted for at least 2 to 3 days. In regions with longer season lengths there is some flexibility to sow later, but consideration of some other factors described below are needed. In short season areas it would be advisable that crops be sown by mid October regardless of soil temperature.

Significant variation exists across the industry when comparing temperatures at both the start and finish of the season (Figure 8.4). While sometimes crops can emerge when sown early, on average the cooler temperatures especially in more southern regions do not translate into an earlier first flower date (Figure 8.5).

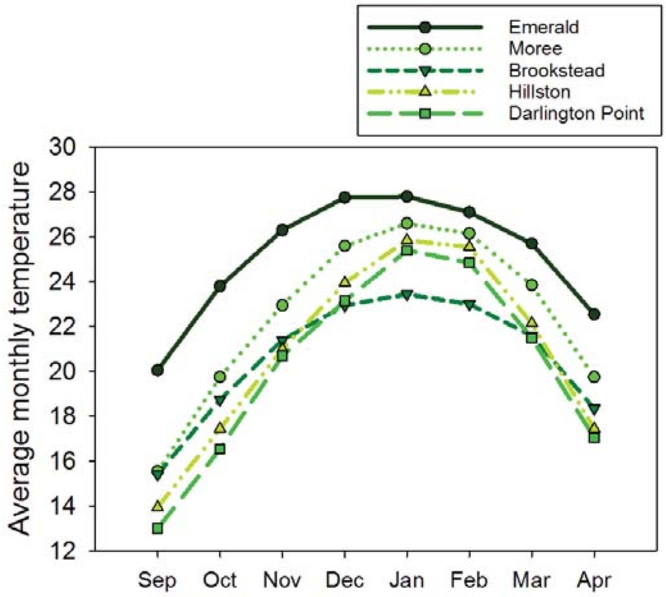

Figure 8.4: Temperatures vary considerably across the industry both at the start and the end of the season. These differences can impact crops when sown and harvested. (Source: Bureau of Meteorology).

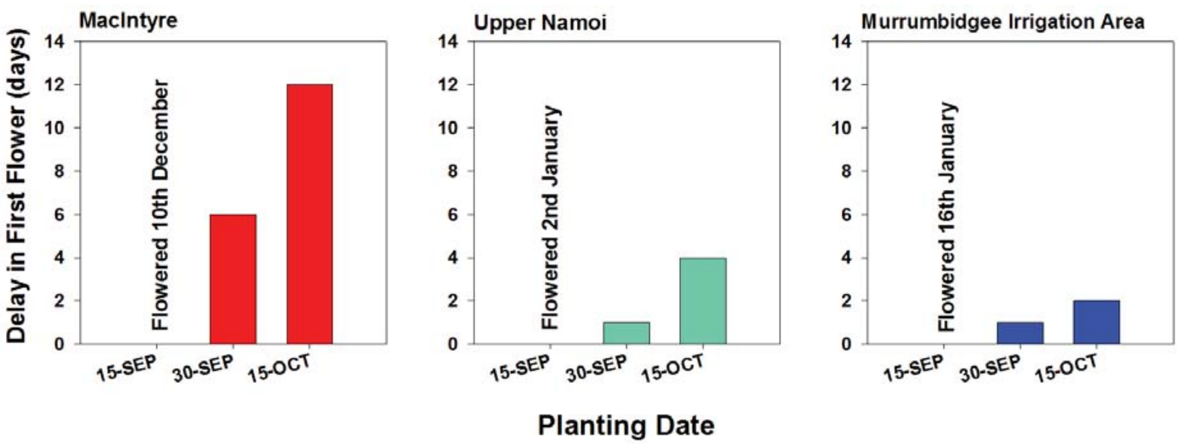

Figure 8.5: Based on historical climate data the estimated average date of first flower based on a sowing date of the 15th September in three cotton regions and the average delay (in days) compared to the 15th Sep. for the 30th Sep. and the 15th Oct. Warmer temperatures with these later sowing times in the more southern regions have little effect on the delay in first flower date. Note that this analysis does not account for crops that can fail to emerge when sown on the 15th Sep.

- Climatic conditions experienced during fibre development – a number of climatic factors (predominantly temperature) will affect fibre length after flowering and fibre maturity during the period mid to late boll filling. Changing the time of sowing will influence the time and thus the climatic conditions experienced during fibre development. High temperatures after flowering have the potential to reduce fibre length. During boll filling, long periods of hot conditions will predispose the crop to high fibre Micronaire; conversely long periods of cool temperatures may lead to low Micronaire. Changing the sowing date in some regions (e.g. those with a long growing season) may offer some insurance against these situations occurring (Figure 8.6).

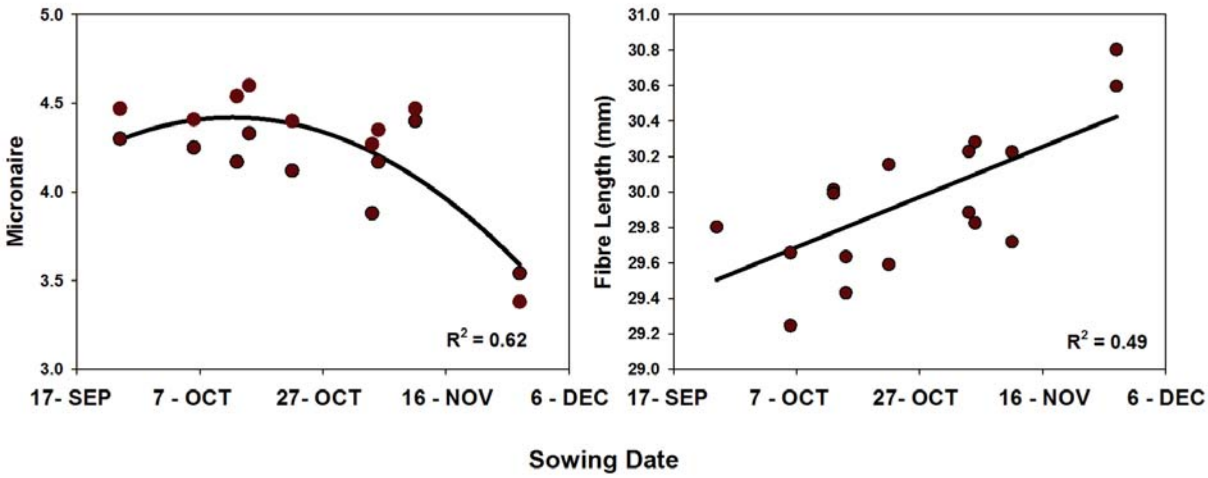

Figure 8.6: Effect of sowing date on fibre quality. Data from three seasons at Narrabri. (Adapted from Bange et al. 2008).

- Fruit Retention – research has shown that changes in fruit retention that results from the use of Bt cotton can influence the time of sowing response. Results showed that Bt cotton maintained its yield through the shorter fruiting cycle (because of its consistent and higher earlier fruit retention) allowing time to support growth of the same number of bolls as earlier sowings. In comparison, non-Bt Cotton varieties had lower yields with later sowings. Yields were also maintained with later sowings (see Figure 8.7). With the advent of Bt cotton with its higher fruit retention, sowing date needs to be reviewed for all long season growing regions that offer an opportunity to maintain yields while improving fibre quality.

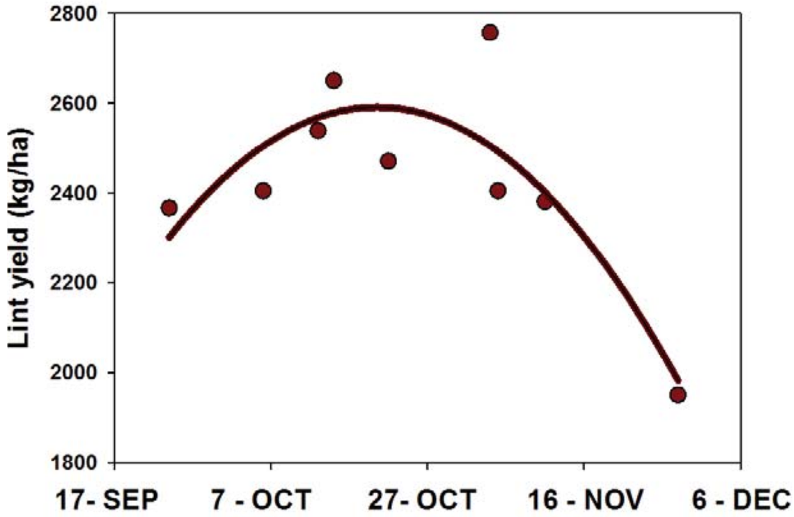

Figure 8.7: Effect of sowing date on lint yield of Bt cotton varieties. Data from three seasons at Narrabri. (Adapted from Bange et al. 2008).

Establishing uniform crops at optimum plant densities

Low plant densities (especially non-uniform densities) can delay crop maturity and contribute to variable fibre properties. Uniform establishment is achieved by preparing an adequate seed bed, choosing the appropriate sowing date to optimise soil temperatures, avoiding disease and herbicide damage, and fertiliser toxicity (such as anhydrous ammonia placed too close to seed line) of young seedlings. Use of good-quality seed will also assist with uniform establishment.

Extremely high plant densities may aggravate fruit shedding of squares and subtending leaves, affecting crop maturity. In addition lower bolls also become vulnerable to shedding due to excessive shading. It is not uncommon for some plants in very high densities to be barren of fruit. Even bolls that are retained will not develop properly and will be undersized which will affect yield and fibre maturity. Thick stands are also vulnerable to boll rot. If these instances can be predicted, a growth regulator can be used (see chapter sowing to first flower).

Specific sowing considerations include:

- Narrow row production systems (including 75cm and 38cm row spacings) have not shown any advantages in terms of fibre quality.
- In irrigated cotton, target 8 to 10 plants per metre of row except where soil type restricts plant size. In these situations a density of 12 plants per metre of row is suggested. Research has shown that irrigated cotton has the flexibility of producing similar yields from 4 to 16 plants per metre provided the plants are distributed uniformly.
- In dryland production the recommended plant population in all row configurations is 7 to 8 plants per metre of row.

Photo: (Warwick Stiller, CSIRO)

- Evenness of stand is more critical than absolute population achieved. A gappy stand is considered one that has an average of two or more gaps greater than 50 cm in length every 5 m of row. A gappy stand is difficult to manage due to the large range in plant size especially with those plants with large vegetative branches - and yield reduction and delayed crop maturity may result. Consider re-sowing if the cost is less than the loss of yield potential of the replanted crop.
- Assess factors that influence plant establishment so that appropriate sowing rates can be estimated. Factors that influence final establishment include: watering up vs. pre watering, soil type, stubble type and amount, soil tilth, sowing equipment, presence of insects (such as wireworm and cutworm), weeds, disease history, soil temperature, seed vigour and expected weather conditions post sowing.

Consider skip row configurations in dryland and limited water situations

In situations where there is a high chance of a sustained dry period early in flowering, the use of skip row configurations (Figure 8.8) are a viable option to maintain fibre length (Figure 8.9).

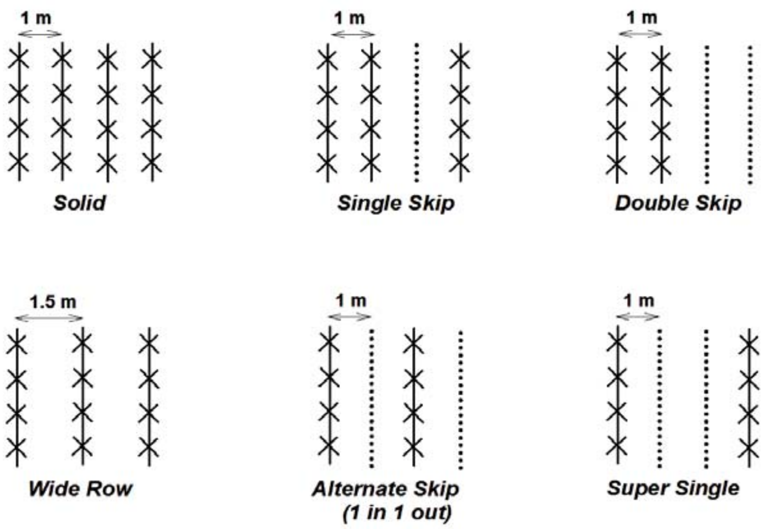

Figure 8.8: Diagrammatic representation of a range of alternative row configurations used in rain-fed cotton production. Solid lines represent rows with plants present, while dotted lines represent skipped rows.

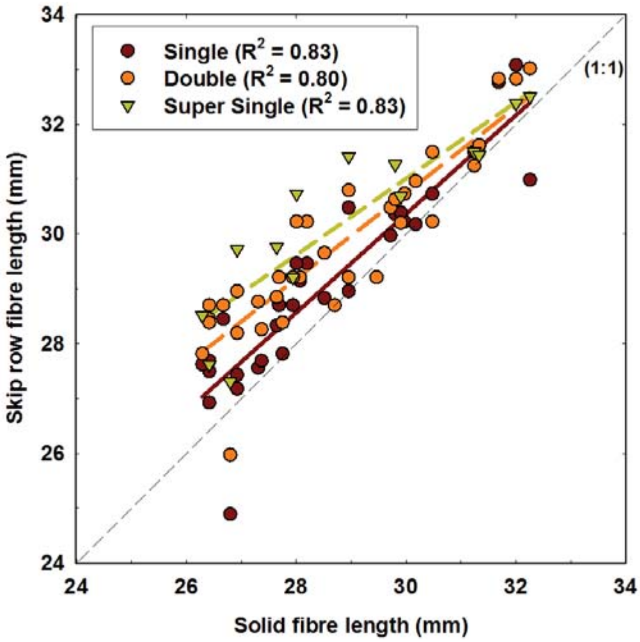

Figure 8.9: Measured fibre length of skip row configurations compared with solid row configuration in dryland cotton systems. As points approach the 1:1 line fibre length of the skip configurations equals that of the solid row configuration. (M. Bange, CSIRO). Note that the wider the configuration the higher the average fibre length.

Further Reading

Bange MP, Roche R (2008) Do sowing rules change for high fruit retention transgenic cotton? In Proc. 14th Australian Agronomy Conference, 22-24 September 2008, (Adelaide, South Australia).

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9. Sowing to First Flower

Although the crop growing during this period is a considerable time away from producing fibre, there are a number of management decisions made now that can significantly influence fibre quality. Principally the decisions affecting quality between sowing and first flower relate to optimising vegetative growth and development that enables the crop to support fruit retention and help bolls and fibres to develop without stress. Management considerations from sowing to first flower include:

- *Monitoring and managing plant size with adequate moisture and nutrition so that crops are in a position to support later fruit growth.*
- *Avoiding herbicide or insect damage that may delay crop development affecting the time of crop maturity.*
- *Maintaining weed control to avoid plant competition and contamination.*

Managing plant size to support later fruit growth.

Managing early growth is important for fruit retention, and for later boll and fibre development. Adequate vegetative growth lays the cornerstone for sustained boll growth and fibre development in later weeks. During the pre-flowering period plant monitoring should focus on plant vigour and square retention. This is especially important for short season areas so that crop maturity is not delayed. In long season growing regions it is important to have a crop with adequate vegetative growth and leaf area to avoid early cut out, especially when fruit retention may be high (e.g. Bt cotton crops).

While vigour and growth characteristics will vary between varieties, plant height and node spacing are good indicators. Plants that are short may have been exposed to stresses such as water, salinity, nutrient deficiency, cold, soil compaction, disease or insect damage. Accurate diagnosis of the cause of inadequate growth is necessary to take the appropriate corrective action.

Photo: (Sandra Williams, CSIRO)

Excessively tall plants are often associated with poor retention in combination with luxurious moisture and nutrition and in high plant populations. Too rapid growth has the potential to cause self shading and limiting yield by causing squares to shed and delay boll set. Continued shedding from the bottom of the plant can delay crop maturity. In these instances where it is predicted there will be too much vegetative growth it may be necessary to use a growth regulator. Monitoring crop growth at this stage includes recording node number, square number and plant height.

Node Development

Monitoring node development is useful to determine whether crop development is matching its potential and may enable identification of sluggish crops which need to be encouraged. Delays in node development can be a result of plant stress due to insufficient water, nutrition or tipping out. Monitoring node development is also useful for calculating the vegetative growth rate (discussed below).

Square Number

Monitoring square numbers helps to ensure that plant growth is translated into fruit production (bolls) that will help attain yield (Figure 9.1). Tracking square numbers can help to anticipate high or early fruit demands, indentify if there has been fruit loss associated with shedding from water stress, lack of nutrition, or insect damage.

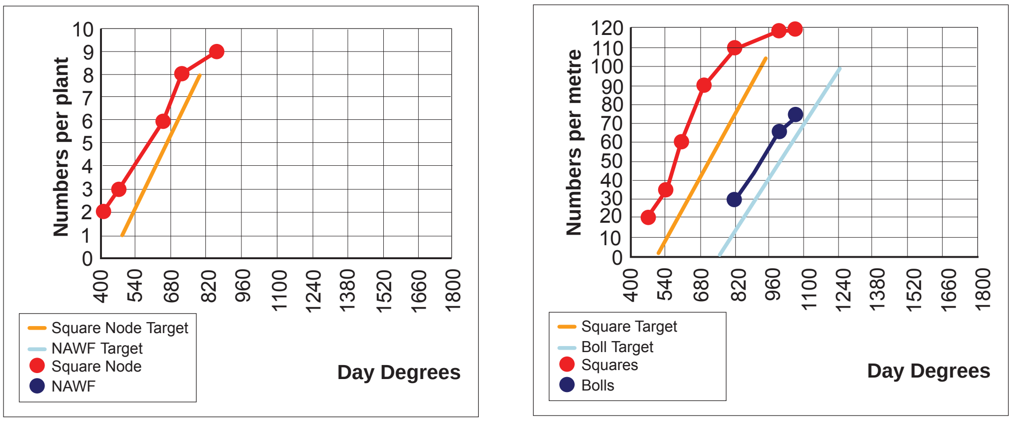

Figure 9.1: Examples of squaring node development and fruit development. The aim in crop managment to optimise yield is to maintian rates with the target rates.

Vegetative growth rate (VGR)

Monitoring plant height in conjunction with node development is used to calculate vegetative growth rate (VGR). VGR (cm/node) is the rate of change of plant height relative to rate of node development and is indicative of crop vigour:

$$VGR = \frac{\text{This week's height - Last week's height}}{\text{This week's nodes - Last week's nodes}}$$

Measurements should be started before first flower, i.e. around 10 mainstrem nodes. The monitoring should continue until mid flowering as rapid increases in growth rate can occur at anytime in this period. To monitor VGR, follow these steps:

1. Measure plant height (in cm) from the ground to the growing point of the main stem (not to the end of the top leaf).
2. Count the number of nodes from the cotyledons (numbered 0) to the top node that has a fully unfurled leaf.
3. Measure the plant height and count the total number of nodes on at least 20 randomly chosen plants.
4. Carry out the same procedure one-week later and then use the VGR formula to calculate the rate of internode increase, measured in centimetres per node.

High VGRs (greater than 5.5) can indicate rank growth and may need to be contained using plant growth regulators such as Mepiquat Chloride (e.g. Pix) that decrease the rate of increase in leaf area or restrict additional plant height increases. Mepiquat Chloride inhibits the development of a plant hormone gibberellic acid (GA) which has a significant role in cell expansion (leaf cells or lint fibres). Because gibberellic acid is needed in other plant growth processes complete inhibition of the hormone is not desirable and therefore the rate of Mepiquat Chloride is also important. Too high or too low rates can result in too little or too much plant control. Other factors that need consideration before growth regulator application at this stage include crop variety, climatic conditions, crop moisture status, and the level of fruit development (Figure 9.2).

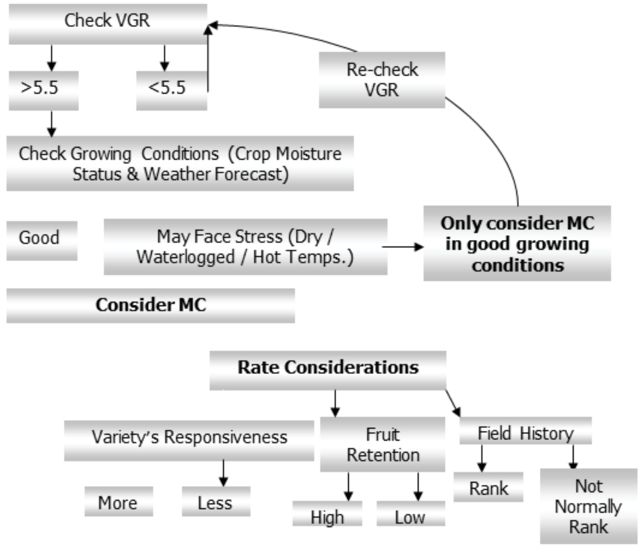

Figure 9.2: Considerations when choosing use and the rate of growth regulator (MC) around flowering.

Practices that can be implemented to optimise plant size also include managing soil moisture and crop nutrition which are now discussed.

Crop Nutritional Management

Nutrition principles were specified in the pre-sowing chapter and points of most relevance to the sowing to first flower phase are:

- Monitoring crops using petiole and leaf analyses to peak flowering (approximately 1000 day degrees).
- Splitting applications of nutrients prior to flowering based on crop needs, especially when high fertilizer rates are required. Avoid high rates of nitrogen during late flowering as this may promote late season growth, delaying boll opening and inhibit defoliation.
- For potassium, supplemental applications of potassium nitrate (KNO_3) can be applied as a foliar spray prior to cutout.
- Ideally completing all fertilizer applications before peak flowering.
- Consider past experience in the particular field with either rank or insufficient growth and adjust rates accordingly.

Crop Irrigation Management

Irrigation management to optimise yield will generally also optimise fibre quality.There are two occasions where fibre quality should be considered f or irrigation scheduling decisions:

- The time leading up to first flower for at least the next four weeks is critical for realising potential fibre length (refer to chapter on fibre biology). During this time, scheduling should particularly be aware of heat waves and bring forward irrigation as necessary.
- The timing of last irrigation is challenging, especially during variable weather conditions. The aim should be to have the soil at normal refill point at defoliation. The impact of late water stress will depend on the exact timing, duration and extent of stress. This is discussed in more detail in the open boll to harvest chapter.

Figure 9.3: Excess nutrition available to the crop requirements can lead to problems with defoliation and regrowth resulting in excess trash at harvest.

Avoiding herbicide or insect damage that may delay crop maturity

The main consequences of herbicide or insect damage during this phase of growth on fibre quality relate to delays in crop maturity (see details in previous chapter). This is a more important issue for short season growing regions than for full season locations. For insects pests good IPM strategies should be implemented, including effective pest sampling, control at appropriate pest thresholds, and conservation of beneficial insects. This will avoid unnecessary pesticide applications while also avoiding delay in maturity or yield loss.

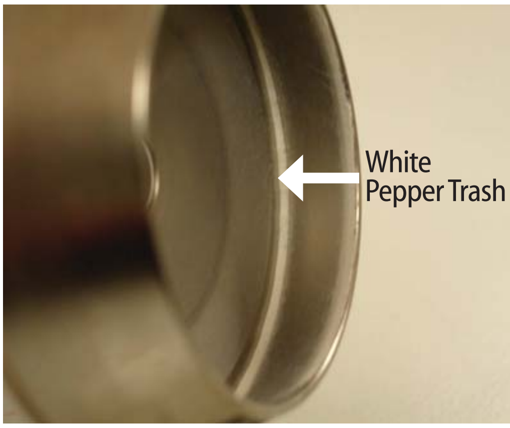

Figure 9.4: Avoiding regrowth will assist defoliation and thus limit lint cleaning in the gin, which shatters and pulverizes large leaf trash into pepper trash. Photo shows a rotor in a spinning mill that has accumulation of (white) pepper trash in rotor groove from trashy cotton. Yarn structure and volume is determined by the shape of the rotor groove. A contaminated rotor groove leads to poor yarn quality and reduced spinning efficiency.

Further Reading

CRDC (2012) 'WATERpak a guide for irrigation management in cotton and grain farming systems'. 3rd edn. (Cotton Research and Development Corporation: Narrabri, NSW). p. 495.

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10. First Flower to Open Boll

This period is the critical phase for developing cotton fibres. As flowers are setting, fibres lengthen and as bolls grow fibres thicken (mature) by laying down cellulose in the secondary wall of the fibre leading to differences in Micronaire. Fibre lengthening is highly influenced by temperature and crop water availability, while fibre thickening leading to differences in micronaire is influenced by the amount of cellulose production affected by photosynthesis which is affected by temperature (see Figure 10.1) and solar radiation (cloudiness), as well as internal competition from bolls on the plant.

There are instances where too many bolls on a plant lead to lower fibre maturity, because of the increased competition between bolls for photoassimilate. Therefore the decisions that affect the availability of resources for growing fibres during this period are important to realise the potential fibre quality attributes of a variety. It is important to maintain a healthy crop whilst maintaining the balance of plant vegetative size with a uniform boll setting pattern.

Management considerations from first flower to open boll are:

- *Avoiding water stress on developing fibres by monitoring the crop or soil moisture carefully.*
- *Maintaining a uniform boll setting pattern through crop monitoring to optimise Micronaire.*
- *Optimising the time of cutout so that crops mature at the appropriate time for local conditions and to maximise yield potential.*

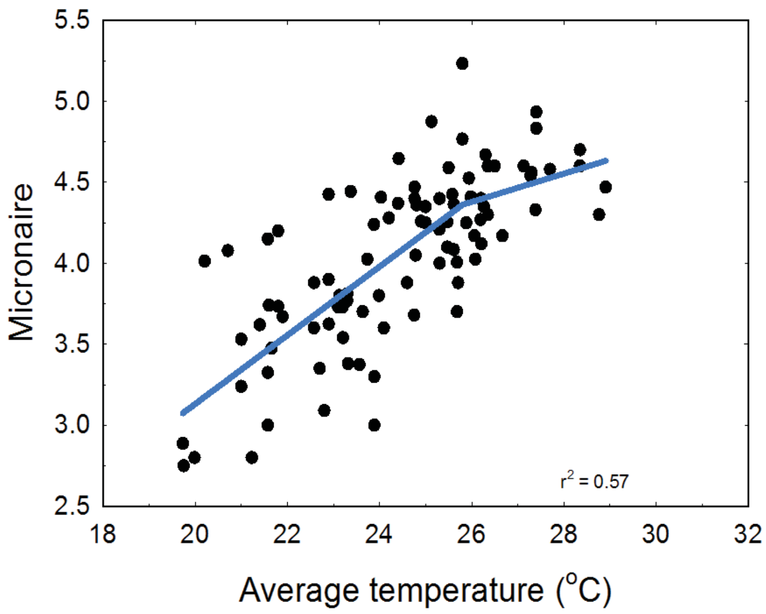

Figure 10.1: The influence of mean daily temperature during the peak boll-fill period on Micronaire. Data collected from a range of varieties grown over the whole of the cotton industry. From Bange et al. (2010).

Avoiding water stress on developing bolls

The impact of late water stress will depend on the exact timing, duration and extent of stress. Generally boll sizes will be reduced rather than resulting in a significant reduction in boll numbers. This can reduce yield and can also reduce Micronaire, but cause little effect on fibre length. A longer duration of stress approaching cutout will cause shedding of later bolls reducing potential yield. The crop Micronaire may be maintained because of the loss of bolls which may have subsequently had low Micronaire. In large vegetative crops that are stressed prior to boll opening, both boll size and number can be reduced, with significant reduction in yield and fibre quality. Use of appropriate irrigation scheduling practices to avoid stress will help to optimise yield and quality.

Maintaining a uniform boll setting pattern through crop monitoring to optimise Micronaire

A critical management concept is the need to balance 'sinks' with 'sources'. Sinks are where resources are utilised (e.g. growth of the fibre and boll), and sources are what provides the resources (e.g. leaves). The balance of sinks to sources on a plant comes from differences in green leaf area to the yield potential (number of bolls). To sustain boll and fibre production (the sinks) cotton needs a canopy of young healthy leaves that are illuminated by the sun to sustain photosynthesis. From a fibre development perspective changes in the relationship between canopy leaf area and boll number affect the maturity (thickness of the secondary cell wall) of developing fibres leading to differences in Micronaire.

For example if boll load is strong (high boll number) on a crop growing with a small canopy there will be strong competition for resources between bolls resulting in less resources for each boll for secondary wall thickening. This results in lower fibre maturity and Micronaire (see Figure 10.2). Conversely if boll load is small on a canopy that is large and actively growing, there is a chance that fibre maturity and Micronaire will be high as there are plentiful resources for each individual boll for secondary wall thickening. Therefore there is a need during this growing period to assess both boll loads and plant size and growth.

Uniform boll setting is also important in balancing the quality of the lint harvested. Micronaire values are generally highest in the middle branches and decline in the top bolls. If, for example, early and late fruit are lost this may pre-dispose crops to higher Micronaire. A reasonable Micronaire can therefore be achieved by harvesting bolls from all nodes on the plant. This also applies to other quality attributes such as: fibre length (shorter from lowest to highest fruiting branch); for neps (highest with top bolls); and for colour grade (best in the middle of the plant).

Immature cotton fibres with low Micronaire (associated with maturity ratios less than 0.85) will dye a lighter hue and will abrade more readily and give a poorer appearance. Micronaire is generally associated with immature fibre (see chapter 3 on fibre biology for definitions). (Photos: CSIRO).

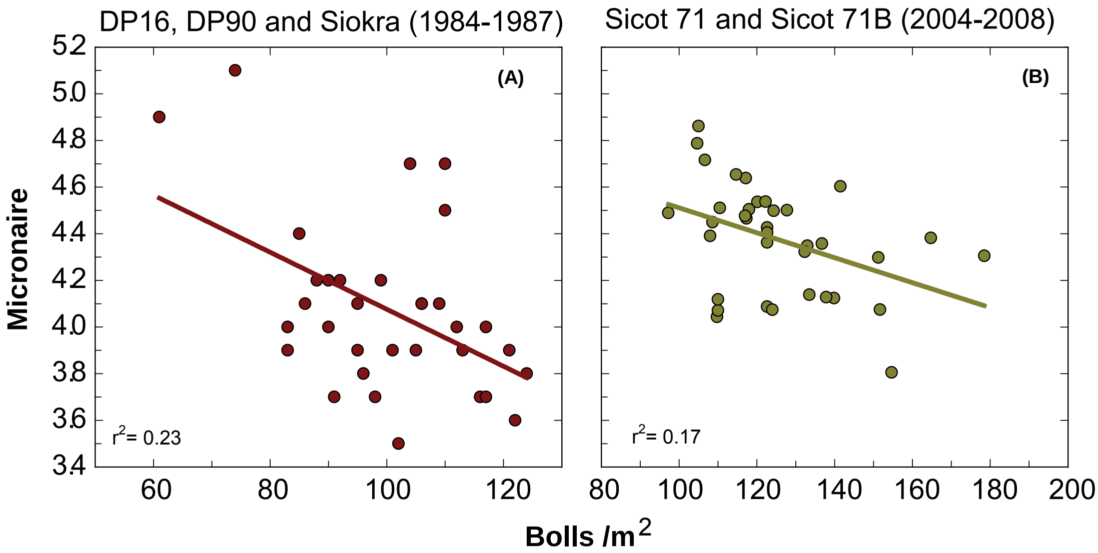

Figure 10.2: Relationship of Micronaire to boll load (bolls/m^2). Fewer bolls per metre trends towards higher Micronaire. (A) Study done in mid 1980's by Brook et al. (1992) (CSIRO Plant Industry) in Namoi Valley which involved manual fruit removal treatments. (B) Data from CSD segmented picking projects in 2004-05 and 2005-06, 2006-07 and 2007-08 which involved sampling commercial crops across many growing areas (Kelly et al. 2008).

Figure 10.3: Crops that have small plant sizes with high boll loads are susceptible to premature senescence which can lower Micronaire. Many factors which influence plant size (e.g. soil compaction, crop water status, crop nutrition) need to be carefully planned and assessed to avoid these situations (Photo: Robert Eveleigh, CSD).

High boll load, small plant

Under these circumstances, there is a need to maintain healthy leaves with appropriate nutrition, water (see above) and pest management to avoid low Micronaire. Monitor and control major pests such as mites and aphids that can significantly affect leaf photosynthesis (Figure 10.3). It will also be important to monitor these crops to avoid early cutout (see next page).

Low boll load, large plant

These circumstances may arise from effects of water or temperature stress or insect damage and there is a need to restrict vegetative growth with growth regulators, water and crop nutrition as soon as possible to avoid generating excessive resources for fibre growth that will lead to high Micronaire. At the same time it is important to encourage growth of new fruit while protecting existing with appropriate pest management. This will help build sinks that help to reduce Micronaire and restrict further rank growth. Major pests to monitor that will directly affect boll number include mirids, Helicoverpa, and green vegetable bug (GVB). There are also instances in dryland crops where high Micronaire can also occur when there has been significant fruit loss due to early water stress and the crop regains ability to grow due to renewed access to water and nutrition.

To assist in managing vegetative growth in balance with boll setting pattern during this growth phase monitor: vegetative growth rate (VGR – see sowing to first flower chapter); boll numbers and retention; and how the crop is progressing towards an appropriate cutout date for the particular region (see below).

Decisions on whether to apply growth regulators should be tempered with information on fruit loads and retention.

For further information on pests and their control refer to the cotton and pest management guidelines.

Optimising the timing of cutout

Cutout is the point at which the crop ceases to produce new fruiting sites (squares). The timing is important as it influences the time when the crop matures. Later cutout means later maturity. Timing crop maturity has important implications for maintaining quality by ensuring a timely harvest to avoid adverse weather conditions; ensuring that defoliation practices are effective to reduce trash; and avoiding instances where there are too many immature bolls that may increase incidences of neps. However as the timing of cutout is directly related to the timing of crop maturity it can also significantly effect yield. Early cutout, like early crop maturity, may reduce yield. Therefore the timing of cutout (resources permitting) must balance the opportunity for further fruit production, that contributes to yield, with potential losses in fibre quality and harvesting difficulties.

The latest cutout date that optimises yield and quality allows the squares and bolls on the plant at cutout to mature and open, and to be harvested before cool and wet weather (see chapter open boll to harvest on harvest timeliness risks). This time can be estimated by predicting the date when the last effective square is produced, leading to the last effective flower. This date can be estimated using the date of first frost (see Table 10.1) or using the date when bolls are expected to be open ready for harvest. The last effective flower date should approximately coincide with when Nodes Above White Flower (NAWF) equals 4. When a crop reaches this point it has attained 95% of it harvestable yield. The use of NAWF as a monitoring tool for managing cutout is discussed below.

Table 10.1: Dates of last effective square and flower for various regions estimated by assuming boll growth ceasing at first frost at the end of the season (minimum 2°C measured in a screen).

Location	**Last Effective Square**			**Last Effective Flower**		
	Earliest	Average	Latest	Earliest	Average	Latest
Emerald*	11 Feb	21 Feb	7 Mar	11 Mar	24 Mar	4 Apr
Dalby	3 Jan	26 Jan	10 Feb	7 Feb	1 Mar	18 Mar
St George	24 Jan	10 Feb	22 Feb	22 Feb	11 Mar	23 Mar
Goondiwindi	18 Jan	3 Feb	14 Feb	17 Feb	6 Mar	19 Mar
Moree	10 Jan	28 Jan	15 Feb	12 Feb	28 Feb	16 Mar
Narrabri	6 Jan	27 Jan	13 Feb	9 Feb	27 Feb	15 Mar
Gunnedah	2 Jan	21 Jan	5 Feb	7 Feb	23 Feb	11 Mar
Bourke	27 Jan	7 Feb	18 Feb	24 Feb	8 Mar	18 Mar
Warren	31 Dec	22 Jan	6 Feb	6 Feb	22 Feb	9 Mar
Hillston	27 Dec	16 Jan	27 Jan	28 Jan	16 Feb	27 Feb
Griffith	20 Dec	9 Jan	28 Jan	11 Feb	29 Jan	1 Mar

*Frost only recorded on 20 occasions since 1957

Monitoring the timing of cutout

The timing of cutout can monitored using NAWF (see Figure 10.4) and be managed by fruit load, irrigation and nutrient management or utilising a late season application of a high rate of Mepiquat Choride®.

Crops approaching cutout (NAWF=4) too rapidly can indicate plant stress due to insufficient water and nutrition, early fruit development or high fruit loads. Management strategies in these instances can include providing irrigation or nutrition to resolve stress and/or to promote vegetative growth. The strategy of promoting new growth must consider if there is time remaining to mature bolls by considering the time of last effective flower.

Crops that that are slow in approaching cutout can indicate loss of bolls (physiological shedding or pest pressure), or continued plant growth due to on-going availability of water and nutrition. If fruit loss is suspected, measure fruit retention, and monitor VGR and apply Pix if necessary. If crops are continuing to grow and the time of last effective square and flower have passed consider extending irrigation intervals and using a late season, high rate growth regulator application to restrict further vegetative growth, induce cutout and avoid immature bolls at harvest.

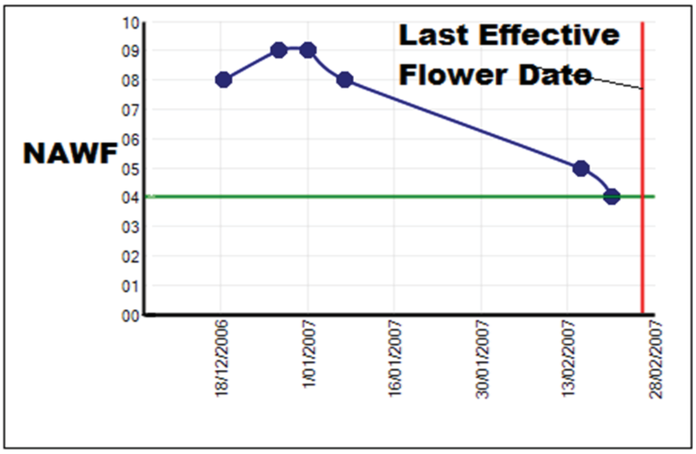

Figure 10.4: Monitoring nodes above white flower (NAWF) in conjunction with the timing of last effective square and flower is useful in determining whether crops are approaching the most appropriate time for cutout (NAWF=4). This example shows that the crop is potentially 'cutting out' too early and limiting yield for the particular region. Red line is the last effective flower date.

Figure 10.5: Tagging flowers around cutout will assist in identifying bolls that are most likely to be mature at harvest.

Bolls produced after the optimum cutout date may not contribute greatly to yield or quality. Along with monitoring NAWF it may also be useful to identify fruiting branches (with ribbons or tags that can be removed prior to harvest) that produced the last effective flower (Figure 10.5). This will assist in ensuring that bolls produced on fruiting branches above this marked position are not included in assessment of harvest aid timing decisions.

Late season growth regulator application

The application of high rates of growth regulator late in the season has become a common practice in many cotton growing regions.

The aim is to assist cessation of production of late vegetative growth (and unnecessary late fruit). The application growth regulator is unlikely to have a negative effect on fibre quality and yield, and may help reduce neps in late crops that would have produced immature bolls. The practice can also reduce risk of providing late season food source for insect pests. Decisions on cutout application of growth regulators (Figure 10.6) are based on:

- Attainment of target boll numbers;
- Resumption of unnecessary late vegetative growth or fruiting; and
- Reaching last effective square or flower date for the region.
- Ensuring that the crop will not endure significant stress following application of the growth regulator as the combination may reduce yield substantially more than the effect of the stress alone.

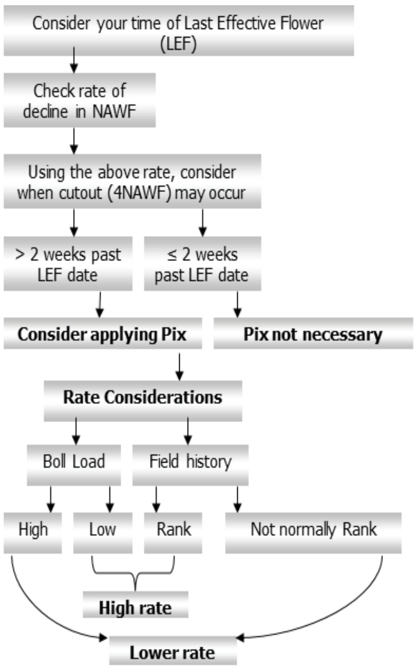

Figure 10.6: Considerations when choosing use and the rate of growth regulator (MC) for application at cutout.

Further reading

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11. Open Boll to Harvest

Ceasing crop growth for a timely harvest involves a number of important decisions. Late flowering and especially regrowth will cause fibre quality problems directly which will be reflected in reduced Micronaire and increased neps, and indirectly with poorer grades. Delayed harvests also expose clean lint to increased chances of weathering. Humid conditions or rainfall increases microbial damage thereby potentially reducing colour grades. Poor and untimely defoliation can have a significant impact on fibre maturity as well as the amount of leaf trash.

Management considerations from open boll to harvest include:

- *Appropriate irrigation management for finishing the crop and avoiding regrowth.*
- *Managing aphid and whitefly infestations to avoid sticky cotton.*
- *Accurately determining crop maturity.*
- *Ensuring timeliness of harvest operations to avoid wet weather.*
- *Effective application of harvest aids.*

A perfect system to attain the highest quality cotton would be to have a field with 70-80% mature bolls, generated from uniform flowering and boll retention resulting in an abrupt cutout that had ample water and nutrition to meet only those requirements of the fruit present at cutout. Leaves would have matured naturally and allowed for easy defoliation at an appropriate time when temperatures were warm. The crop would be ready to harvest when the chances of rainfall were small.

Irrigation management for finishing the crop

Crop management to synchronise crop maturity dates and harvesting operations with climate and weather is one aspect of timeliness. Excess nitrogen rates (see sowing to first flower chapter) or events which cause late regrowth (e.g. excess soil moisture at harvest) can interfere with defoliation practices and picking. Therefore fibre quality can be reduced as lint can be stained by the soft regrowth and additional moisture can be added to modules which promote rot and increase risk of module fires (chapter 12). Substantial amounts of leaf trash increases the need for additional lint cleaning in the gin that can further damage the fibre (see post harvest chapter). Delayed growth may also mean that fibre development may also occur in cooler weather (reducing fibre maturity lowering Micronaire).

Unnecessary and late season growth also supports late season insects which can damage yield and quality by feeding on developing bolls (Helicoverpa) and secreting honeydew that can cause stickiness (whitefly and aphids). In wet or humid weather leafy crops may also contribute to boll rot.

The timing of last irrigation is a balance between ensuring that (1) there is enough moisture to allow the growth and maturity of harvestable bolls, and (2) that fields are dry enough to assist defoliation, limit regrowth, and minimise picking delays and soil compaction. The moisture required for late crop growth is related to the time of defoliation. The broad aim is to have soil moisture levels to refill points by defoliation.

Determining end of season crop water requirements

End of season water requirements can be estimated from the date of the last effective flower which is when the Nodes Above White Flower (NAWF) measurement is equal to 4 (see chapter 10). The last harvestable bolls takes approximately 750 degree days to reach crop maturity. Therefore for crops in some regions to be defoliated towards the end of March, the last effective flower needs to occur in the last week of January. Crop water use needs to be considered for this period. At the time of first open boll, crop water use may be 5-7 mm per day and may decline to around 4 mm per day prior to defoliation.

Factors to consider:
1. Days to defoliation
2. Boll maturity rate
3. Crop water use
4. Plant available water - ability to extract water below normal refill point
5. Soil moisture objective at defoliation

Days to defoliation (general example - need to generate values for local district):
- Defoliate when Nodes Above Cracked Boll (NACB) is equal to 4 (see next section on determining crop maturity).
- Takes 42 degree days, around 3 days (up to 4 days in cooler regions) for each new boll to open on each fruiting branch.
- (Total NACB minus 4) multiplied by 3 = days to defoliation.
- Aim to be at or close to refill point at time of defoliation.

Two examples are listed below on final water requirements (Table 11.1).

Table 11.1. Determining the timing of last irrigation. If refill the deficit for the particular soil is 70 mm

	Crop A	Crop B
Total fruiting branches	13	13
% open bolls	25-30%	Zero
NACB	9	13
Days to defoliation	(9-4) x 3	(13-4) x 3
(NACB = 4) estimate	15	27
Estimated daily water use until defoliation	5 mm/day	5.5 mm/day
Total water requirement	(5 x 15) = 75 mm	(27 x 5.5) = 148 mm

Crop A Irrigate now? - This will depend on the capacity of the crop to extract moisture below its normal refill point. If the crop can extract moisture to 90 mm, at the end of the season, and there is 35 mm (half a profile) of available water still in the profile, irrigation may not be necessary. However if the crop can not extract below 70 mm, an irrigation may be recommended (even if there is 35 mm left in the profile).

Crop B Requires close to two full irrigations - Rainfall needs to be considered in such decisions (a rainfall efficiency of 40-50% should also be considered).

Determining crop maturity

Sampling to assist in the determination of crop maturity needs to be conducted on plants that are representative of the crop. Methods include:

% bolls open – Crops can be safely defoliated after 60-65% of the bolls are open. This is a useful method to track how quickly a crop is approaching maturity. This method is simple and works well in crops with regular distribution of fruit. However, if the distribution is not regular e.g. a fruiting gap, then this technique is not accurate as fruit from the top of the crop will be more immature compared to those from a plant that contains no fruiting gap. Similar issues can occur with gappy stands where there are vegetative bolls of varying ages.

NACB (Nodes Above Cracked Boll) – In most situations 4 NACB equates to the time when the crop has 60% bolls open (Figure 11.1). This is a useful methodology on crops that are uniform in growth, and is less time consuming than % open bolls; therefore a greater sample size can be taken. NACB are recorded as the total number of main-stem nodes between the uppermost harvestable boll and the highest first position cracked boll. A cracked boll is one that has sutures on the boll allowing the cotton inside the boll to be visible

Boll cutting – The easiest and probably the most effective method to determine if bolls are mature or immature (Figure 11.2). It can be used effectively even when crops are not uniform (e.g. tipped out plant, gappy stands). Bolls are mature when: they become difficult to cut with a knife; the seed is well developed (not gelatinous) and the seed coat has turned brown; and when the fibre is pulled from the boll it is stringy (moist but not watery).

Specific considerations include:

- Consider only monitoring bolls that will be harvested.
- Consider a range of approaches especially if the crop has non-uniform maturity.

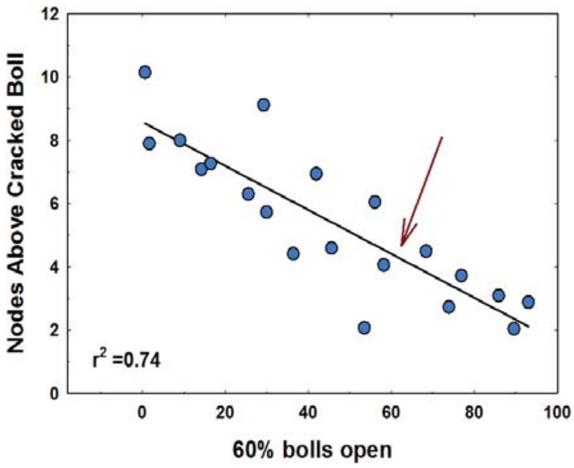


Figure 11.1: Relationship of Nodes Above Cracked Boll (NACB) versus 60% bolls open. Note 4 NACB approximates to 60% bolls open (red arrow). (Adapted from Bange et al. 2010).

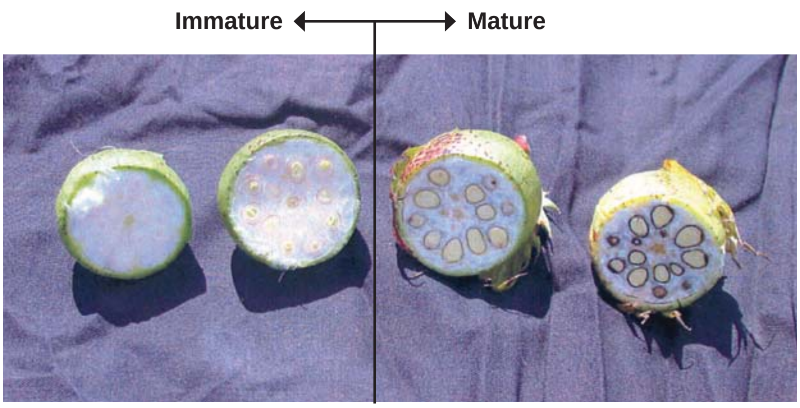
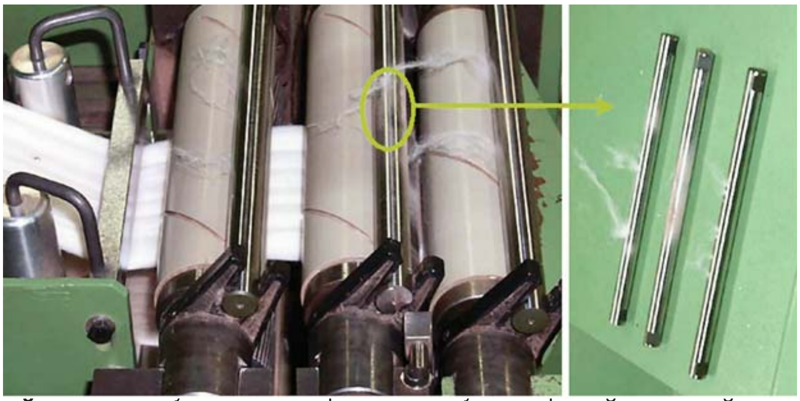


Figure 11.2: Bolls that are mature have seed coats that are turning brown. (Photo: courtesy Cotton Seed Distributors).

Managing Aphid and Whitefly Infestations to avoid sticky cotton

Sticky cotton is a major concern for spinning mills. Physiological plant sugars in immature fibres, contaminants from crushed seed and seed coat fragments, grease, oil and pesticide residues are all potential sources of stickiness. A significant proportion of all cases of stickiness are attributable to honeydew exudates of the silverleaf whitefly (*Bemisia tabaci* B-biotype) (SLW) and the cotton aphid (*Aphis gossypii*) (Figure 11.3). The sugar exudates from these insects lead to significant problems in the spinning mill including a build-up of residues on textile machinery which results in irregularities and stoppages in sliver and yarn production (Figure 11.4). Even at low to moderate contamination levels, sugar residues build up decreasing productivity and quality, and forcing the spinner to increase the cleaning schedules. An industry or regional reputation for stickiness has a negative impact on sales, exports and price for cotton.

Figure 11.3: Aphids infesting a cotton leaf (Photo: T. Smith, CSIRO).



processing inefficiencies. Here cotton is sticking on the drafting section of the draw frame. (Photos reproduced with permission, Hequet and Abidi (2002)).

Presence of honeydew on the surface on cotton late in the season can also contribute to reductions in grade as it provides a substrate for sooty moulds and other fungal growth (Figure 11.5). In humid conditions the growth of fungal spores along with honeydew may increase the grey colour of the lint. Honeydew on cotton can also retain plant debris, sand and dirt whipped up by wind and rain.

Silver leaf whitefly and aphids prefer to feed on the under surface of the leaf allowing the small transparent droplets of honeydew to fall onto leaves and open bolls below. Both species are sap sucking insects which feed by inserting their mouthparts into leaf tissue to access the phloem which is rich in sugars but poor in amino acids. Because amino acids are essential for insect growth SLW and aphids have to ingest large amounts of sap to obtain sufficient amounts to grow. The residual simple plant sugars (e.g. fructose, glucose) are modified in the insects gut and are secreted as more complex sugars from the rectum of the insect in the form of honeydew. The sugar melezitose is the primary component of aphid honeydew while trehalulose is the primary component of SLW honeydew. Trehalulose is more problematic than melezitose as it is not sticky when dry but has a low melting point, and becomes liquid and sticky at temperatures created in the drawing phase of spinning of the spinning process.

The best way to manage honeydew contamination is to avoid them in the first place. The level of contamination by honeydew is directly dependant on the numbers and species of insects present. Control of these pests is especially important once bolls start to open. Some issues to consider are:

- If the risk of aphid or SLW populations is high, then the selection of varieties less favourable to them will help to reduce this risk. Varieties with tall open canopies, okra leaf varieties, and varieties with smooth leaves and high gossypol content are less suitable for SLW.
- Adopt sound Integrated Pest Management strategies to reduce the risk of generating aphid or SLW populations that exceed thresholds. Sample for pests and manage according to recommended strategies (see Cotton Pest Management Guide).

- Monitor aphids and SLW abundance and honeydew levels and manage according to recommendations.
- Comply with the Insecticide Resistance Management Strategy when choosing control options for aphids and whitefly to avoid insecticide resistance or spray failures.
- Avoid late maturing crops or regrowth as these will be 'sinks' for adult aphids and SLW which are migrating from nearby cotton crops defoliated earlier.
- Practice good weed control during and after the crop cycle to remove potential host plants that these pests could survive during winter.
- Consider the positioning of crops on the farm and nearby farms and avoid growing cotton near crops that are hosts for these pests.
- In managing SLW once bolls start to open, consider the time left to defoliation and whether control action is warranted.

Figure 11.5: Silver leaf whitefly honeydew can be a substrate for fungal growth such as sooty moulds. (Photo: M. Bange, CSIRO).

Recent research has shown that sunlight alone is unlikely to reduce honeydew in the field while rainfall and overhead irrigation can. Rainfall events of 15 or more mm in a single event (Figure 11.6) can remove relatively low levels of honeydew on the outer fibres of contaminated open boll. Intensity and distribution of rainfall also plays an important role in honeydew removal.

Another occasional pest in cotton that maybe necessary to control at this stage of growth is the pale cotton stainer (*Dysdercus sidea*). These pests feed directly on bolls and seed cotton staining lint with their watery faeces reducing colour grade and the increasing the potential introduction of fungal contamination into developing bolls during feeding. Staining can also occur as bugs can be squashed during the picking operation. The presence of fungal spores and microbes can increase the chances of reduced grade.

For specific recommendations for management of pests refer to specific extension material and the Cotton Pest Management Guide.

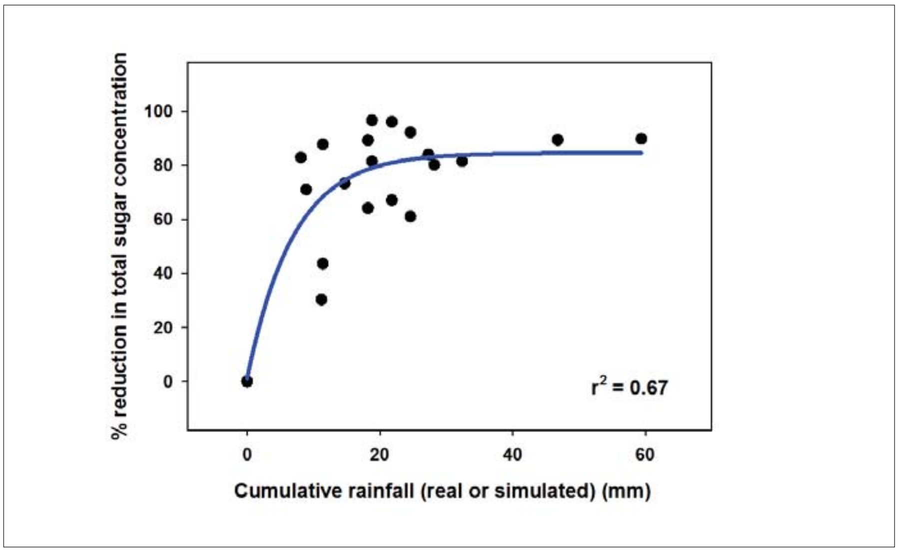


Figure 11.6: Relationship between the % reduction of honeydew concentration and the cummulative rainfall (Heimoana and Wilson (2015)).

Timeliness of harvest operation

Cotton that is severely damaged from weather is also undesirable in textile production because the lint surface has deteriorated and this is perceived to have dye uptake problems. It also can increase the roughness of the fibre which alters its frictional properties and thus how the fibre performs in the spinning mill.

As cotton weathers it loses reflectance, becoming grey due to moisture from both humidity and rain, exposure to ultraviolet radiation (UV) and from fungi and microbes that grow on the lint or wash off the leaves (Figure 11.7). Damage to the fibre will reduce Micronaire as the fibre surface becomes rough retarding air movement in the Micronaire chamber when measured with HVI. Weathering will also reduce fibre strength making fibres susceptible to breakage during the ginning process, reducing length and increasing short fibre content (see Table 11.2) leading to issues in yarn production.

When a boll opens under humid conditions microbes begin to feed on the sugars on the surface of the fibre and stain the lint. Under very humid conditions fungi can multiply on the lint causing 'hard' or 'grey locked' bolls which can reduce both quality and yield.

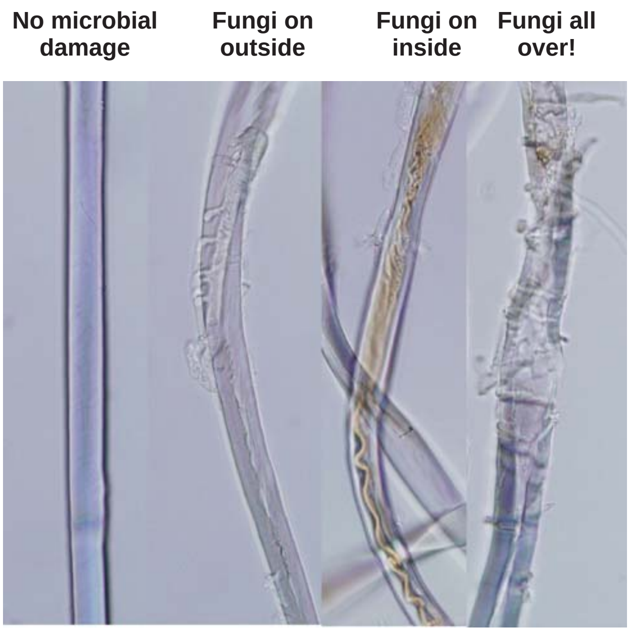


Figure 11.7: Photos of fungi affecting the quality of fibre. (Photo: Courtesy of Stephen Allen).

If bolls are opened prematurely by frost they may have a yellow colour that varies with intensity of the frost. Injury to moist boll walls as a result of frost damage releases gossypol which stains the cotton yellow.

Table 11.2: Effect of weathering on fibre properties (Meredith, 1988).

Fibre quality traits	Average number of days weathering			
	0	8	21	50
Rd reflectance	81.1	79.3	78.2	77.1
+b yellowness	8.4	8.2	7.5	7.2
Length (decimal inches)	1.10	1.10	1.10	1.09
Uniformity Index	83.4	83.3	82.8	83.0
Strength (g/tex)	25.6	25.4	26.1	25.3
Micronaire	4.7	4.7	4.2	4.3

A grower should examine their harvest capacity, regional weather patterns, and have monitored their crop development to avoid excessive weathering.

Other specific considerations include:

- Time harvest to avoid excessive rainfall once bolls are open. See regional summaries for rainfall frequencies in harvest months in Appendix 2.
- Plan to have the crop defoliated before first frost (see Table 11.3).

Table 11.3: Dates of first and last frost for cotton production.

Region	Years of Climate Data	Average Date of First Frost	Date of Earliest Frost Recorded
Emerald	111	9 Jun	23 Apr
Dalby	111	26 May	17 Apr
St George	43	7 Jun	7 May
Goondiwindi	107	2 Jun	23 Apr
Moree	111	28 May	12 Apr
Narrabri	43	25 May	27 Apr
Gunnedah	62	22 May	11 Mar
Bourke	43	12 Jun	10 May
Warren	43	27 May	27 Apr
Hillston	43	17 May	1 Apr
Griffith	43	14 May	14 Apr

Effective application of harvest aids

Application of harvest-aid chemicals is a practice to prepare the crop for a timely and efficient harvest. Defoliation induces leaf abscission which is the formation of a break in the cellular structure joining the leaf to the stem allowing the leaf to fall off. Leaf removal is critical for reducing the amount of leaf trash in machine harvested cotton. This practice allows timely and efficient harvest of the lint to reduce quality losses from weathering and leaf stain from excess leaf trash. Overall effective defoliation can assist in reducing moisture in seed cotton needed for harvest and can reduce boll rot. Boll opening is also accelerated by defoliation as removal of leaves exposes bolls to more direct sunlight, promoting increased temperatures for maturation,drying and cracking of the boll walls.

Application of harvest aids stem around determining the timing, the type of chemical used, and the rates applied. The effectiveness of harvest aids is dependant on: uniformity of plant growth, weather conditions, spray coverage, and adsorption and translocation of the chemical by the plant. Optimum timing of harvest aids must strike a balance between further boll development and potential losses from adverse weather and the inclusion of immature fibre which can lower Micronaire and increase neps (Figure 11.8). Avoiding regrowth resulting from residual nitrogen and moisture in the soil will also contribute to harvest aid effectiveness, as regrowth plants have high levels of hormones that can interfere with defoliation.

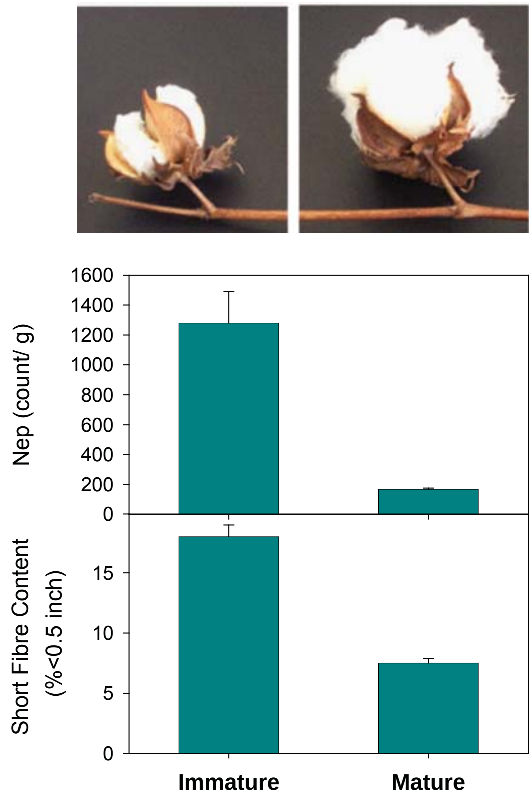


Figure 11.8: Pursuing late bolls may put fibre quality at risk. Un-fluffed immature bolls contribute little to yield but significantly increase neps and short fibres. (Rob Long, CSIRO).

Types of Harvest Aids

The categories of harvest-aid chemicals include herbicidal and hormonal defoliants, boll openers, and desiccants each with a different mode of action:

Defoliants (Thidiazuron, Diuron, Dimethipin) - All defoliants have a common mode of action to remove leaves. They increase the ethylene concentration in leaves by reducing the hormone auxin and/or enhancing ethylene production. Dimethipin alters the concentration of ethylene by reducing the amount of water in the leaf stimulating ethylene production. This change in ethylene concentration triggers separation in the abscission zone at the base of the petiole (leaf stalk). Chemical defoliant enters leaves through the stomates (minor route) or through the leaf cuticle (major route). Hormonal defoliants are applied to reduce auxin and/or enhance ethylene production, while herbicide defoliants injure or stress the plant into increasing ethylene production (similar to waterlogging or drought effects). If herbicide defoliants are applied at too high rates the plant material may die before releasing enough ethylene to cause defoliation resulting instead in leaf desiccation (leaf death).

Boll openers/conditioners (Ethephon, Cyclanillide, Aminomthanane Dihydrogen Textraoxosulfate) - These chemicals specifically enhance ethylene production by providing a chemical precursor for the production of ethylene, which leads to quicker separation of boll walls (carpels). During boll opening abscission zones form between the burrs which then dry and bend backwards as fibre strands inside the boll shrink and contract. At higher rates these chemicals can also be used as leaf defoliants or used in combination with other defoliants to enhance their performance

Desiccants and herbicides (Sodium Chlorate, Magnesium Chlorate, Glyphosate, Diquat, Paraquat, Carfentrazone-ethyl) – Desiccants are contact chemicals that cause disruption of leaf membrane integrity, leading to rapid loss of moisture, which produces a desiccated leaf. Desiccants should be avoided as they dry all plant parts (including stems) which can increase the trash content of harvested lint. Sometimes it is necessary to use desiccants if conditions do not enable the effective use of defoliants (e.g. very cold weather). Desiccants are also a reliable method to reduce leaf resulting from regrowth. High rates of some defoliants can act as desiccants.

Refer to the Cotton Pest Management Guide for details on each chemical.

Timing of the Application of Harvest Aids

The type of defoliation product is unlikely to impact on fibre quality if timing is correct however, early defoliation can cause a significant reduction in all desirable fibre properties. Too early defoliation will increase the number of bolls (often from the top of the plant) harvested that have immature fibre with reduced fibre strength and Micronaire. This may cause fibres to break during ginning lowering fibre length and uniformity, increasing short fibre content and neps. It is important to note that immature fibre will not allow for correct assessments of fibre strength using HVI (see the section on fibre strength in chapter 6 on the importance of fibre quality).

Application of defoliations earlier than 60% of bolls open increase neps and immature fibre which can reduce dye uptake in fabric (Figure 11.9). In crops that have non-uniform maturity it is advisable that there be no more than 29% immature bolls (of total boll number) that are defined as immature bolls using the boll cutting technique to avoid neps increasing.

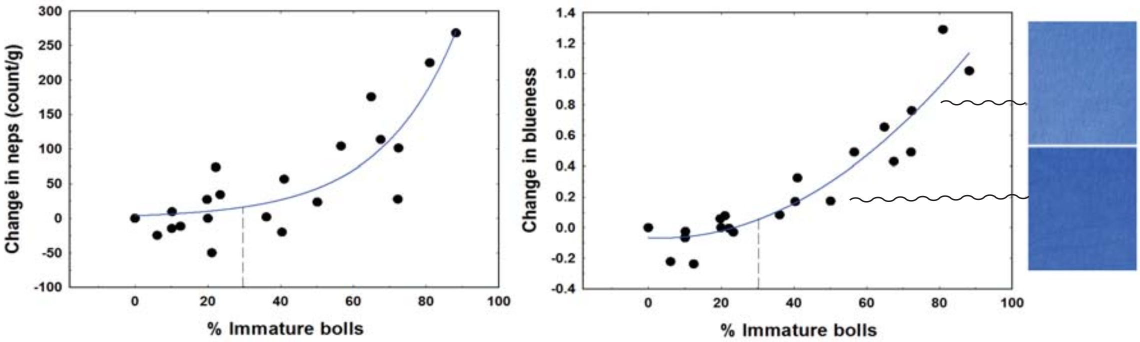


Figure 11.9: Impact of time of defoliation on neps and fabric blueness related to immature bolls at defoliation. Defoliation with more than 29% immature bolls increases neps and lower a fabric's ability to take up dye (Adapted from Bange et al., 2010 and Long and Bange, 2011).

Key issues for use of defoliants:

Timing Issues

- Ensure defoliation practices occur before the onset of frost. Frost can cause damage to the abscission zone making defoliants ineffective.
- Aim to have soil moisture at refill points at defoliation. Severely water stressed crops will not allow defoliants to act effectively.
- If boll openers/conditioners are applied prior to boll maturation they may cause bolls to shed and reduce yield (Figure 11.10).
- The use of boll opener/conditioners should only be considered if the bolls that will be forced open are mature. Bolls that are immature and are prematurely opened may contribute slightly to yield and lower Micronaire of the crop as a whole but they may also increase the incidence of neps or cause issues with fabric dyeing during processing.
- Avoid application of defoliants when there is a risk of rainfall shortly after. Some defoliants are taken up slowly by the leaves and will wash off by rain, resulting in incomplete defoliation. In some cases if rainfall occurs after a boll conditioner has been applied boll opening maybe interupted and 'tight lock' may occur.
- To avoid regrowth issues it is prudent not to defoliate an area bigger than can confidently be harvested within 2 weeks.

Rate and Chemical Selection Issues

- Varieties can sometimes differ in the needs for defoliation as they can differ in the quantity of wax on the leaf surface which affects harvest aid uptake.
- Leaves most susceptible to defoliant are older leaves. Higher rates of defoliant will be needed for young healthy leaves. However, there is a chance that young leaves may 'freeze' on the plant if defoliant is applied in too warmer weather.
- Cool temperatures, low humidity and water stress prior to defoliant application can increase the waxiness and thickness of the leaf cuticle reducing the efficiency of chemical uptake. Wetting agents or spray adjuvants can assist with this problem.

- Because leaf drop requires production of enzymes, the speed with which a leaf falls off is highly dependant on temperature. There are different optimal temperatures for defoliant performance. Hormonal defoliants and boll conditioners have a higher optimal minimum temperature of around 18°C compared with herbicide defoliants that have optimal minimum temperatures ranging from 13 to 16°C. Higher rates are often needed to offset the effects of low temperatures.
- The defoliating effects of a chemical are usually complete within 7 days after application.

Application Issues

- Low humidity during application decreases uptake because chemicals dry rapidly on the leaf.
- For penetration of defoliants lower into the canopy consider using larger droplet size, or directed sprays in the case of ground rig use. Use of spray adjuvants may decrease droplet sizes and this may work against chemical penetrating deeper into the canopy.
- Many growers use combinations of defoliants with different modes of action and multiple applications to enhance defoliation. Multiple applications are beneficial because leaves deep in the canopy can be accessed and covered fully.
- If increased waxiness of the leaves is suspected applying the defoliant in warmer conditions can assist chemical penetration as the waxy layer is more pliable.

Refer to the Pest Management Guidelines and manufacturers details for specific chemical defoliation options and rates.

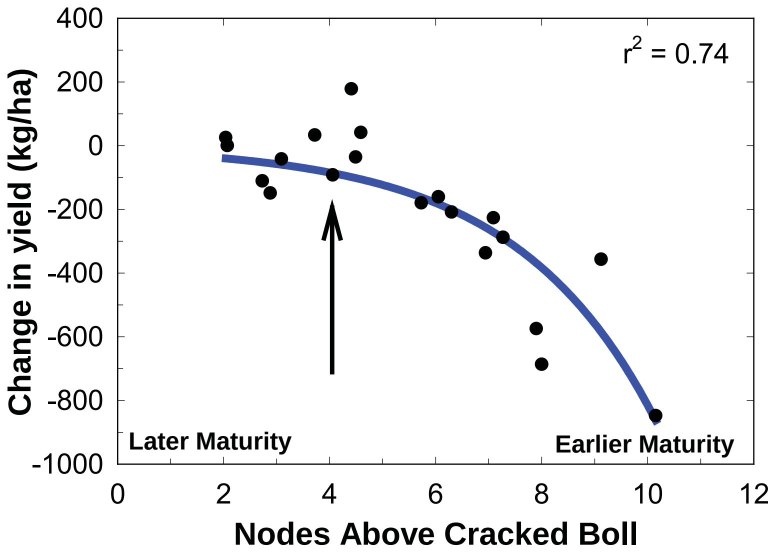


Figure 11.10: Effect of early defoliation on lint yield (adapted from Bange et al. 2009). Yield is reduced if defolation occurs before 4 nodes above cracked bolls (NACB). 4 NACB equates to about 60% bolls open.

Further Reading

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2. Harvest to Gin

To avoid damage to quality and reduce crop value harvesting, module building, storage and transport must be carefully managed. Key considerations from the harvest operation to delivery and storage at the gin include:

- *Use of a properly maintained picker that is setup correctly.*
- *Avoiding harvest operations when cotton is wet.*
- *Following guidelines for module placement, construction, tarping and transport.*
- *Keeping good module records.*
- *Avoiding contamination by maintaining farm hygiene, adjusting picking height, and maintaining hydraulics on pickers, boll buggies, and module builders.*
- *Pre-harvest communication with harvesting contractors and module carters is important. The aim is to ensure a common understanding of how harvest and module transport is to be managed.*

Use of a properly maintained picker that is setup correctly

Two types of mechanical harvesting equipment are used to harvest cotton which are the spindle picker and stripper. The spindle picker, which is used to harvest the bulk of the Australian crop is a selective type harvester that uses rotating tapered, barbed spindles (Figure 12.1) to pull seed cotton from opened bolls into the machine. Spindle harvesters are large and complex machines that are expensive to purchase, costly to maintain and require precise setup, adjustment and trained and skilful operators to obtain the maximum yield and value per hectare possible. Special care should be given to the spindles, moistener pads, doffers, bearings, bushings, and the cam track. Proper maintenance and correct setup of harvesters will help to ensure a clean and effective pick. Your best source of information about maintenance and setup is your harvester operator's manual.

The other type of harvesting machine is the cotton stripper, which is a non- selective type harvester that uses brushes and bats to strip seed cotton from bolls (Figure 12.2). These harvesters are predominately used to harvest seed cotton from rain- fed (dryland) cotton with shorter plant heights and lower yields. Stripper harvesters remove not only the well opened bolls but also the cracked, immature and unopened bolls along with the burrs (carpel walls), plant sticks, bark and other foreign matter, Strippers are not very popular in many countries, since the seed cotton, so harvested, often increases ginning costs and results in lower turnout and lower grades, as well as significantly higher nep levels.

As Australian cotton is mainly picked by means of the spindle harvester, this chapter will focus mainly on this system, however, many issues will apply to both spindle and stripper cotton harvesting systems.

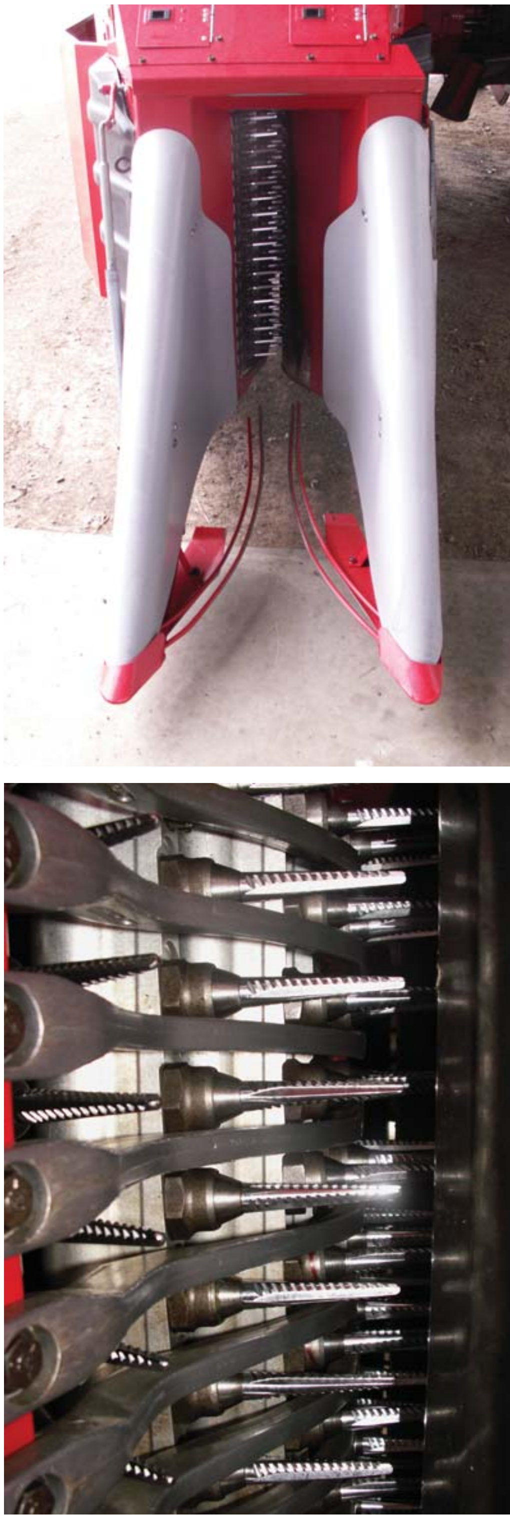

Figure 12.1: Spindle pickers require regular maintenance to operate at high efficiency. (Photos: M. Bange).

Generally agronomic practices that produce high quality uniform crops contribute to good harvesting efficiency. The field should be well drained and rows laid out for effective use of machinery. The soil should be relatively dry in order to support the weight of the harvesting machinery and avoid unnecessary soil compaction. Row ends should be free of weeds and grass and should have a field border for turning and aligning the harvesters with the rows. Plant height should not exceed about 1.2 m for cotton that is to be spindle picked and about 0.8 m for cotton that is to be stripped. Plant height can be controlled to some extent by using chemical growth regulators at the proper growth stage. Crop nutrition, irrigation and pest management are important to managing plant height and a uniform crop maturity (see previous chapters).

Moisture is added to the spindles to keep them clean and to enhance the adherence of the fibre to the spindle and allow for its removal by the doffer. The spindles generally require less moisture in the morning than in the afternoon. Potable water alone is usually sufficient to keep the spindles clean. However, wetting agents, spindle cleaners or soluble oil may also be added to the water. These additives are especially helpful when harvesting rank cotton that has green leaves. Weak acids have also been applied to picker waters in order to reduce the growth of micro-organisms (e.g. Cavitoma) after a wet harvest.

Figure 12.2: Sripper pickers are often used to harvest rain-fed cotton (Photos: USDA and CSIRO).

Pre season maintenance includes:

- Checking and replacing damaged tyres.
- Inflating tyres to the pressure specified before making any field adjustments.
- Ensuring that row units are tilted as specified by machinery manufacturer.
- Replacing bent, broken or worn spindles and ensure that all spindles are sharp and free of rust.
- Checking spindle bushes for excessive wear.
- Ensuring all spindles have similar length and diameter.
- Ensuring all spindles turn when the row unit is rotating.
- Doffers need to be ground and reset properly as required. Replace when damaged.
- Checking moisture pads, bar heights and grid bars. Moisture pads should wipe each spindle clean to remove plant juices (sap) that may cause spindle twist.
- Checking cam track, roller, drum head and bar pivot stud for excessive wear.
- Checking pressure doors for wear, bends, gap and alignment.
- Cleaning basket pre-cleaners and picker basket top.
- Checking hydraulic lines, components and air hoses for leaks.
- Ensuring drive belts are adjusted correctly and universal joints in the drive train are lubricated and in good condition.
- Checking condition of steps and handrails on harvester.

Daily setup and checks include:

- Proper cleaning and servicing of the harvester before, during and after harvesting will result in better performance and lower the potential of fire.
- Checking engine oil and coolant levels before starting engine of harvester for the first time in the morning.
- Picker heads should be greased when they are warm. To prevent excessive wear systems also require light greasing every two to four hours throughout the day. Spin heads to remove excess grease and wash down if excess still remains.
- Ensuring head heights are set correctly (too high and bolls are not harvested, too low and soil is collected).
- Ensuring correct setting of pressure doors for crop conditions. Dented or worn doors cause inefficient picking. Adjust doors to allow efficient removal of lint but avoid excessive green boll and stem bark removal.
- Doffers need to be checked daily and throughout operation. Too much clearance leads to improper doffing and spindle twist in the lint while lack of adequate clearance leads to rapid abrasion of doffer plates by the spindles leading to presence of doffer pad specks (often not detected until textile manufacture).
- Spindles and bushes should be regularly checked for wear, especially the ones near the ground.
- Worn parts should be replaced.
- Spindles should be kept clean as dirty spindles cause spindle twist (wrap) and incomplete doffing resulting in excessive accumulation causing the unit air system to choke, as well as inefficient picking.
- Using a recommended spindle cleaner in conjunction with the correct nozzle output determined by existing conditions (especially if there is green leaf present on the plants).
- Performing regular cleaning, either using a broom, your hands or compressed air, of the picking air suction doors, basket or bale chamber. Dispose of fly cotton where it cannot contaminate the module.
- Adjusting water volume correctly according to the time of day and picking conditions. Higher rates are usually needed in the middle of the day when conditions are drier.
- To avoid harvesting green bolls, pressure doors should be set to light to medium and all grid bars should be in position.
- Seed cotton should be harvested at moisture levels of less than or equal to 12% to prevent downgrading of fibre and seed.

Photo: Grant Roberts

Avoiding harvest operations when cotton is wet

Cotton that is picked wet will result in cotton being twisted on the spindle (spindle twist – roping that occurs when spindles are partially doffed) which may lead to seed cotton being more difficult to process in the gin. Moist cotton during the ginning process can lead to increased gas for heating usage, reduction in production, blockages, and the possibility of fire. The harvesting operation itself is also interrupted as picker doors are blocked more often when cotton is too moist and efficiency declines as a result of poor doffing efficiency, i.e. no flow out of the basket. Doffers and moisture pads on pickers can also be damaged.

Typically cotton is too moist for harvest at dawn in Australia but cotton can be picked well into the night provided relative humidity remains low. Moisture monitoring needs to be more frequent at each end of the day as the change in moisture can be quite abrupt, e.g. moisture can increase abruptly from 4% to 6% within 10 minutes as night and dew point temperature fall rapidly. Figure 12.3 shows the lint moisture in seed-cotton modules measured through the course of one day with conditions similar to those experienced in Australia. Harvesting seed-cotton greater than or equal to 12% moisture is not recommended, although it is acknowledged that modern harvesters will readily pick cotton greater than 12%. Use of a well calibrated moisture meter is essential if harvesting is to occur at moisture levels of 12% or less.

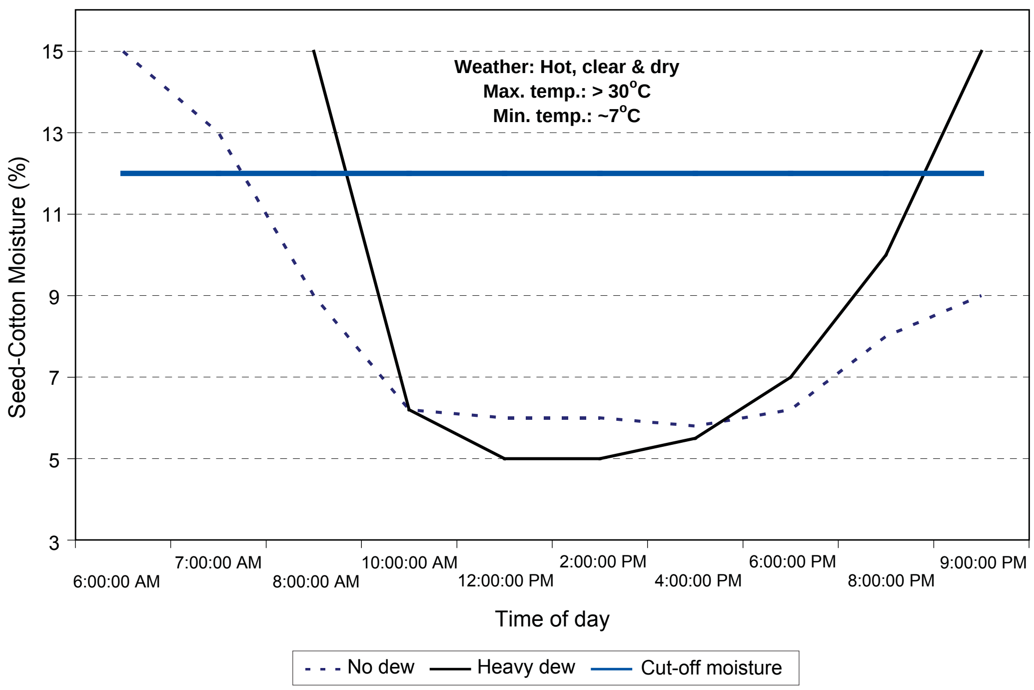

Figure 12.3: Lint moisture over a day during harvest – adapted from (Mayfield et al.). The blue line shows the harvest cut-off point (12%) at which seed-cotton moisture is excessive.

If wet cotton is processed into a module in the field it will also increase the risk of the module self-combusting and also emits a strong unpleasant odour. Other fibre properties such as micronaire, length, strength and elongation can also be affected. Seed cotton moisture also has a significant influence on seed quality if required for planting, with an increase in moisture content resulting in a decrease in germination and vigour, due to an increase in free fatty acid content and aflatoxin level. Increased moisture content also leads to increased mechanical damage to the seed, resulting in an increase in the quantity and weight of seed coat fragments and mote at ginning.

The colour degradation seen in moist or wet seed-cotton in modules is caused by micro-organisms whose activity is accelerated by moisture and warmth. Both temperature rise and maximum temperature of the modules are important indicators of microbial activity; temperature rises of 11°C or more, or temperatures above 49°C indicate the need for immediate ginning to minimize quality degradation and the potential of fire (See Figure 12.4). Sustained heat generation after harvest is caused by biological fermentation, which is reliant on oxygen and living micro-organisms and works best at moisture contents between 12% and 20%; and then by exothermic processes (a chemical reaction that gives off of heat) that causes even sharper increases in temperature. Yellowing is also accelerated at high temperatures. The rate of lint yellowing increases sharply at moistures above 13% and can increase even after the temperature of a module drops. Seed cotton harvested above 16% will suffer losses even if it is ginned immediately.

Modules during storage on-farm and in the gin should be monitored every five to seven days for temperature rises. A rapid temperature rise of approximately 8 to 11 °C or more in 5 to 7 days signifies a high moisture problem and that module should be ginned as soon as possible. Modules that have temperatures rising to 43 degrees Celsius need to be ginned immediately. The temperature of modules harvested at safe storage moistures will not increase more than 5.5 to 8 degrees in 5 to 7 days and will level off and cool down as storage period is extended.

Some rules of thumb to consider relating to moisture on cotton to be harvested include:

- Installing moisture measuring equipment on the harvester, or use hand held moisture meters.
- Moisture measuring equipment should be calibrated to ensure correct readings.
- Noting that hand held moisture meters are usually ± 1% accurate
- Taking readings from previously constructed modules.
- If moisture is present on vehicles while harvesting it is most likely that the cotton is too wet.
- The seed should feel hard (cracks in your teeth)
- When a handful of cotton collected in the palm of your hand is squeezed into a ball and then released, the moisture content is

Round Module picker (Photo:James Quinn).

acceptable if the seed cotton springs back to near its original size.

- If you can feel moisture on the cotton it is too wet.
- Moisture is added to the spindles to keep them clean and to enhance the adherence of the fibre to the spindle and allow for its removal by the doffer. Consider that machine picking can also add 2% moisture to seed cotton.
- The addition of green leaf will add moisture.
- A symptom of moist cotton is frequent blocked doors, throwing cotton out the front of the picking heads.
- If cotton is being expelled into the basket in dense blobs and is not fluffy it may be too moist.
- Suitable picking conditions late into the night are rare.
- Notifying your ginner of modules that may be moist so that they may be ginned first, or at least monitored in the module yard.

Figure 12.4: Harvesting moist cotton (greater than 12% moisture content of seed cotton) can increase risks of modules self combusting. (Photo: Rene van der Sluijs, CSIRO).

Guidelines for module placement, construction, tarping and transport

The primary advantage of using modules is the decoupling of the harvesting capacity from the ginning process. Growers can build modules rather than leave the crop exposed to weather in the field. To avoid damage to fibre quality and reduce crop losses cotton should be dry when harvested and modules carefully stored.

Irrespective of which harvesting method is used the key considerations for module production is to maintain quality are module placement, construction, tarping, storage and transportation to the gin. Typically harvesters with basket systems require module builders to produce conventional (traditional) modules that have a maximum size of 2.4 x 3.0 x 12 metres. These modules can weigh 12 000 to16 000 kg which produces an average of 24 bales. In contrast harvesters with on board module building capacity produce round modules which weigh 2000 to 2600 kg which produce an average of 4 bales. Another important consideration is ensuring personnel involved in the harvesting operation are instructed and observe a sanitary workplace in terms of contamination. Workers should abide by the dictum that no unworn clothing, rags, papers, tools, non-cotton ropes, lunch bags etc. are left in close proximity to the harvesting operation.

The introduction of the John Deere harvester with on board module building capacity, offer labour and efficiency gains due to non-stop harvesting and the elimination of in-field unloading to boll buggies and processing in module builders. In Australia where these machines now harvest in excess of 90% of the total crop. These harvesters, which have been described as a hybrid of a cotton harvester and an oversized round hay baler, produce round modules which are covered with an engineered polyethylene film that both protects the seed cotton and provides compressive force to maintain module density. Despite the advantages of these harvesters some concerns have been raised regarding seed cotton moisture, plastic contamination (Figure 12.5), soil compaction (effecting yield of subsequent crops), variability in quality, as well as the high cost of the plastic wrap.

Figure 12.5: Plastic contamination in round module and classing samples (Photo: Rene van der Sluijs, CSIRO).

As this harvester can harvest without stopping to unload the operator needs to decide where and when to drop the modules. Typically, the finished module is carried until it can be dropped on a turn-row. But if the yield is very high, or the row lengths are long, it may be necessary to drop the modules within the field. This action has no impact on the operation of the harvester, but stalks may puncture or tear the plastic wrap increasing subsequent contamination.

Round Module Considerations

The key consideration once the round modules are produced is module staging (the method used to place modules together for transport). Modules must be picked up from where they were dropped in the field, and staged together for pickup. The most common system used is a mast-type tractor mounted implement that holds the module with the axis parallel to the tractor rear axle (Figure 12.6). Because round modules can weigh up to 2600 kg, a large tractor is required for staging. Key factors that need consideration include:

- Transport speed of the tractor with a module on the handler should be kept to a safe speed to suit current conditions and not exceed 16 km/h .
- When transporting modules through harvested rows, the module should be carried high enough to minimize contact with those rows.
- Gap between the underside of the module and the ground should be sufficient and never be less than 15 cm during module staging to prevent drag and tearing of underside of wrap.
- Modules should be staged only in well drained areas of bare soil,

such as turn-rows. If the soil is wet, wheel slip by the truck can cause the loading chains to tear the plastic wrap.

- Modules should be staged on a high flat surface. Staging on well-defined flat driveway or a flat disked surface is optimal. Modules will take the shape of the surface they are placed on. Setting on beds or uneven surfaces requires digging into the ground with the module truck chain to safely get under the entire surface of the module.
- Avoid placing the module on cotton stalks, as the movement of the modules on the stalks can puncture the plastic wrap. If possible, avoid staging in areas where the truck cannot access the modules if rain occurs.
- When staging round modules together for transport or for storage, lift the module 30 cm or more above the ground. A lower position can result in stalks tearing the exposed wrap on the bottom.
- When placing modules together for transport, a gap should be left between each module.
- Do not allow module ends to touch, as this will cause water to enter the modules rather than to run off down the ends. The modules should be aligned so that the centrelines are within a +/- 13 cm band. If not properly aligned, the wrap may be damaged by the sidewalls of the module truck.
- Stage round modules for transport as per transport operators required method. The two typical staging types are 'sausage' (end to end) and "wagon wheel" (at 90° from end to end). The 'wagon wheel' is more common for loading by articulated loaders and transport by flat top trucks. The 'sausage' staging is for the more specialised self-loading chain-bed trailers.
- Significant wrap tears must be repaired in the field before module truck pickup to prevent further wrap damage and ginning problems.
- Loose outer tails must be secured with a high strength spray adhesive or lint bale repair tape.
- Module pads should have enough space to allow easy access for the equipment and trucks.
- Located near a well-drained field road and avoiding areas where water accumulates.

Figure 12.6: Round modules automatically made and discharged from pickers avoid to a large extent the problem of contamination, although contamination from tarps and coverings, which need to be removed before ginning, remains an issue. (Photos: Rene van der Sluijs, CSIRO).

Conventional Module Considerations

Construction

A module builder compacts seed cotton to a density of about 190 kg/m^3. A tighter module better sheds rainfall on the sides and less cotton is lost during storage, loading and hauling. Considerations include:

- Building modules in a straight line which will assist the carrier to avoid misalignment of modules on the trailer that could cause an over-width load, breakage of the module and lost cotton.
- Ensuring ample space around the module builder so that harvesting equipment, trucks and infield loaders have easy access. Module builders should not be elevated with blocks as this can create oversized and overweight modules. Only build module weights which are appropriate to the transportation system. Do not exceed 16 t if chain beds are to be used, with flat top trucks able to handle

more weight.
- The top of the module should be rounded to allow the top of the module when covered to shed water. In addition a well compacted module will help reduce freight costs to the gin.
- Good communication is needed between module-builder operators, picker and boll buggy drivers to allow appropriate time for modules to be built and to avoid spillages. Cotton that is spilled from modules should be carefully added back into the module avoiding contamination whilst following strict health and safety guidelines (Figure 12.7).
- A constant lookout for oil leaks on both cotton pickers and module builders is needed to prevent contamination. Oil leaks on builders should be repaired as soon as they are noticed. Oil contaminated cotton needs to be removed from the module as soon as it is identified.
- Away from heavily travelled dusty roads, and other possible sources of fire and vandalism.
- Clear of overhead obstructions such as power lines.

Figure 12.7: Vigilance during module construction should avoid potential contamination. (Photo: CSIRO).

Tarping

Use of a high quality tarpaulin on modules is important to avoid moisture affecting quality as well as avoiding significant contamination of the cotton from the tarpaulin itself (Figure 12.8). Before using tarpaulins inspect them for holes, tears and frayed edges and that they repel water.

Tarpaulins should be chosen taking into consideration their tensile strength to avoid tearing, resisting puncturing and abrasion, adhesion of coatings, UV resistance, and cold crack temperature. If tarpaulins have seams they should be double stitched, with a minimum number of stitches. Centre seams (unless heat sealed) should be avoided as it is a potential weak point to allow water to enter the module. All these factors should be weighed up in light of the overall cost of the tarpaulin and its life expectancy. The tarpaulins should be kept in a dry, vermin free store to ensure their quality and longer life expectancy.

Figure 12.8: Tarps needs to be of sufficient quality to ensure moisture is repelled and last while modules are stored ready for ginning. (Photo: Courtesy Cotton Australia).

To avoid contamination and fibre quality losses tarpaulins need to be securely fastened to the module. For best performance of tie-down type module covers use all loops and grommets provided. Cotton rope is the most appropriate fastener to limit contamination and synthetic rope should never be used. Ensure rope has enough strength to endure strong winds. Belly ropes should be avoided if possible as they may break. A tarp should be large enough to cover at least half to two thirds of the ends of the module.

Keeping Good Module Records

Identifying when and where each module is produced can help with producing better fibre quality outcomes as the grower can discuss with the ginner the quality of the cotton of each module and thus tailor the ginning process to suit. The grower can also use these records to better understand the variability that exists within a field to refine management practices for that particular field in subsequent seasons. Each module should have a record (with a duplicate kept in a safe place), which includes the date and weather conditions when picked. Any records or numbers assigned to modules should be as permanent as possible. Permanent marker pens should be used on cards attached to modules in a sealable plastic bag.

This may not be necessary if the Radio-Frequency Identification (RFID) tags that are embedded in the module wrap of the round modules are utilized as these tags are able to document eleven of the most important data points during module formation to improve traceability of cotton modules as they move from the field to gin lot and through the ginning process.

Transportaion

The safe loading and transport of cotton modules (round or conventional) is vitally important in preventing injury to module transport operators, other road users and preventing damage to property. The Cotton Australia Module Restraint Guide has thus been drawn up to provide cotton growers and transport operators with practical information and advice to help meet relevant legal compliance and avoid unnecessary accidents and/ or penalties through the safe loading, restraint and transport of cotton modules on Australian roads where flat-top open sided trailers are used.

Further Reading

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Searcy SW, Willcutt MH, Buschermohle MJ, Wanjura JD, Brashears AD, Barnes EM (2010) Seed-Cotton Storage and Handling in Modules. (Cotton Incorporated, Raleigh, North Carolina, USA). p. 34.

13. Post Harvest Management

The main concerns for this phase are to maintain quality, optimise lint yield and contain the costs of ginning. Appropriate ginning and handling practices post-harvest are important to maximise returns for growers and maintain the industry's reputation for high quality. Good communication between growers and ginners is a key factor in assisting this process (Table 13.1)

Table 13.1: Summary of key post harvest decisions for optimising quality.

Objectives	At the Gin
Maintaining fibre length	In the gin, fibre length can be preserved and short fibre content reduced, by reducing the number of lint cleaner passages (depending on quality of seed cotton) and ensuring fibre moisture is between 5 and 7 % over the gin and between 5.5 and 6.5 % 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 fibre breakage.
Reducing the incidence of neps	Lint cleaners are responsible for most of the neps found in baled cotton. Reducing the number of lint cleaners reduces neps. Maintenance of prescribed setting distances, e.g. feed and grid bar distances to the lint cleaner saw reduces fibre loss and nep creation, as does close and proper setting of the doffing brush to the saw. Preservation of fibre moisture as prescribed for length preservation also helps reduce nep creation.
Preventing contamination	Clean gravelled module storage yards. Frequent inspection of tarps and wrap on modules. Appropriate bale covering/wrap. Storage and handling to avoid country damage.

The ginning industry in Australia is relatively modern, with higher throughput gins compared with other countries. The principal function of the cotton gin is to separate lint from seed and produce the highest total monetary return for the resulting lint and seed, under prevailing marketing conditions. Current marketing quality standards most often reward cleaner cotton and a certain traditional appearance of the lint.

A ginner has two objectives: (1) To produce lint of satisfactory quality for the grower's classing and market system, and (2) to gin the cotton with minimum reduction in fibre spinning quality so the cotton will meet the demands of its ultimate users, the spinner and the consumer. The spinner would prefer fibre without trash, neps and short fibres. Unfortunately, the highly mechanised (and productive) harvesting and ginning processes used today, mean that removing trash is difficult without introducing some neps and increasing short fibre.

Modules ready for ginning (Photo: Rene van der Sluijs, CSIRO).

The challenge for the ginner is therefore to balance the amount of cotton produced (turn-out), the speed at which it is ginned and the effects that the various cleaning and ginning components have on the fibre quality. Particular settings in a gin for speed or heat can exacerbate nep and short fibre content. The use of lint cleaners, while removing trash, also increases the number of neps and short fibres. Whilst not included in existing classification systems for cotton, the presence of neps and short fibre seriously affect the marketing ability. The ginner must also consider the weight loss that occurs in the various cleaning machines. Often the weight loss to achieve higher grade results in greater removal of lint as well, which results in a lower total monetary return to growers and ginners as they are both paid on a per bale basis.

Cotton quality after ginning is a function of the initial quality of the cotton, and the degree of cleaning and drying it receives during ginning; the exact balance between turnout and grade will depend upon the particular premium-and-discount (P&D) sheet applied to the cotton in question. For every P&D sheet there will be a point in the balance between turn-out and grade that maximises the return to the grower. Given this need to balance competing considerations, it is essential that growers seek to; ensure defoliation and harvest practices limit trash; contamination is limited; and the size and moisture of the module are appropriate. Ultimately it is important that growers communicate with ginners these aspects of their harvest prior to the start of the ginning season. An understanding of the issues that were faced in the field may give the ginner insights on how the cotton can be handled to optimise turn-out and quality together.

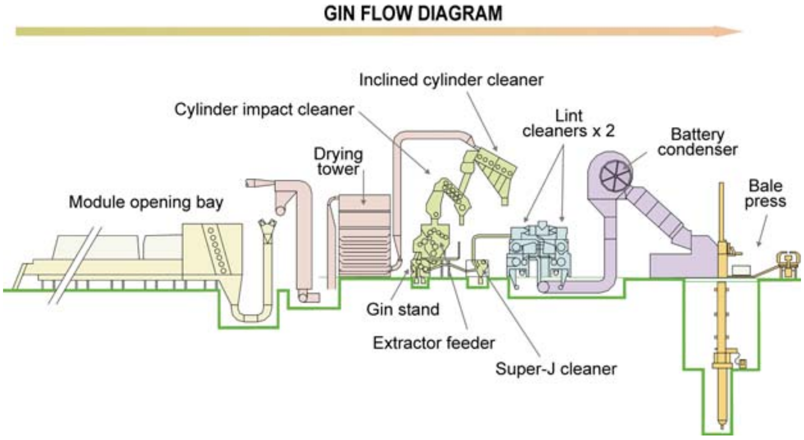

Figure 13.1: Gin flow diagram showing cross-sections of machines used in a modern gin to process spindle harvested cotton

Ginning Process

Modern gins are highly automated and productive systems that incorporate many processing stages. Gins must be equipped to remove large amounts of plant matter from the cotton that would significantly reduce the value of the ginned lint, according to the classing grade standards. Figure 13.1 shows the cross-section of a gin with machines that are typical of those found in a modern gin. It is noted that most Australian gins typically have more pre-cleaning stages. This gives them the flexibility to process both spindle harvested cotton and stripper harvested, which requires more pre-cleaning.

At ginning the lint is separated from the seed. Moisture can be added to dry cotton prior to the gin stand at either the pre-cleaning stage or after the conveyor distributor above the gin stand. However, In Australia the moisture addition at these points is not common. After ginning, fibre travels by air to one or two lint cleaners for further cleaning and preparation. At the lint cleaners moisture content is critical to prevent cotton from significant damage (neps and short fibres). Cotton that is too dry (< 5.0% moisture content) will be damaged to a greater degree during the lint cleaning process.
The following sections give more detail on the processes in; the module bay, pre-cleaning, drying and moisture restoration, ginning, lint cleaning and bale moisture restoration.

Module Bay

Ginning begins with seed-cotton delivered in modules to the gin (Figure 13.2). Modules of seed-cotton are opened by a series of beaters and transported by air through ducts to one or a series of pre-cleaners, which remove large trash e.g. sticks, stones, unopened bolls, before the gin. If the seed-cotton is too wet pre-cleaning may be preceded by passage through a drying tower or chamber where the seed-cotton is dried with large volumes of dry heated air. Drying wet cotton improves the cleaning ability of the seed-cotton, which in turn improves the classing grade.

The module bay also acts as one of the only intervention points for removing non-cotton contamination from modules. Contaminants or contaminated seed-cotton (from oil spills and stains etc) should be removed clear of the module and module bay floor. The number of incidences and types of contaminant must be reported to the grower.

Pre-cleaning

The use of stick machines and extended incline and impact cylinder machines should be considered in the light of whether; the cotton harvested has been well presented and defoliated for harvest; the harvest period has been wet and/or the crop has been spindle or stripper picked. Some gins have more extensive pre-cleaning equipment, e.g. combinations of stick machines, drying equipment and inclined and impact cleaners, than others. Very clean Australian

Figure 13.2: The module bay is an important intervention point for removing non-cotton contamination from modules. (Photos: Rene van d Sluijs and M. Bange CSIRO).

cotton requires only minimal pre-cleaning to achieve satisfactory classing grade results. The use of these machines does not ordinarily damage the fibre in the same way that the ginning and lint cleaning processes do.

Drying and moisture maintenance

To ameliorate the harsh effect of heat and/or dry cotton in the gin, moisture restoration systems are available. These systems typically add moisture to seed-cotton immediately before ginning and in doing so help maintain fibre length and reduce the number of fibres broken at the gin stand and lint cleaners, which translates into improved yarn quality. Newer work is looking at moisture restoration of lint before lint cleaning. Other benefits resulting from moisture restoration include reducing the static electricity level of the cotton, reducing the volume of the cotton required to achieve a given bale size and reducing the force required to press the bale. The resilient forces exerted on the restraining bale ties are also lower for the higher moisture cotton.

Many approaches have been used to restore moisture in cotton fibre. Moisture restoration may occur at several locations such as module feeder, feed control, pre- and post-gin dryer, above extractor feeders, into moving-bed conditioners, at battery condensers and other apparatus in the lint slide. There is a physical limit to the quantity of moisture that may be added to seed-cotton. Wetting of the cotton by condensation within machinery and pipes must be prevented or choking will result. If liquid water is present on the seed-cotton mass, gin stand operation will become irregular and may cease altogether. Cotton with fibre moisture in excess of 9% may be rough in appearance and will not smooth out properly when processed through the lint cleaners. Thus, the recommended fibre moisture level of 6% to 7% is based on production aspects as well as quality aspects. Lint moisture in the bale must be uniform and must not exceed a maximum value of 7.5% in order to avoid fibre discoloration and significant weight loss during storage.

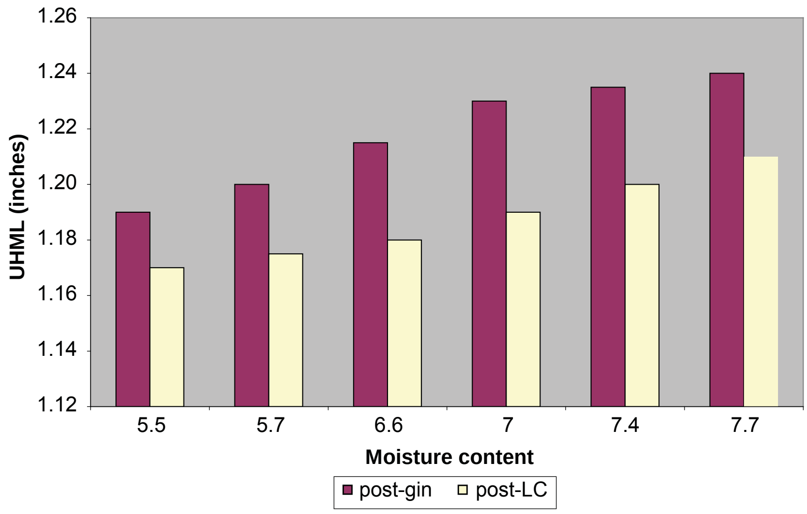

Figure 13.3: The effects of humidified air moisture restoration on fibre length measured as UHML (Upper half mean length). Fibre samples taken post gin and post lint cleaner (fibre test results courtesy of Auscott Ltd.).

One approach is to use humid air to moisten cotton. The air must be heated to carry sufficient moisture to the cotton fibre. This humid air is then blown through the cotton causing fine water droplets to form on the cotton fibres throughout the cotton batt. The amount of moisture restoration with this system is limited, especially at higher ginning rates, adding typically no more than 1% moisture to seed-cotton depending on ambient conditions. Whilst in absolute terms this amount seems insignificant, significant improvements are seen in fibre quality, gin productivity and bale weight as a result. Figure 13.3 shows improvements in fibre length through the same gin stands and lint cleaners with increasing amounts of moisture applied. The improvements in fibre length give rise to concomitant improvements in length uniformity, short fibre content and fibre strength. Note the damaging effect of the lint cleaner on fibre length.

Another approach is to atomise water and spray it directly on the cotton. Sometimes a wetting agent is added to the water to hasten its distribution through the cotton. Applying water as an atomized spray directly on cotton or seed-cotton during ginning or cleaning is fraught with difficulty, although if applied successfully can result in fibre quality improvements. In general studies have shown atomizing sprays applied, for example prior to the distributor conveyor, result in fibre with longer staple length and reduced short fibre content. Most Australian gins use this spray system on the cotton at the lint slide in order to restore moisture and weight to the bale, although sprays can also be applied in other parts of the gin, e.g. in the post-dryer, pre-cleaning area. Extreme care must be exercised to avoid wet spots in the bale, which promote bacterial and fungal growth and cause degradation of the fibre.

Ginning

The ginning process works when seed-cotton is fed into a cylindrical chamber to form a seed roll, against which up to 200, 12 to 18 inch gin saws perform a raking process that detaches lint from the seed and draws it through ribs separating each saw. A doffing brush removes the lint attached to the saws and propels it through ducting to the lint cleaners, usually via a Super-J cleaner (see Figure 13.1).

There are many machine settings around the seed box that influence the quality of ginning. Quality at this point is largely defined in terms of turn-out (percent lint extracted) and efficiency (bales per hour). There are also some consequences for fibre quality, although the regard for these is not high at this point. The main factors affecting ginning quality are gin saw sharpness, saw speed, gin point wear and seed roll compaction. Indicators of poor ginning quality are higher levels of residual lint on ginned seed, which leads to lower turn-out, and seed coat damage found as seed coat neps in ginned lint.

Lint cleaning

It is widely known that the batt saw lint cleaner damages fibre during cleaning and preparing cotton for market. Many studies have

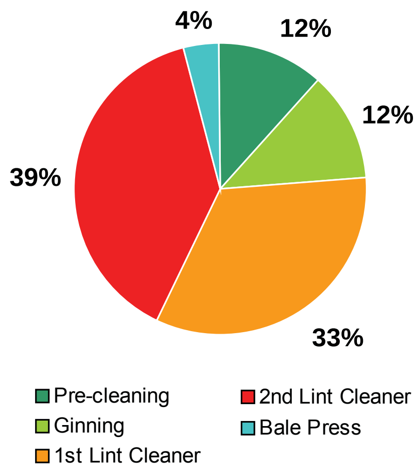

Figure 13.3: Nep creation in Australian base grade cotton at different stages through the gin. Data courtesy of D. Draheim, Auscott Ltd.

been conducted that show levels of nep and short fibre increase, while staple length and residual trash decrease with the number of passages through the saw lint cleaner. Figure 13.4 shows the results of an Australian study on the effect of each ginning stage on nep creation. In the study over 70% of neps found in baled lint were created when lint was cleaned through two saw lint cleaner passages. The impact of lint cleaning is greater on immature fibre and also on longer, finer fibre types. Figure 13.5 shows the effects of the number of lint cleaner passages and percent immature cotton at harvest on the number of neps.

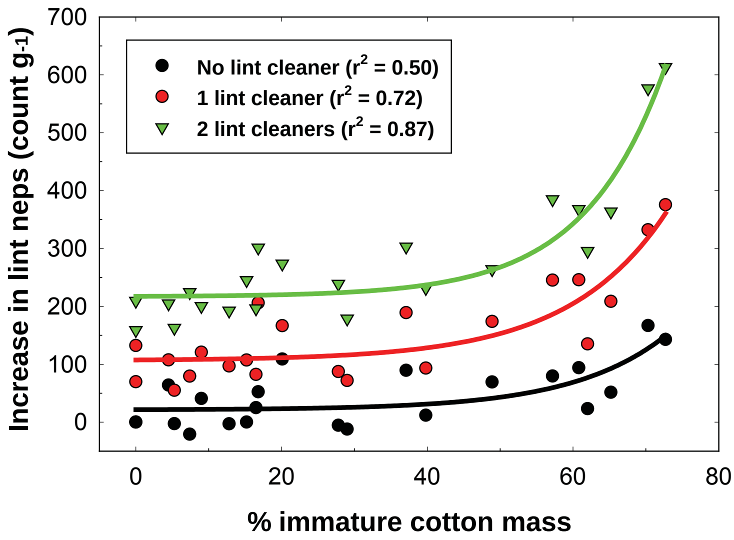

Figure 13.5: The effects of immature cotton and the number of lint cleaners on neps (Bange et al. 2009). Understanding whether cotton is more or less mature may help with decisions on the number of lint cleaning passages.

Modern lint cleaning, in most cases, refers to the fixed or controlled-batt saw type lint cleaner, which was introduced to gin operations after World War II following the advent of mechanized harvesting, which also increased the amount of trash found in cotton. Figure 13.6 shows the main elements of a fixed-batt saw lint cleaner. In these systems ginned lint is formed into a thick batt of around 250 g/m2 on a slow moving condenser drum. The formed batt is then doffed from the condenser and fed with minimal draft through a series of close set rollers to a nip point between a final resiliently mounted feed roller and fixed feed bar. The batt is then combed onto a saw moving in excess of 1500 m/min. The draft i.e., the ratio of the surface speeds between the final feed roller and the saw, is fixed and is usually set between 20 and 35. The fibre transferred onto the saw is cleaned by grid bars, which deflect the contiguous fibre web back into the saw teeth at the same time as expelling heavier discrete trash particles that are subject to greater centrifugal force than the fibre. Most modern lint cleaners use between five and eight grid bars. Fibre is removed from the saw by a brush cylinder revolving at 1.35 times the speed of the saw, i.e. a speed in excess of 2000 m/min. Lint doffed by the brush can be subject to further identical lint cleaning passages or can be collected and compressed into a bale.

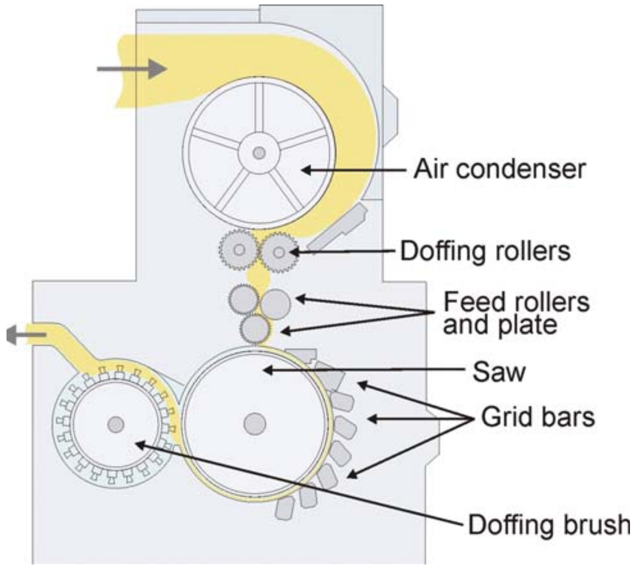

Figure 13.6: Cross-section of a fixed-batt saw lint cleaner.

The feed zone, and in particular the transfer point between the final feed roller and the saw, is where fibre is damaged most during the lint cleaning process. Damage is reflected in increased neps and short fibre content and reduced staple length. The other elements used to clean and move cotton through this system, i.e. the grid bars and brush, create little damage by comparison. The longer and finer a cotton is, the greater the damage at this point. Lower combing ratios, extra draft in the feed work, more consistent batt density and lint conditioned between 5.5% and 6.5% are the best methods of reducing damage at the lint cleaner.

Maintenance of bale moisture

Excessive moisture in bales stored for extended periods creates quality problems for merchants and mills. Moisture augmentation of cotton bales resulting in excessive amounts of water, mainly via spray systems, leads to a reduction in fibre quality. Cotton colour grade can be adversely affected (increased yellowing and greyness) with moisture levels as low as 7.5% impact greyness and yellowness.

Achieving a moisture content less than 7.5% is a difficult task when applying moisture via sprays to cotton at the battery condenser and/or lint slide. Two important problems are associated with spray systems: (1) applying just the right amount of water to reach the most desirable moisture content and; (2) applying the water in an even and consistent manner. Direct spraying of liquid water on the top of a fast moving thick batt of cotton, achieves only uniform application to the top surface of the batt. It is generally believed that transfer of the liquid water to the remaining 10 to 30 centimetres of cotton is difficult because raw cotton fibre does not readily absorb liquid water because of its hydrophobic wax layer, and that the cotton bale is immediately packaged at high densities, which greatly retards any further movement of water vapour or liquid. In this respect humidified air, which contains water in a vapour phase is more readily absorbed by fibre, and that it is pulled or blown through the cotton by means of a condensing unit, means that moisture is absorbed in a relatively more uniform manner.

Australian gins have a good reputation in achieving appropriate moisture content of bales. This is largely a result of most Australian gins (> 80%) testing the moisture of each ginned bale using the Australian Vomax microwave technology.

Bale wraps

Cotton lint is baled at the gin after removal and separation from the seed. The wrapping material that covers the bale is designed to protect the baled lint during transport, storage and delivery to Australian and overseas spinning mills. From this perspective the wrapping should have sufficient strength to protect the lint from damage and contamination en-route to the final destination.

Figure 13.7: Correct warehousing of cotton bales is important to maintain quality. (Photo: Rene van der Sluijs, CSIRO)

Around the world cotton bales are covered in a range of wrapping materials; from fabric constructed from natural fibres such as cotton and jute, to synthetic fibres such as polypropylene (PP) and plastic films such as polyethylene (PE). Each material has its own distinct advantages and disadvantages. The majority of bales produced world-wide are covered by a cotton material.

Whilst jute hessian is relatively cheaper and durable these attributes are not significantly different from alternate packaging including cotton.

Of all bale wrapping materials only cotton (Figure 13.7) presents as contamination-free packaging. As well as being zero-risk in terms of contamination cotton wrap material is also favoured by spinning mills in terms of ease of disposal. Polyethylene film (plastic) is reasonably low-risk in that it does not separate out into fibres and is more easily removed in mill cleaning processes. Polypropylene and jute are however difficult to remove and easily incorporated into yarn and fabric because of their fibrous nature.

Despite cotton being the least durable of the bale wrap materials, the majority of the world's cotton producing nations use cotton as bale wrapping. For Australia, which sends the bulk of its cotton overseas, the issue of cotton's low inherent strength compared with alternate wrapping materials can be addressed by specifying heavier woven or knitted cotton fabrics. This adds some cost to the wrapping material but ensures that bales delivered overseas are able to maintain their appearance during delivery.

Cotton, jute and woven PP also allow the cotton to equilibrate (breath) to ambient conditions. A sealed PE bag is the only packaging that will retain, for better or worse, the moisture that is in the cotton when the bale is pressed. Very careful moisture management through the gin must prevail to preserve the quality of cotton in PE bags.

Bale Warehousing

The best warehouses are those that are fully enclosed and both clean and conditioned. Conditioned warehouses ensure the best returns for merchants (the warehouse owner or user) and spinners alike. The type of warehouse conditioning that can be used is dependent upon the the local climate. In dry, hot areas evaporative cooling (and conditioning) represents one of the best options as the water transition to vapour is dependent upon the existing ambient conditions. Water sprays must be used very carefully, similar to their application in baling. Serious quality issues can arise in the baled cotton if excess amounts of water are allowed to be sprayed. Where warehouses are located in sub-tropical or tropical areas no conditioning is required, only protection from water. Figure 13.7 shows cotton and jute hessian wrapped bales in a typical Australian bale storage area.

Classing

Most cotton today is still 'classified' for quality using a classer's subjective assessment against a physical grade sample, e.g. like the United States Department of Agriculture (USDA) physical grade boxes. Unfortunately, the value attached to cotton from this type of classing does not enable spinners to properly assess the value of the cotton they buy. Thus demand from modern spinners and retailers, largely affected by cost pressures, has generated the need for all cotton to be rapidly and objectively measured. Whilst exporting countries such as Australia, USA and Brazil have long classified their fibre using high volume automatic testing systems, other countries are now being encouraged to apply objective testing. The instrument systems, termed high volume instruments (HVI), give the cotton spinner valuable and transperant information about the fibre characteristics of every bale of cotton they purchase or intend to purchase. Figure 13.8 is a photo of HVI classing lines in Australia. This ensures growers are paid on the performance qualities of their fibre. For spinners, HVI results are used to maintain product consistency in cotton blended from bale laydowns in the mill ensuring in processing and yarn quality.

If Australia is to maintain its reputation as a consistent supplier of high quality cotton it needs to ensure that the Australian classing facilities consistently specify their cotton. To this end the Best Management Practice (BMP) for ginning and classing has been implemented to ensure that all gin and classing facilities comply with the industry standards.

Figure 13.8: Modern classing rooms use both traditional classing methods and HVI to grade cotton and establish fibre quality traits esentially for marketing and for spinning mill requirments. (Photo: Rene van der Sluijs, CSIRO)

Further Reading

Anthony WS, Mayfield WD (1994) ‘Cotton Ginners Handbook’, USDA ARS Publication No. 503.

Anthony WS (2004) Moisture management practices at gins. In Proceedings Cotton Incorporated Engineered Fiber Selection Conference (Greenville SC). p.21.

Anthony WS (1999) Post-harvest management of fiber quality. In ‘Cotton fibers: Development biology, quality improvement and textile processing’, Basra AS (ed.) (Food Products Press, Binghampton NY) pp.293-333

Anthony WS (2006) The harvesting and ginning of cotton. In ‘Cotton: Science and technology’ Gordon SG and Hsieh YL (eds.) (Woodhead Publishing, Cambridge) pp.176-201.

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Cotton Incorporated (2015) ‘The Classification of Cotton’, p 24.

CCAA (2017) ’Best Management Practice Classing Handbook’, version 19, p 16.

Appendix 1 – Detailed Descriptions of Spinning Processes to Produce Yarn

Ring spinning

Ring spinning is the process of further drawing out roving to the final yarn count needed, inserting twist to the fibres by means of a rotating spindle and winding the yarn on a bobbin. These three stages take place simultaneously and continuously. Ring spinning is a comparatively expensive process because of its slower production speeds and the additional processes (roving and winding) required for producing ring spun yarns. Ring spun yarns produce high quality and are mainly produced in the fine (60 Ne, 10 tex) to medium count (30 Ne, 20 tex) range, with a small amount produced in the coarse count (10 Ne, 60 tex) range. End uses include high quality underwear, shirting, and towels.

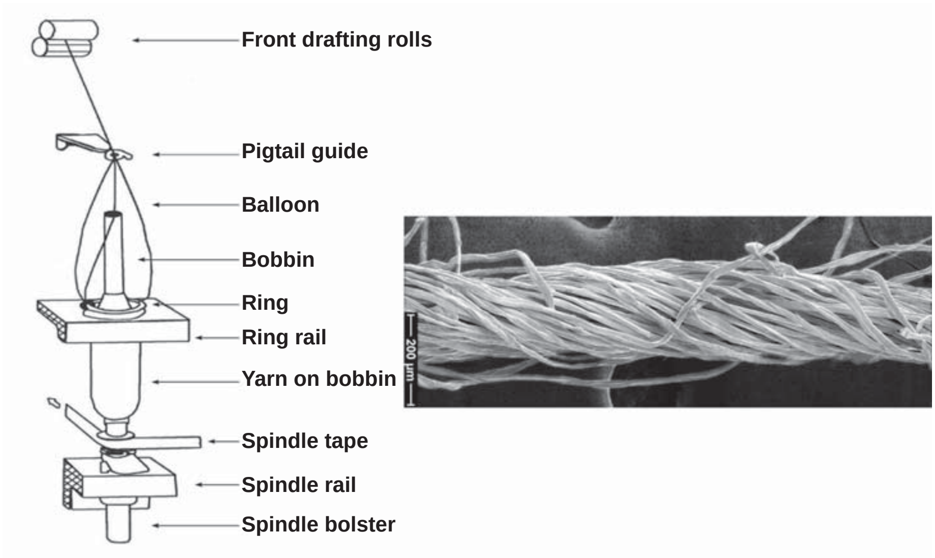

Figure A1: Schematic representation of the ring spinning process (Courtesy of Short Staple Manufacturing- McCreight, Feil, Booterbaugh and Backe, (Carolina Academic Press – 1997)) and resulting yarn (Photo: CSIRO).

Rotor spinning (open –end spinning)

Sliver is fed into the machine and combed and individualized by the opening roller. The fibres are then deposited into the rotor where air current and centrifugal force deposits them along the groove of the rotor where they are evenly distributed. The fibres are twisted together by the spinning action of the rotor, and the yarn is continuously drawn from the centre of the rotor. The resultant yarn is cleared of any defects and wound onto packages.

The production rates of rotor spinning is 6-8 times higher than that of ring spinning and as the machines are fed directly by sliver and yarn is wound onto packages ready for use in fabric formation the yarn is a lot cheaper to produce. Rotor spun yarns are more even, somewhat weaker and have a harsher feel than ring spun yarns. Rotor spun yarns are mainly produced in the medium count (30 Ne, 20 tex) to coarse count (10 Ne, 60 tex) range. End uses include denim, towels, blankets socks, t-shirts, shirts and pants.

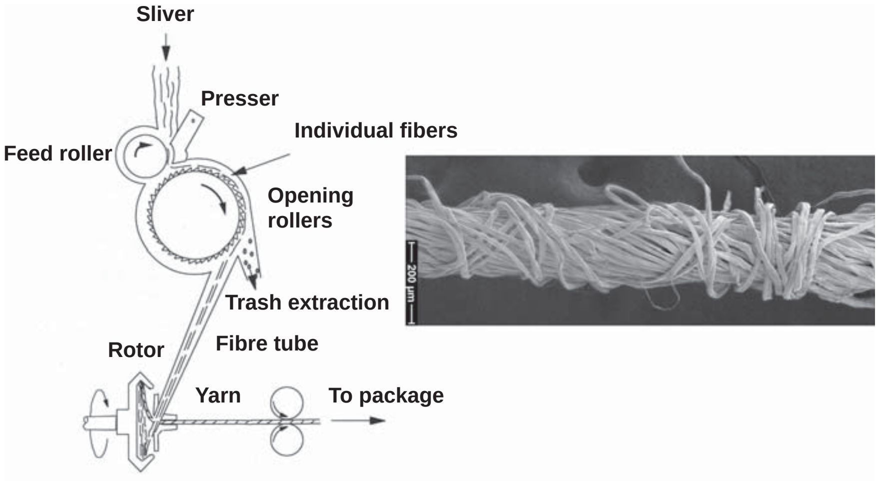

Figure A2: Schematic representation of the rotor spinning process (Courtesy of Short Staple Manufacturing - McCreight, Feil, Booterbaugh and Backe (Carolina Academic Press – 1997)) and resulting yarn (Photo: CSIRO).

Air jet spinning (vortex)

Sliver is fed into the machine and is further drawn out to the final count and twist is inserted by means of a rotating vortex of high pressured air. The resultant yarn is cleared of any defects and wound onto packages ready for use in fabric formation. The production rate of air jet/vortex spinning is 3-5 times higher than rotor spinning and 10-20 times that of ring spinning and, like rotor spinning, air-jet spun yarn is a lot cheaper to produce as it also uses fewer production stages. As is the case with rotor spun yarns, air jet yarns are more even, but weaker and have a harsher feel than ring spun yarns. Air-jet spun yarns are mainly produced in the medium count (30 Ne, 20 tex) range and are mainly polyester/cotton blended yarns. End uses include woven sheeting and knitted lightweight shirting.

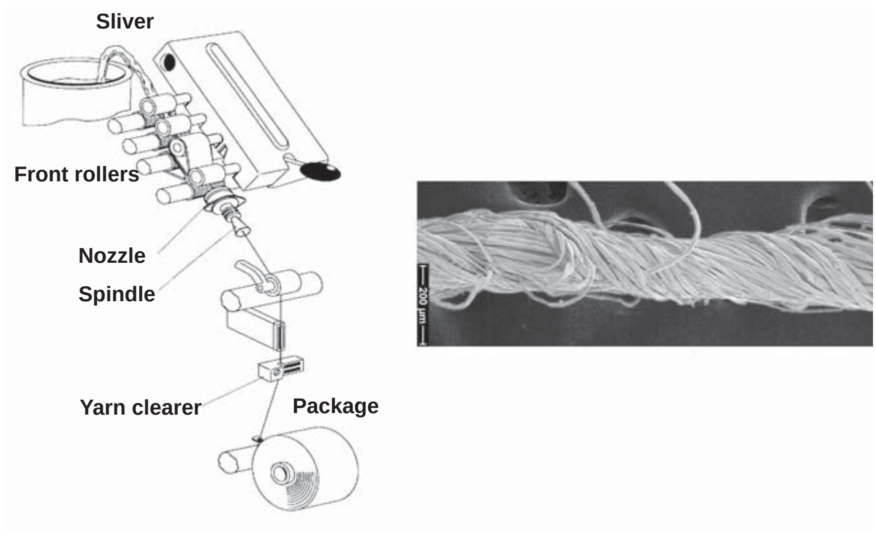

Figure A3: Schematic Representation of the Air-jet spinning Process (Courtesy Murata Machinery, Ltd.) and resulting yarn (Photo: CSIRO)

Appendix 2 – Rainfall Amounts and Frequencies for Major Cotton Growing Locations

Emerald

Variable	Mar	Apr	May
Mean rainfall (mm)	68	36	34
Standard deviation (mm)	68	41	42
Mean raindays	6	4	4
Median (mm)	51	21	24
80% yrs at least (mm)	14	2	2
20% yrs at least (mm)	100	65	54
Mean monthly maximum temperature (°C)	31.9	29.5	25.7
Mean monthly minimum temperature (°C)	19.7	16.5	12.5

Dalby

Variable	Mar	Apr	May
Mean rainfall (mm)	64	37	37
Standard deviation (mm)	51	38	37
Mean raindays	6	4	5
Median (mm)	55	27	26
80% yrs at least (mm)	19	5	9
20% yrs at least (mm)	105	66	56
Mean monthly maximum temperature (°C)	29.5	26.7	22.5
Mean monthly minimum temperature (°C)	16.8	13.3	9

St George

Variable	Mar	Apr	May
Mean rainfall (mm)	64	37	37
Standard deviation (mm)	51	38	37
Mean raindays	6	4	5
Median (mm)	55	27	26
80% yrs at least (mm)	19	5	9
20% yrs at least (mm)	105	66	56
Mean monthly maximum temperature (°C)	29.5	26.7	22.5
Mean monthly minimum temperature (°C)	16.8	13.3	9

Goondiwindi

Variable	Mar	Apr	May
Mean rainfall (mm)	54	33	39
Standard deviation (mm)	60	43	44
Mean raindays	4	3	3
Median (mm)	35	16	30
80% yrs at least (mm)	10	2	7
20% yrs at least (mm)	78	48	59
Mean monthly maximum temperature (°C)	31.6	27.6	22.9
Mean monthly minimum temperature (°C)	18.3	13.7	9.4

Moree

Variable	Mar	Apr	May
Mean rainfall (mm)	58	34	41
Standard deviation (mm)	62	37	41
Mean raindays	5	4	5
Median (mm)	41	24	28
80% yrs at least (mm)	11	4	9
20% yrs at least (mm)	89	54	64
Mean monthly maximum temperature (°C)	30.7	26.5	21.8
Mean monthly minimum temperature (°C)	17.2	12.8	8.7

Narrabri

Variable	Mar	Apr	May
Mean rainfall (mm)	58	40	49
Standard deviation (mm)	60	43	46
Mean raindays	5	4	5
Median (mm)	39	28	34
80% yrs at least (mm)	13	4	11
20% yrs at least (mm)	90	73	81
Mean monthly maximum temperature (°C)	30.9	26.9	22
Mean monthly minimum temperature (°C)	16.4	12.1	8.2

Gunnedah

Variable	Mar	Apr	May
Mean rainfall (mm)	49	39	44
Standard deviation (mm)	53	36	38
Mean raindays	5	4	5
Median (mm)	36	34	33
80% yrs at least (mm)	11	7	10
20% yrs at least (mm)	78	60	74
Mean monthly maximum temperature (°C)	29.7	26	20.9
Mean monthly minimum temperature (°C)	16.4	12.2	8.3

Bourke

Variable	Mar	Apr	May
Mean rainfall (mm)	35	28	30
Standard deviation (mm)	49	40	32
Mean raindays	4	3	4
Median (mm)	18	14	21
80% yrs at least (mm)	3	1	3
20% yrs at least (mm)	47	47	47
Mean monthly maximum temperature (°C)	31.6	27.2	21.9
Mean monthly minimum temperature (°C)	17.8	13.4	9.2

Warren

Variable	Mar	Apr	May
Mean rainfall (mm)	43	40	39
Standard deviation (mm)	47	50	35
Mean raindays	4	4	5
Median (mm)	27	25	31
80% yrs at least (mm)	5	3	11
20% yrs at least (mm)	85	62	60
Mean monthly maximum temperature (°C)	30	25.7	20.4
Mean monthly minimum temperature (°C)	15.1	10.3	6.6

Hillston

Variable	Mar	Apr	May
Mean rainfall (mm)	33	28	34
Standard deviation (mm)	41	32	26
Mean raindays	4	4	5
Median (mm)	16	16	27
80% yrs at least (mm)	4	3	10
20% yrs at least (mm)	59	47	57
Mean monthly maximum temperature (°C)	29.3	24.3	19.2
Mean monthly minimum temperature (°C)	15.5	11	7.6

Griffith

Variable	Mar	Apr	May
Mean rainfall (mm)	34	33	38
Standard deviation (mm)	60	43	44
Mean raindays	3	4	5
Median (mm)	19	22	28
80% yrs at least (mm)	10	2	7
20% yrs at least (mm)	78	48	59
Mean monthly maximum temperature (°C)	28.1	22.9	18.4
Mean monthly minimum temperature (°C)	13.6	9.4	6.4

Data source: Rainman Ver. 4. and www.bom.gov.au

Key information Resources

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