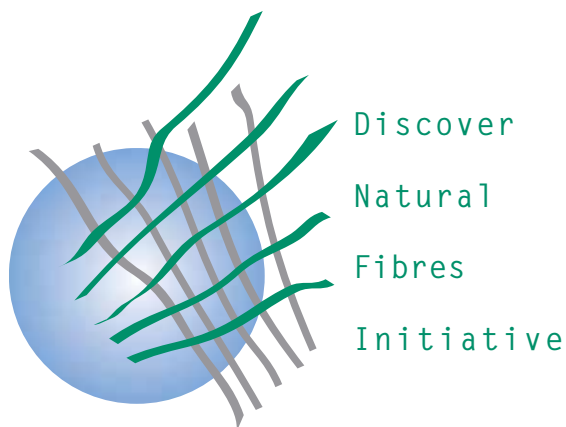




THE ICAC RECORDER

International
Cotton
Advisory
Committee



Technical
Information Section

VOL. XXXIII No. 2
JUNE 2015

Update on Cotton
Production Research



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By Jianlong Dai and Hezhong Dong, Cotton Research Center, Shandong, China	

Introduction

The first article in this edition of the *ICAC RECORDER* is on “Natural Fibers with Particular Reference to Cotton”. Natural fibers are divided into three main categories, i.e. vegetable fibers, animal fibers and mineral fibers. Cotton is classified as a vegetable fiber, which are further divided into seed fibers, stem fibers, hard fibers and fruit fibers. Cotton is a major natural fiber and accounted for 28% of world fiber consumption at the end-use level and 78% of all natural fibers produced worldwide in 2013. Jute, kenaf and allied fibers accounted for 10% of natural fibers and were the second most important natural fibers produced in the world in 2013. Coir is the third most important natural fiber, with a global production of 1.2 tons, and accounted for 3.6% of all natural fibers. Wool is the fourth most important natural fiber and accounted for a 3.5% share of natural fiber production on a clean basis in 2013. Other natural fibers, including flax, sisal, ramie, abaca, kapok, hemp, silk and other fibers of animal origin cover almost 5% of natural fiber production. All natural fibers are briefly discussed in this article.

The second article is on “Nonwoven Uses of Cotton – An Update” and goes beyond the two previously published articles on this subject (*ICAC RECORDER* issues of September 2003 and 2008, respectively). This article is based on papers and summaries/abstracts of papers published in the Proceedings of the Beltwide Cotton Conferences from 2009 to 2015. No international paper on nonwovens was presented at the Beltwide Cotton Conferences in the same period. The current article reveals that the use of cotton in mattresses was quite widespread up until the early 1970s, at which time the US government enacted a Smolder Ignition Standard for all mattresses produced and sold in the country. Polyester and polyurethane foam were better able to comply with the new standard. In 2007, the standard was changed to include resistance to ignition by an Open Flame Source, a test in which cotton performs better than competing materials. As a result, cotton continues to recover market share in the mattress raw material industry. Flame retardancy and durability after washing (not applicable to mattresses) remains a concern for

enhanced market share of cotton in nonwovens. All these issues are discussed in the current article.

China is the largest producer and consumer of cotton in the world. In the recent past, cotton area has declined, and India surpassed China as the world’s leading producer in 2014/15. However, cotton yields in China in 2014/15 were almost 200% of the world average and significantly higher than those in India, Pakistan and the USA. Many factors specific to China are responsible for such high yields. The intensive farming technologies and cultural practices include double cropping, transplantation of seedlings, plastic mulching, plant training and super-high plant density, which are not utilized in other countries. Though contributing to higher yields, these technologies are labor-intensive and involve extensive use of various kinds of chemical products, such as fertilizers, pesticides, and plastic film. The low comparative benefits of cotton production, compared to competing crops, have inevitably caused the planted area to decrease year after year. Thus, there is a need to implement a series of comprehensive measures to increase benefits through simplifying field operations and mechanization, reforming cropping systems and reducing soil pollution through the rational use of plastic films and chemicals. Dr. Jianlong Dai and Dr. Hezhong Dong of the Cotton Research Center, Shandong Academy of Agricultural Sciences, Jinan, Shandong, China, discuss many more aspects of cotton production, with a focus on increasing yields, in the third article.

New Dates for the World Cotton Research Conference-6

The dates for the World Cotton Research Conference-6 have been changed to May 2-6, 2016. The Conference will be held in Goiânia, the capital of the State of Goiás in Brazil. Two hundred and thirty eight researchers from 28 countries had pre-registered by June 8, 2015. The full registration package will be available from August 20, 2015. For additional information, visit the Conference web page at <http://www.wcrc-6.com>.

12th Meeting of the Inter-Regional Cooperative Research Network on Cotton for the Mediterranean and Middle East

The 12th Meeting of the Inter-Regional Cooperative Research Network on Cotton for the Mediterranean and Middle East will be held in Sharm El-Sheikh, Egypt, from October 7-9, 2015. The meeting will discuss all aspects of cotton production research and recent developments in the cotton sector in the regions. The Organizing Committee has invited eminent researchers from outside the region to present an international perspective of current issues in production research. Researchers from the public and private sector from the regions and outside are invited to attend. Brochure

and registration are available at <https://www.icac.org/tech/Regional-Networks/Inter-Regional-Cooperative-Research-Network-on-Cot>. While the registration must be made immediately, the deadlines to submit abstracts and make hotel reservations are July 31 and August 15, 2015, respectively.

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Natural Fibers with Particular Reference to Cotton

M. Rafiq Chaudhry and Lorena Ruiz, ICAC

(The authors do not specialize in all natural fibers, so the facts and figures in the present article have been taken from many sources that are greatly acknowledged for their contributions to natural fibers)

Cotton is a natural fiber produced by a perennial tree that has been domesticated to grow as an annual plant. The extensive research done on cotton became more formal and better understandable after it was discovered that there are genes that carry a blueprint of the characters to be expressed under a given set of growing conditions. Such discoveries, unimaginable in the early years of cotton research, were severely questioned and remained shelved for about half a century. The theory of evolution did not satisfactorily address many concerns and it was practically impossible to give up the long-held belief in the inheritance of acquired characters. Fortunately, however, the law of inheritance of characters and the independent assortment of genes were rediscovered and applied. Thus began the formal breeding process we know today, and the world's most important natural fiber crop best benefitted from this is cotton. Almost another half century went by before the structure of DNA was described in the 1950s. The interspecies transference of genes was followed by the technique of actually modifying the DNA. Once again, cotton was the crop that benefitted most from the interspecies crossover of genes, which by now is no longer a novelty. Cotton was one of the first crops to make use of recombinant DNA technology to induce a mechanism of inbuilt resistance to the most damaging bollworms and tolerance to the most frequently used herbicides. Currently, over two thirds of the world cotton area is planted to insect-resistant and herbicide-

tolerant biotech varieties created by means of the thorough implementation of the development process mentioned above. The present article does not deal exclusively with cotton but also discusses, to a limited extent, the other natural fibers and the challenges they face, particularly in view of the rapid growth in the production of manmade fibers.

According to ICAC figures, 83.3 million tons of textile fibers were consumed in the world in 2013. In the same year, the production of natural fibers decreased for the second consecutive year and did not surpass 34.7 million tons. Cotton lint is the major natural fiber consumed around the world. It accounts for 28% of world fiber consumption at the end-use level, and for 78% of all natural fibers produced worldwide. About 3.29 million tons of jute, kenaf and other similar fibers were produced in 2013¹, making the group the second largest block of natural fibers. Together they accounted for almost 10% of natural fibers in the world. Coir, with a global production of 1.2 tons², is the third largest natural fiber produced in the world, and accounted for 3.6% of all natural fibers. However, coir fiber rarely finds its way into textile products. Wool is the fourth largest natural fiber produced. It accounts for 3.5% of the total share, with a global production of 1.16 million tons in 2013, clean basis³. All other natural fibers, including flax, sisal, ramie, abaca, kapok, hemp, silk and the group of fibers of animal origin, such as camel hair or vicuna wool, amount to almost 5% of natural fiber production.

1&2) Food and Agriculture Organization of the United Nations, December 2014.

3) International Wool Textile Organization

Table 1: Production of Natural Fibers

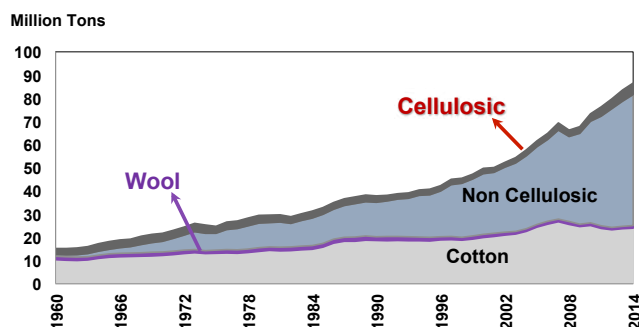
Fiber Type	Production in 000 Tons	Production by Share in %
	2013	2013
Vegetable Fibers		
Cotton	26,270.0	75.7
Jute	3,422.7	9.9
Coir	1,205.6	3.5
Flax and tow	303.1	0.9
Sisal	281.6	0.8
Other Bastfibers	257.2	0.7
Ramie	124.3	0.4
Abaca (Manila fiber)	103.5	0.3
Kapok	101.3	0.3
Hemp tow waste	56.4	0.2
Total:	32,125.6	92.6
Animal Fibers		
Wool, greasy	2,126.9	6.1
Silk raw	167.9	0.5
Total:	2,294.8	6.6
Mineral Fibers		
Asbestos cloth, glass, fiber glass, minerals and other fibers not included above	269.4	0.8
Total:	269.4	0.8
Total:	34,689.7	100.0

Source: ICAC for cotton and FAO for other fibers

Table 2: Production and Consumption of Textile Fibers - Change in 50 Years

Fibers	Share in Consumption (%)		Change in 50 Years	
	1964	2014	Change in Production	Change in Consumption Share
Cotton	62.8	27.7	Increased by 121%	Decreased by 56%
Wool	8.5	1.3	Decreased by 26%	Decreased by 85%
Cellulosic fibers	19.0	5.8	Increased by 53%	Decreased by 69%
Non-cellulosic fibers	9.8	65.3	Increased by 3250% or 33 times	Increased by 568%
	100.0	100.0		

Source: World Textile Demand, ICAC, April 2015

Figure 1: World Consumption of Textile Fibers

Synthetic fibers are referred to severally as manmade, chemical, artificial and modern fibers. Synthetic fibers may be of two kinds: cellulosic, which are only partly synthetic, and non-cellulosic, which make up the largest group among all fibers consumed in the world. ICAC statistics show that over the past half century, dramatic changes have occurred in world consumption of the major textile fibers. Consumption of textile fibers increased from 15 million tons in 1961 to an estimated 86.5 million tons in 2014 and over 90.0 million tons (forecast) for the year 2015.

Natural Fibers

Natural fibers are substances produced by plants and animals and capable of being spun into yarn, thread, rope and filaments.

Natural Fibers	Synthetic Fibers
1. Natural fibers have been used for centuries and are produced under natural conditions.	1. Synthetic fibers were invented one by one over the last 140 years. The first synthetic fiber was developed in the early 1880s, but for use in light bulbs, not textiles. - Nylon was developed in 1931 - Polyester fiber in 1941 - Acrylic in 1951
2. The raw material required to produce natural fibers is also naturally occurring. Natural fibers can be produced without any synthetic materials, though synthetic materials, such as agrochemicals, may be used to boost production and improve quality.	2. Synthetic fibers do not necessarily depend on naturally occurring materials; they depend mostly on chemical reactions with certain directed objectives. Selective chemical actions and reactions can be hazardous.
3. Natural fibers are more comfortable to wear but do not last as long as synthetic fibers. They do not develop an electrostatic charge and allergic reactions to wearing them are few or non-existent.	3. Because of the chemicals involved in their production, synthetic fibers are more prone to heat damage and develop an electrostatic charge when they are rubbed together. Some people are allergic and simply cannot wear manmade fibers.
4. Natural fibers have naturally occurring qualities. The four most important natural fibers are: - Cotton. Soft, highly absorbent and able to take various treatments, including dyes. - Wool. Warm and wrinkle resistant making it perfect for winter clothing. - Silk. Lightweight, very sheer, highly flexible and capable of being spun at higher counts to provide an excellent luster. Silk is naturally anti- bacterial and energy efficient in ironing. - Linen. Fabric produced from flax. Like cotton, it is a cellulosic fiber, but almost twice as strong and over 20 times longer. Wrinkling is a limitation, but blending with cotton for garments has potential and is on the increase.	4. All the qualities of synthetic fibers are expressed by design and can be manipulated better than in natural fibers where linkages and negative impacts are more pronounced. Synthetic fibers are comparatively easy to alter to comply with the qualities preferred by consumers. Changes and improvements are being introduced at a much faster rate than in natural fibers.
5. Natural fibers are biodegradable and disappear back into nature for the improvement of the environment.	5. Synthetic fibers are not biodegradable and those that are degradable do so at a much slower rate than natural fibers and may leave an impact on the environment.
6. Natural fibers compete for land to the detriment of food crops. The competition is getting stronger as a result of population increases and climate change. The need to find better land may exert downward pressure on world cotton area in the future. Other natural fibers, of which jute and hard fibers are another major group, also compete with food crops in India, Bangladesh and China, the three most populated countries and almost the sole suppliers of jute in the world.	6. Synthetic fibers do not compete with food crops for land, but the two important limitations are: - Heavy initial investment involved in putting up manufacturing plants. - Very high energy requirements that limit production to areas with the required conditions.
7. Natural fibers may be staple (cotton) or filament (silk). The composition of natural fibers cannot be changed. Cotton is almost 96% cellulose, but scouring and bleaching can raise the concentration to 99%. The cellulose content cannot be lowered through breeding or any other natural process.	7. Synthetic fibers are long filaments but can be cut for use as staple fibers. In most cases, the sources of raw materials used to make a particular synthetic fiber or composition can be adjusted. Acrylic, nylon and polyester can be made from oil and coal products.
8. Most natural fibers can absorb water. Cotton is capable of absorbing over 25 times its weight in water.	8. Synthetic fibers are hydrophobic and can retain only small amounts of moisture. Synthetic fibers dry faster than natural fibers and are easy to care for.

Natural fibers were the first to be produced; manmade fibers were invented to compensate for the shortfall in the supply of the natural raw materials used to make goods for human consumption. Anything that cannot be spun to make yarn, thread or rope and converted into a cylindrical shape cannot be considered a fiber. The only part of the cotton plant that is used for fiber is an outgrowth from the seed coat that has a specific length. The tiny cellulosic material, similar to the constituents of a cotton fiber that cling to the seed coat during ginning, is called fuzz. This material is removed by mechanical and chemical means and put to many uses. From 90 to 92% of the rest of the ginned seed components are all profitably used, but linters/fuzz find their way into viscose, cellulosic esters and ethers, cellulose nitrate, paper yarn (lamp and candle wicks, twine rugs, mops, etc.) and felts (automotive upholstery, pads, cushions, furniture upholstery, comforters, mattresses, etc.). So, linters as short fibers find their way not only into natural fiber materials, but also into synthetic fiber materials.

The quality characteristics of natural fibers may be altered, but not at the will of the consumer industries. Cotton consumers would very much like to have cotton lint supplied in natural colors, such as yellow, blue, black, etc. However, the necessary research is not yet sufficiently advanced. It is certainly possible to have the plant botanically form a lumen with material bodies that can express a brown color (currently, brown in various shades) or a lipid biopolymer sandwiched between the lamellae of the cellulose microfibrils in the secondary wall. Research is not limited to materials in the lumen or lipid biopolymers, as is the case with currently available colored cottons, and many more options are feasible utilizing non-traditional approaches.

Quality improvements in cotton have achieved tremendous advances. The traditional demand from the textile industry for longer fibers has effectively been met. Textile needs have shifted to a lower micronaire, then to a stronger fiber, and then to a more uniform fiber, etc. and these requirements have been met through the concerted efforts of cotton researchers without straying from the key focus of improving yields. The results achieved so far may not be as significant as in synthetic fibers, but they are being attained with a minimal impact on the environment. Every bit of cotton fiber production today is much more sustainable than twenty, thirty or forty years ago. Similarly, great strides have also been made in other natural fibers.

Throughout the history of their development, technological innovations have followed different courses. This is true for natural fibers (produced from living organisms) as well as for the chemical processes involved in the textile finishing industry. One such recent technological innovation was the use of genes from non-*Gossypium* species to achieve targets within a very specific range of possibilities. In this case, the objective was not to change the nature of the fiber produced by the cotton plant, but to eliminate the obstructions that prevent growers from achieving cotton yields that are

perfectly feasible. Transgenic cotton achieved by borrowing a gene from another naturally occurring living organism still produces a natural fiber. The agronomic practices implemented over the last twenty years of commercialization of this technology have worked for the good of the economy and for the environmental solidarity of the natural fiber—cotton. Undoubtedly, both avenues have had a beneficial impact on the social wellbeing of the communities concerned. Farmers were able to reduce their unit cost of production and millions of marginal growers were able to continue producing cotton. Without the development and adoption of biotech cotton it would be difficult to imagine what the pesticide industry would have had to bring on line to achieve similar results. The recovery of the cotton industry from various insecticide resistance management strategies would have been much slower and no one knows with any degree of certainty how many more countries might have become ensnared in the implications stemming from the use of insecticides—the most dangerous chemicals ever applied to produce not only natural fibers, but food crops as well. The cotton production map of the world might have been changed and the share of natural fibers consumed at the end use level in the world would have declined even further than the cumulative loss of 28% recorded in 2014.

Cellulosic fibers can also be manufactured from naturally occurring materials like wood pulp, but they are not considered to be natural fibers. Manufactured cellulose or semi-synthetic fibers are made from plant materials that are ground into a pulp and then processed and formed by methods similar to those used in manufacturing synthetic fibers. The best examples of semi-synthetic or cellulosic fibers, wherein a natural raw material is used to make fibers, are rayon and viscose rayon. Rayon is made from regenerated cellulose, mostly acquired from purified wood pulp. The pulp is converted into a soluble cellulose compound and then processed to produce a chemically solidified filament. The end result of pulping, conversion into a soluble material and chemical solidification is a pure cellulosic fiber/filament, not a natural fiber. However, because of its origins in natural materials, rayon can be processed to have many of the same properties as natural fibers.

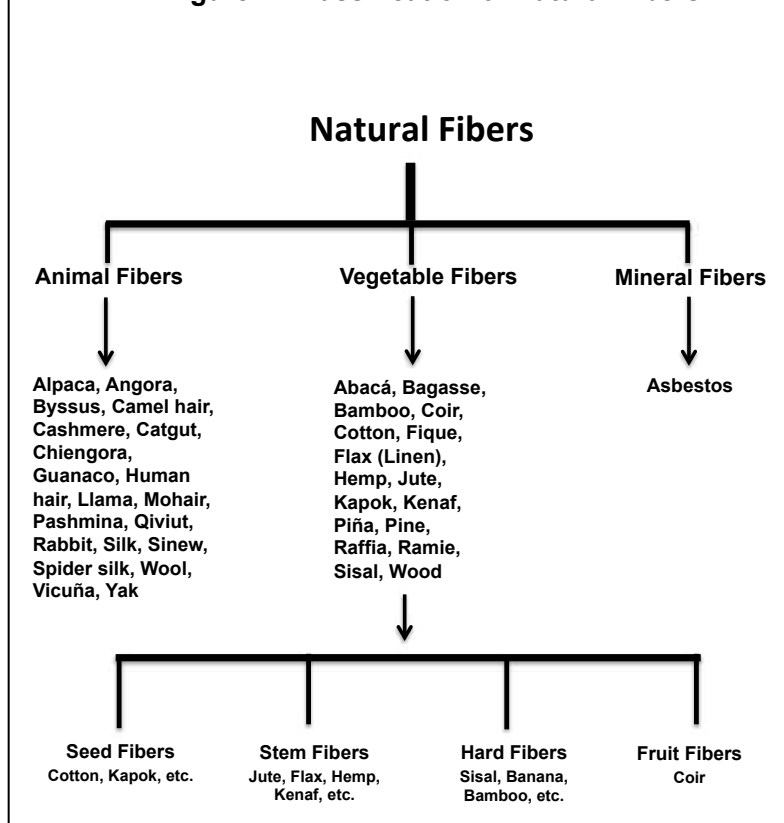
Types of Natural Fibers

Natural fibers are classified as vegetable fibers or plant fibers, animal fibers and mineral fibers.

Plant Fibers

- Seed Fibers

The sources of vegetable or plant fibers are seeds like cotton and kapok. Cotton is known for being the most important and dominant natural fiber in the world. Kapok (*Ceiba pentandra*) is a tree and the fibers produced by this perennial tree are also called kapok. Just as cotton fiber grows on the cotton seeds, kapok fibers grow on kapok seeds. Kapok is a rainforest tree that grows up to

Figure 2: Classification of Natural Fibers

a height of sixty meters. A full-grown tree can yield up to 15kg of fiber a year. The trunk of the kapok tree is used as a source of timber, which is currently its main application. The fibers grow inside a pod that is naturally shed by the plant. When the pods are mature, they burst open and expose the whitish fibers in which the round, brown-colored seed is imbedded. Wind can carry the fibers around together with the seed. Most of the kapok fiber output is used in stuffing or insulation, but it has been replaced in these uses by polyester and foam plastics.

- **Stem (Bast) Fibers**

Bast fibers are collected from the inner bark or bast surrounding the stem of the plant. These fibers have higher tensile strength than other fibers. Therefore, these fibers are used for durable yarn, fabric, packaging and paper. Jute is the most important bast fiber; it accounts for almost 7% of all natural fibers produced and is second only to cotton. Other examples of bast fibers are flax, kenaf, hemp and ramie. Jute is produced in high rainfall areas, mostly in Bangladesh, China and India. According to the International Jute Study Group, jute (*Corchorus capsularis* and *Corchorus olitorius*), and similar fibers such as kenaf (*Hibiscus cannabinus*) and roselle (*H. sabdariffa* var *Altissima*), are mostly produced in a handful of major producing countries: India, Bangladesh, China, Thailand, Myanmar and Nepal.

Together, these account for about 95% of all jute and similar fibers. India and Bangladesh are the world's foremost manufacturers of jute. India alone represents almost two thirds of world jute production, Bangladesh about one third and only minor amount are produced in other countries. China produces mostly kenaf while Thailand produces kenaf and roselle.

Linen fabric is produced from fiber extracted from the stems of the flax plant. Flax seeds are used to produce linseed oil. Hemp (*genus Cannabis*), a close relative of marijuana, produces a fiber that looks very much like linen and its seeds are used to make birdfeed and to extract oil. Many European countries produce small quantities of hemp, but China remains the biggest source of hemp fiber.

Ramie is a perennial tree that grows well in areas with good rainfall. The main species is *Boehmeria nivea*, but several closely related species are also grown. The ramie plant has the appearance of a shrub and grows to a height of over 1.5 meters. The stems are usually harvested after flowering and when its color has changed from green to yellow. Leaf shedding is another indication that the crop is ready to be harvested. With good soil and suitable weather, the ramie plant can produce as many as six cuttings, i.e.,

harvests, a year. A ramie plant can produce fiber up to 12 centimeters in length, but requires chemical treatment for removal of the resin that causes the fibers to adhere to the main stem.

- **Hard Fibers**

Hard fibers are collected from leaves and fruit parts. Sisal, banana and bamboo are some examples of leaf fiber production. Many species of the genus *Agave* are produced around the world. The general appearance of most species is that they lack a stem and that the leaves emerge directly from the roots. However, some species do have a visible stem and uses other than for fiber are also well documented. *Agave Americana* is the source of the agave found in Mexico and southern parts of the United States. The leaves of several other agave species also yield fiber and many agave species are grown as ornamental plants.

Sisal (*Agave sisalana*) is a perennial plant with an average lifespan of 7 to 12 years. The plant flourishes in dry-hot soil and weather conditions, reaching an average height of 4-6 meters (about one third of a meter height increase each year). About 300,000 tons of sisal are produced every year almost without any insecticides, irrigation water or fertilizer. The leaves that yield the fiber are composed of about 90% water. Leaves grow to a length of 1.0 to 1.5 meters in length and have spikes on the edges, which

makes it hard to walk through the fields. The first harvest can be brought in when the plants are about two years old and they remain productive for 10 to 12 years. Each plant produces 180 to 240 leaves in its lifetime and yields 1 to 4 tons of fiber per hectare. The leaves are removed from the plant only when they are ready to be processed. Storage of leaves is not recommended because the quality of the fiber tends to deteriorate. The fibers are extracted through a process known as decortication wherein the leaves are processed by running them through crushers to free the fibers and get rid of the pulp. After the pulp has been squeezed out, the fibers are washed or brushed to leave them more perfectly clean. In East Africa, decortication is done in factories. The leaves are crushed between rollers and then beaten by a rotating wheel with blunt blades. Then the fibers are washed and dried. The key features of sisal fiber are high resistance to bacterial infestation and to deterioration in saltwater. The flowers produced by the sisal plant are usually sterile and the common way of propagating the next generation is through suckers that grow at the base of the plant or by means of small bulbs produced on the flower peduncle. In the past, 96% of the leaf weight was discarded, but today it is used for fertilizer, cattle feed and as fuel for biogas production. Just over 200,000 tons of sisal fiber are produced worldwide and Brazil, with almost two thirds of global production, is the largest producing country.

Banana fibers are extracted from the stem of the banana plant (*Musa sapientum*). The fiber may be harvested from young shoots or from the mature stem after the fruit has been collected. Unlike many other vegetable/plant fibers, the parts of the plant from which the fiber is extracted -- young shoots and/or older stems-- have an important impact on the quality of the fiber. Young shoots are comparatively easy to process and produce much finer fibers. Accordingly, their uses are also different. Young shoots are harvested periodically and boiled in lye to prepare fibers for making yarn. Even in young shoots the outer layers of the stem produce much coarser fibers than the inner ones. The mature trunk in its entirety, commonly used in Nepal to obtain banana yarn, produces a vast quantity of coarser fibers. According to the literature, the fibers of the banana plant may be extracted by chemical, mechanical or biological methods. Banana fibers look like bamboo and ramie fibers but have a better spinning performance than the other two. The fibers have poor elongation characteristics, but dry rather faster. Banana fibers are comprised of cellulose, hemicellulose, and lignin. Mukhopadhyay *et al.* (2008) reported that the botanical composition of banana fiber is about 31% cellulose and some 15% hemicellulose and lignin, the rest being moisture, ash and extractives. The uses of banana fiber vary greatly depending on the fineness, but only a minimal amount goes into the garment industry. Right now, banana fiber is a waste product of banana cultivation

and it is utilized inefficiently or only partially. The extraction of fiber from the pseudo stem is not a common practice and much of the stem is not used to produce fiber at all.

- **Fruit Fibers**

Coir is the primary fruit fiber. It is produced from the fibrous pulp surrounding the hard shell of the seed of the coconut palm (*Cocos nucifera*). Coconut palms flower monthly but since the fruit requires a year to ripen, any given coconut palm will always contain fruit at all 12 stages of maturity. Harvesting usually takes place on a 45-60 day cycle, with each tree yielding 50-100 coconuts per year. Before the coconut fruit is shipped to market, it is stripped of its leathery external skin, as well as its 5-8 cm thick intermediate layer of fibrous pulp. The fibers recovered from that pulp are called coir. Coir is the third most important natural fiber produced in the world, after cotton and jute. The main producing countries are India and Sri Lanka, with some minor production in the Pacific countries. About 75% of coir fiber comes from India and Vietnam. Total production rose to 1.2 million tons in 2013.

The fibers are extracted by various methods involving retting and soaking. The husk is kept in an environment that encourages the action of naturally occurring microbes. This action partially decomposes the husk pulp, allowing it to be separated into coir fibers and a residue called coir pith. After the husks are naturally softened by the above methods, the fibers are extracted manually by beating or mechanically through various mechanisms. The fibers thus removed are sieved for cleaning purposes before processing to obtain the final product. The main uses are rope, fishing nets, brushes, doormats, rugs, etc. Fibers are 100% biodegradable. Coir fibers measure around 35 centimeters and contain one of the highest concentrations of lignin, making it stronger than cotton but less flexible and unsuitable for dyeing. The two categorizations of coir fibers are color (brown or white) and fiber length. Coir fibers longer than 20 cm are called bristle fiber and those shorter than 20 cm are called mattress fiber.

Animal Fibers

The two fundamental animal fibers are silk and wool.

- **Silk**

Silk is a filament fiber produced in nature as a protein by *Bombyx mori*, the mulberry silk moth. Mulberry *Morus* spp. is a perennial cultivated mainly for foliage production, but it is also the only source of nutrition for the mulberry silkworm. According to the International Sericulture Commission, four types of natural silks are commercially produced in the world. Among them mulberry silk is the most important and accounts for as much as 90% of world production. Thus the term "silk" generally refers to the silk of the mulberry silkworm. It

is reported that 60% of the cost of cocoon production goes into the cultivation of the mulberry leaf. Silk quality also depends on the quality of the mulberry leaves and on silkworm seed production. Mulberry is grown in the fields as an agricultural crop. The leaves are harvested and brought to the silkworm rearing facilities where they are fed to the silkworms in separately erected platforms or trays. After a gestation period of about four weeks, the mature worms are gathered and transferred into the montages for spinning the cocoons. The spinning process will be completed within three days and the cocoons can be harvested for marketing after five days. About 70-75% of world silk is produced in China, about 15% in India and the rest in some 15 other countries around the world.

- Wool

Wool, a protein fiber, is the fourth most important natural fiber traded in the world. It accounts for over 6% of total natural fiber production. The four main sources of wool are sheep, goats, camels and rabbits. The wool from diverse sources has different fiber diameters and, therefore, huge differences in quality. Wool fiber can be as fine as cashmere/merino (diameter about 15 microns) to make expensive garments or it can be coarse enough (diameter about 40 microns) to make carpets. A single sheep can produce up to 11 kilograms of wool a year (clean basis). It is estimated that half of all wool production goes into the garment industry and the other half is used to make blankets, carpets and other goods. The flame-retardant and heat-resistant qualities of wool make it one of the safest of all household textiles. Technical textile uses include police uniforms, military uniforms, thermal insulation, billiard cloths and automotive composites. Wool is produced in about 100 countries, but Australia, China and New Zealand account for half of the world's production.

International Year of Natural Fibers - 2009

The United Nations General Assembly declared 2009 as the International Year of Natural Fibers. The Food and Agriculture Organization of the United Nations, in collaboration with governments, regional and international organizations, non-governmental organizations, the private sector and the relevant organizations of the UN facilitated the observance of the Year. The ICAC actively participated in the celebration

and success of the Year by carrying out numerous activities. The Year proved to be effective in increasing awareness of the importance of natural fibers. An overview of fifteen natural fibers -- abaca, alpaca, angora, camel, cashmere, coir, cotton, flax, hemp, jute, mohair, ramie, silk, sisal and wool -- is available on their web page.

Future Trends

The last 150 years have completely changed the fiber spectrum. Synthetic fibers have aggressively outstripped the share of natural fibers produced in the world. New technologies are being developed at such a fast pace that it is becoming increasingly difficult to fully comprehend the future of both kinds of fiber, natural and synthetic. What is needed now is for natural fibers to incorporate some of the qualities of synthetic fibers, while the synthetic fiber industry needs to endow its products with the combined features of natural fibers. Neither of the two options is a clear-cut choice and both depend on access to technological advances. It seems clear, however, that the future lies somewhere in the middle ground. Biotechnology and its allied sciences, innovative material advances and fiber engineering will play a key role in determining the future of all kinds of fibers.

For more reading refer to:

<http://www.naturalfibres2009.org>
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<http://www.madehow.com/Volume-6/Coir.html>
http://inserco.org/en/types_of_silk
<http://www.iwto.org/wool/the-natural-fibre/>

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Nonwoven Uses of Cotton – An Update

This article is an update of two previously published articles on nonwovens. Readers are strongly advised to consult the articles in Volume XXI, No. 3, 2003 and Volume XXVI, No. 3, 2008 of the *ICAC RECORDER*. The reason is that this article is comprised of papers/summaries presented at the Beltwide Cotton Conferences, organized by the National Cotton Council of America, from 2009 to 2015; papers prior to 2009 are not included here. Cotton continues to account for a small proportion of the nonwoven segment of the industry but, because of its inherent characteristics, has huge potential to enhance its share in this sector. The 2003 article of the *ICAC RECORDER* focused on technologies used in bonding fibers and on the market for nonwovens. In the 2008 article, which focused on the future of cotton in nonwovens, Amar Paul Singh Sawhney and Brian D. Condon discussed the factors responsible for the more limited use of cotton in nonwovens compared to synthetic fibers. Ultra high speed nonwoven production technologies demand uninterrupted mass-scale production of standardized nonwoven products. So, cotton can improve its share only if continuity in processing can be assured. The current article goes beyond the two previously published articles. All papers and summaries or abstracts of papers published in the Proceedings of the Beltwide Cotton Conferences since 2009 were reviewed and appear here organized by subject matter. The information is consequently limited to US conditions.

Use of Cotton in Mattresses

Cotton is readily flammable and requires chemical modification to become flame-resistant for safety and high volume uses. The use of cotton in mattresses was quite widespread until the early 1970s, when the US government enacted a smolder ignition standard (16 CFR 1632) for all mattresses produced and sold in the country. The standard for the flammability of mattresses and mattress pads provided for a test to determine the ignition resistance of a mattress or mattress pads, based on exposure to a lighted cigarette. The standard also provided optional test methods for ticking and edge tape substitution that can be used to reduce the number of additional prototype tests. This test method only evaluated the ignitability of mattresses. To evaluate the burning behavior, the mattress needed to be tested with larger ignition sources. Polyester and polyurethane foam could easily comply with the smolder ignition standard but not with an open flame standard. Cotton researchers tried to develop a product that could enable cotton to comply with the requirement but were unable to devise a successful product in due time. Consequently, cotton started losing its share in mattress raw materials. Later, in February 2006, the US Consumer Product Safety Commission adopted a new regulation (16 CFR 1633) that required mattresses, mattress sets, and futons manufactured on or after July 1, 2007, to resist ignition by an open flame source, such as a

candle, match or cigarette lighter. Cotton performed better to an open flame source than competing raw materials. A lot of work has been done to develop a fire-resistant feature for mattresses. The two commonly used means by which cotton is made fire-resistant are: treatment with boric acid (boron) and phosphates. Much research has been done to improve the safety and durability of these products. As a result, cotton continues to perform better and recover market share in the mattress raw material industry.

Researchers have been working to improve the flame-retardancy of cotton in nonwovens. Technologies were explored successfully, but the problem was that the flame retardancy property was not durable to washing. Wash durability does not apply to mattresses, but is required in some nonwoven applications. The flame-retardancy feature has to be induced using a treatment that is economically feasible at the commercial use level. The third important issue is that mutual/combined suitability of flame-retardant materials and binders must be achieved such that some degree of permanency is maintained. On the other hand, most durable materials treated for flame retardancy exhibit lower strength properties and permeability, shortcomings that need to be avoided. Mercimek *et al.* (2009) concluded from their studies that chemical binders have an important effect on the wash durability of cotton-based, flame-retardant nonwoven webs. The effect of binders on the durability of a web is much more pronounced in samples that have 10% binder in the formulation of their flame-retardancy solutions. In the samples studied in their research, as chemical binder levels increased, so too did the percentage loss of flame retardant chemicals used in the retardancy treatment. The tests revealed that a chemical bonding agent is required for the investigated flame retardant chemicals in order to achieve wash durability in cotton-based nonwoven webs. The Limiting Oxygen Index tests showed that the cotton web is able to pass this test even after washing if the desired level of flame-retardant chemical can be obtained.

In the light of the new regulation 16 CFR 1633, the Southern Regional Research Center of the USDA is working on an approach to delay the flash burst of a mattress when it catches fire. The mattress would burn slowly and flashover would occur 30 minutes later, thus allowing occupants to escape safely. Limiting the intensity of a mattress fire will save lives and reduce injuries from home fires. The ‘green barrier fabric’ is unique in the sense that it is made from a renewable source; it is biodegradable and economical to produce since it employs unbleached cotton, thus increasing its marketability. Work is also proceeding on the Moisture Vapor Transport Rate (MVTR), which is a critical factor in determining the use of lightweight cotton nonwovens in chemical and biological protection materials.

High Loft and Flame-Retardancy in Nonwovens

It is estimated that about 14,000 household fires occur in the USA every year, causing 330 deaths and property losses estimated at US\$300 million (Uppal *et al.*, 2010). Some other numbers in different terms are also quoted, but there is no doubt that undesired fires are extremely dangerous and result in huge losses. According to Uppal *et al.* (2010), flame-retardancy has been a serious bottleneck in the development of cotton-blended high volume bulky high loft fabrics. Various mixes of cotton-blended high loft fabrics were tested in order to improve flame resistance and physical resiliency. Flame-retardant cotton fibers that had been chemically treated with a flame resistant chemical (developed at the Southern Regional Research Center) were used. The flame-retardancy formulation consisted of MDHEU (5%), diammonium phosphate (10%), urea (5%), Triton X-100 (0.7%), polyethylene emulsion, MgC_{12} , $6\text{H}_2\text{O}$ (1%), citric acid (1%) and water (75.8%). Thirteen different blends were prepared by mixing greige cotton, Southern Regional Research Center For Retardant cotton, fire retardant Lenzing rayon and binder in order to form high lofts for evaluation. Binder limits ranged from 15 to 25% while the three materials varied from zero to 85%. Samples were tested for flammability employing the Limiting Oxygen Index, the most common test for textile materials, and the small open flame test (TB604 or 16CFR part 1634). The samples produced in the experiments were subjected to the flammability test after conditioning them for at least 24 hours under standard laboratory conditions ($21^\circ\pm 1^\circ\text{C}$ and $65\%\pm 10\%$ relative humidity). The Limiting Oxygen Index method described the tendency of a material to sustain a flame. The flame retardancy of fire-retardant cotton blends with varying degrees of binder fibers (from 15 to 25%) was the highest among the 13 blends tested in this experiment. Blend samples containing greige cotton in some proportion showed poor Limiting Oxygen Index performance. The results demonstrated that the Southern Regional Research Center formulation for flame retardancy was quite effective, since the formulation imparted flame-resistance to the high lofts, and that greige cotton definitely required flame-retardancy treatment.

A paper on a similar topic was presented at the 2011 Conferences wherein Rohit Uppal and his collaborators tested five blends in various mixes of fire-retardant grey cotton, antibacterial grey cotton and bicomponent binder fiber, comprising 13 total entries, as above. They observed that blended high loft nonwoven fabrics showed high Limited Oxygen Index except for the cases in which cotton was not treated with any fire retardant. Antibacterial properties from the treatment for bacterial activity were also verified. Hence, since there is no need for a coating, the product retains a soft feel. In this study, the Southern Regional Research Center flame-retardant cotton or fire-retardant rayon was blended with a binder to form high lofts and then evaluated. Using the

Limited Oxygen Index test, the Southern Regional Research Center flame-retardant cotton with a binder yielded a Limited Oxygen Index value of up to 31.5, whereas flame-retardant rayon with a binder yielded a Limited Oxygen Index of up to 26 only. Results showed that the formulations imparted flame resistance to the high lofts.

Diammonium phosphate (DAP) compounds offer resistance to combustion by lowering the decomposition temperature of cellulose, favoring dehydration and thus reducing the formation of a combustible volatile fuel compound. In addition, DAP decomposes at a temperature lower than the degradation of the cotton and leaves a large insulating char residue that prevents further burning. Any deficiencies in the process are complemented by addition of urea. Nam *et al.* (2010), of the Southern Regional Research Center, tested the phosphorus-nitrogen (P-N) synergism of DAP and urea to determine their optimum ratio in flame-retardant greige cotton nonwoven fabrics. They concluded that, compared with the treatment of DAP alone, the addition of urea at %P:%N = 2.5:4.6 enhanced the flame resistance of fire-retardant nonwoven fabric made from greige cotton. The Limited Oxygen Index increased by 13% from 32.3% to 36.6% while the char length decreased from 10.9 cm to 7.1 cm, a 54% decrease. They linked the synergistic flame retardancy to the increased activation energy of thermal decomposition and the formation of nonflammable insulated coating on the fiber surface. Further increase of the nitrogen percentage did not show any improvement in flame retardancy.

In their 2011 paper, Nam *et al.* focused more on the decomposition of flame-retardant cotton. They used needle-punched nonwoven cotton fabric (made from greige cotton) and treated with DAP and urea. They observed that the greige hindered phosphorous and nitrogen absorption, as the samples was treated with both chemicals by dipping. The main observation was that DAP and urea affected the activation energy (E_a) throughout the thermal decomposition of greige cotton nonwoven fabric. The E_a of the fabric was significantly increased with the DAP treatment alone.

The addition of urea induced a higher E_a , but further addition of urea resulted in lower E_a than with DAP alone. Such results indicate that flame-retardant greige cotton fabric decomposes with greater difficulty than the untreated one. Urea additive increases the thermal stability and enhances the efficiency of diammonium phosphate in decomposing cellulose chains in the crystalline region. Refer to their paper regarding calculation of E_a .

The durability of the fire retardant characteristic after repeated washings continues to be an issue. The primary concern is that the treatment applied for retaining the retardancy feature after washing has to be economically feasible to use in all its stages, including application. The process used to produce nonwoven cotton webs using a binder fiber, subjecting them to a through-air bonding process, and treating them with commercially available fire-retardant chemicals and binders showed that it is

important to select the correct combination of flame retardants and binders, since both have an effect on the durability of the webs after washing. Research is under way to develop a model that takes these mutual effects into account in order to help select the best combination for optimum fire-retardant performance. A paper along these lines was presented at the 2010 Beltwide Cotton Conferences.

Addition of a fire-retardant property and efforts to make the feature persist after multiple launderings, in those cases where washing is needed, must also deal with the negative impacts on the nonwoven material itself. Imparting fire-retardant properties also impacts a number of desirable mechanical properties, such as resistance, harsh handling and lower air permeability, independently of whether the fiber is made from cellulosic or synthetic fibers. It is known that web density also impacts fire retardancy. In most cases, fire retardancy is achieved through chemical treatment and high loft cotton nonwovens lose the high loft and soft feel desired for soft finishing as they go through chemical finishing treatments.

Enhancing the Value of Nonwovens

A 2011 paper on 'Plasma treatment of cotton nonwovens' dealt with the addition of other desirable features to nonwovens made from cotton. The researchers assessed the degree to which plasma treatment performs in a fashion somewhat similar to the effects of scouring and bleaching on cotton fabrics. Researchers used atmospheric pressure plasma treatment, which is considered to be better than vacuum plasma treatment because it spreads evenly over the entire surface of the material being treated.

The working hypothesis was that the treatment would increase the wettability, printability and adhesive properties by increasing the surface energies of the materials. The findings showed that there was almost a 50% reduction in wax content in the plasma-treated fabric compared to the pre-treated fabric. The research samples were also tested to assess any changes in strength after the plasma treatment: no significant decrease in tensile strength values was found. Abrasion testing results showed a non-significant increase in abrasion resistance after the plasma treatment. But this improvement in abrasion resistance confirmed the effectiveness of plasma treatment in increasing the adhesive properties of the treated material. The lower wax content in treated fabric improved the wettability of the material, thereby enhancing its capacity for dye uptake.

A field study was conducted to determine the biodegradation rates of nonwoven rayon, cotton, polylactic acid, and polypropylene fabrics in a silt loam soil under warm and moist conditions. Researchers (paper presented at the 2011 Conferences) placed fabric samples in the soil at a depth of 10 cm and dug them up after 7, 14, 21, and 28 days of burial to determine the amount of fabric remaining by comparing them with a non-buried fabric. The biodegradation of rayon and cotton was described using first-order kinetics and the rate constants were determined to be 0.094 and 0.056/d,

respectively. No biodegradation of polylactic acid and polypropylene was observed during the entire 28 days. The half-life values, i.e., the time required for 50% loss of the material, was 7.4 and 12.4 days for the nonwoven rayon and cotton, respectively. Data for tearing and shear strength parameters after the fabrics were recovered from the soil were determined and may be available from researchers.

Use of Greige Cotton in Nonwovens

Currently, very little greige (raw) cotton or even bleached cotton lint is used to manufacture nonwoven products. According to the paper presented at the 2011 Conferences, manufactured fibers are preferred by the nonwoven industry because of their cleanliness (no trash), pure white color and consistency of supply. Greige cotton always contains some non-lint foreign trash that must be removed during processing, especially for certain higher quality end-use products and applications. However, most nonwoven goods manufacturers do not have the needed cotton opening, cleaning and carding capabilities to properly process run-of the mill, greige raw cotton. Researchers at the Southern Regional Research Center used pre-cleaned cotton and proved that it could be used to make quality products without bleaching. The mechanically pre-cleaned cotton was processed to make needle-punched and hydroentangled nonwoven base materials of 100% non-bleached cotton content for certain end-use applications, such as household quilts and crafts, throw blankets, furnishings and wipes. Based on preliminary test data on wax content before and after certain levels of specific hydroentanglement energy, it appeared that most of the greige cotton's natural waxes might be removed during the hydroentanglement process. Pre-cleaned cotton without trash has a potential for greater use in nonwovens. It has already been established that greige cotton has a higher absorption capacity than bleached cotton.

Normally, all fabrics, woven, nonwoven, or knitted, made from greige cotton must undergo the chemical process of scouring to enable them to absorb dyes and other finishing substances. Researchers studied the effects of bleaching and dyeing hydroentangled greige cotton fabrics with and without traditional scouring and/or bleaching treatments. The hydroentangling method was used to produce nonwoven fabrics using low and high levels of bonding water pressure. The fabrics were bleached and dyed with and without the traditional scouring treatment. The results were presented at the Beltwide Conferences in 2012 wherein scoured only, bleached only (i.e., w/o conventional scouring), and scoured and bleached pre-cleaned greige cottons were compared. According to the authors, their findings show that fabrics made from greige cotton can be bleached and even dyed satisfactorily without the traditional scouring process, which is costly and cumbersome.

Greige Cotton in Medical Uses

The use of cotton-based nonwovens is limited. According to some sources, they comprise 1% of total nonwovens, although

others calculate this share at 3%. It may safely be said that only 2-3% of the raw material used in nonwovens today is cotton and that whatever cotton is used has been mechanically and/or chemically processed. Other natural fibers used in nonwovens amount to about 1%. Therefore, synthetic fibers make up about 96% of nonwovens. Elimination of scouring and/or bleaching could lower the cost of raw cotton as a material for nonwovens. Recently, as a result of improved methods of cleaning cotton to eliminate non-lint matter, increasing attention is being given to the use of greige cotton for use in absorbent products. The nonwoven processes that open and expose the hydrophilic cellulosic component of greige cotton fiber to water absorption have also favored the use of greige cotton. Greige cotton has excellent pro-coagulant properties and promotes clotting of blood at a two-fold greater rate than bleached cotton (Edward *et al.*, 2014). Edward *et al.* (2014) prepared nonwovens using hydroentangling from greige cotton, which had been mechanically cleaned and tested for wound-healing properties and used as a cover stock layer in diapers. Greige cotton as a hemostat and carrier acts synergistically to enhance silicon dioxide mediated clotting. According to the same paper, hydroentangled cotton samples performed similarly or slightly better in generating hydrogen peroxide levels previously found to be involved in stimulating healing. Generation of low-level hydrogen peroxide by hydroentangled nonwoven greige cotton is consistent with the retention of accessible levels of pectin correlated to enhanced granulation tissue or improved cell proliferation and fibroblast and macrophage production.

The results suggest that highly cleaned (but not scoured and bleached) greige cotton nonwovens possess properties that may improve maintenance of dryness by incontinence products and promote skin care in absorbent products. Results have shown that mechanically cleaned greige cotton can now be considered as a low-cost bio-based fiber alternative to synthetic fibers for top sheet use and design products. The results of the work of Edward *et al.* (2014) show that mechanically cleaned cotton constitutes a bio-based, eco-friendly alternative to synthetic fibers when designed into the layers of incontinence products. The results further show that cotton can perform the function of a top sheet in diapers and other similar products. Mechanically cleaned greige cotton retains the cotton fiber cuticle lipids (hence it is more hydrophobic than scoured and bleached cotton) and primary cell wall pectin, which are removed in scoured and bleached cotton. Although bleached and scoured cotton provides highly absorbent properties for many applications, it does not typically have good rewet and strikethrough properties. Greige cotton also proved to have superior rewet and strikethrough properties. Results also showed that use of greige cotton has the following benefits:

- Lower processing cost due to the elimination of the scouring and bleaching steps.
- Elimination of processing is also beneficial in terms of cotton footprints.

- Cuticle and primary cell wall are not damaged. Pectin and natural waxes that help to heal wounds are retained.
- Rewetting capability of nonwovens from greige cotton is higher than that of processed and synthetic fibers.
- Transmits synthetic urine more rapidly than currently used products.
- Greige cotton performs better in nonwovens.

New Technologies

The USDA-ARS Southern Regional Research Center in New Orleans, USA, has done extensive work on cotton-based nonwovens. Dr. Sawhney has devoted many years of research on traditional textiles and nonwovens. In their 2009 paper "Nonwovens Manufacturing Technologies and Cotton's Realistic Scope in Nonwovens," Dr. Sawhney and his colleagues reviewed the subject thoroughly. Since then, Dr. Sawhney and his colleagues have published numerous peer-reviewed papers and articles on the cotton-based nonwovens in reputable journals, including the Textile Research Journal. Some of the selected publications since 2009 are listed below:

- Advent of Greige Cotton Non-Wovens Made using a Hydro-Entanglement Process. *Textile Research Journal*, 80 (15). pp. 1540-1549. (2010)
- Effect of Water Pressure on Absorbency of Hydroentangled Greige Cotton Non-woven Fabrics. *Textile Research Journal*, 82 (1). pp. 21-26. (2011)
- A Comparative Study of Nonwoven Fabrics Made with Two Distinctly Different Forms of Greige Cotton Lint. *Textile Research Journal*, 81 (14). pp. 1484-1492. (2011)
- Effect of Web Formation on Properties of Hydroentangled Nonwoven Fabrics. *World Journal of Engineering*, 9 (5). pp. 407-416. (2012)
- Whiteness and Absorbency of Hydroentangled Cotton-Based Nonwoven Fabrics of Different Constituent Fibers and Fiber Blends. *World Journal of Engineering*, 10 (2). pp. 125-132. (2013)
- Effects of Greige Cotton Lint Properties on Hydroentangled Nonwoven Fabrics. *Textile Research Journal*, 83 (1). pp. 3-12. (2013)
- Bleaching of greige cotton-based nonwovens without scouring. *Textile Research Journal* (TRJ) April 2014.
- Progressive and cumulative fabric effects of multiple hydro-entangling impacts at different water pressure on a greige cotton substrate. *Textile Research Journal*, May 2015.
- Rethinking Cotton in Nonwovens. Advanced Textiles Source, Industrial Fabrics Association International (IFAI). April 2015.

The Southern Regional Research Center in New Orleans, Louisiana, houses a state-of-the-art nonwovens research laboratory that deals with all the processes involved in the

development and optimization of processes for the successful use of cotton in nonwovens. The lab also focuses on development of cotton-nonwoven blends and composites for specific applications using new chemistry and other relevant sciences and technologies. In addition, the lab studies the cost and environmental impacts of any successful research and development project.

More research needs to be done to enhance the use of cotton in a variety of products produced from nonwovens. One such minor field is the use of cotton-based products capable of controlling hemorrhaging, when and where necessary. Edwards *et al.* (2009) observed that both aminized cotton and bentonite show promise as hemostatic agents and in lethal arterial hemorrhage control, respectively. Although the sealant properties of bentonite are well documented and the potential to use aminized cotton based on its ability to promote aggregation of negatively charged platelets has been verified, little is known about the effects of both of these materials on blood clotting. The study showed that the relative effects of both of these materials have similarities and differences. The nearly similar lag phase which accounts for clotting time is interesting. On the other hand, thrombin formation and potential appear to be more pronounced with aminized cotton. The studies showed the potential of these agents for use in hemorrhage control.

The flame-retardancy and fireproofing of nonwoven products made from cotton has improved substantially, but both features still need to be further improved. Interactions among the treatments and chemicals need to be enhanced and multiple washings should have a minimum impact on the flame-retardancy feature of nonwovens.

One of the issues that limit the use of cotton, and particularly greige cotton, which has proved to be better in the work presented here, is the availability of nonwoven end products in only one color (white). The market trend is to design patterned fabrics, thus creating product differentiation and brand recognition by the consumer. So, pattern choices need to be added in nonwovens made from cotton or other natural fibers.

References

The Cotton Incorporated has a good source of information on suppliers dealing with nonwovens roll goods, cotton fiber, and nonwovens converted products on their web page at <http://www.cottoninc.com/product/NonWovens/Nonwovens-Sourcing-Directory/Nonwovens-Rollgoods-Suppliers/>

The following are some of the papers on nonwovens presented at the Beltwide Cotton Conferences from 2009 to 2015:

Edwards, J. Vincent, D. V. Parikh, Brian Condon, Phyllis S. Howley and Sarah Batiste. 2009. Improving on Army Field Gauze for Lethal Vascular Injuries: A Progress Report.

Edward, J. Vincent, Nicolette Prevost, Elena Grave, Brian Condon, Lawson Gary and Edmund Carus. 2014. Nonwoven Greige Cotton for Wound Healing and Hygienic Product Applications.

Mercimek, Hatice, M. G. Kamath, Gajanan Bhat, D. V. Parikh, Brian Condon and Janet O'Regan. 2009. Approaches to Improving the Durability of Flame Retardant Treatments on Cotton Nonwovens.

Nam, Sunghyun, Dharnidhar V. Parikh and Brian Condon. 2010. Phosphorus-Nitrogen Synergism in the Fire Barrier of Greige Cotton Nonwoven Fabrics.

Nam, Sunghyun, Dharnidhar V. Parikh, Brian Condon and Fei Yao. 2011. Effect of Phosphorus and Nitrogen on Thermal Decomposition Kinetics of Flame Retardant Cotton.

Sawhney, Paul, Brian Condon, D.V. Parikh, Mike Reynolds and Jim Riddle. 2009. Nonwovens Manufacturing Technologies and Cotton's Realistic Scope in Nonwovens.

Uppal, Rohit, Hatice Mercemik, Gajanan Bhat, Sunghyun Nam, Dharnid V. Parikh and Brian Condon. 2010. Flame Retardant Cotton Based High Loft Nonwovens.

Wolf, Duane C., Mary M. Warnock and Edward E. Gbur. 2011. Biodegradation of Nonwoven Fabrics in Soil.

Intensive Cotton Farming Technologies in China

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Abstract

Cotton (*Gossypium hirsutum* L.) production in China has developed rapidly during the last sixty years. In 2014/15, the planted area and total output in the country were 4.35 million hectares and 6.53 million tons, respectively, and the unit yield was 93% higher than the world average. China currently

accounts for about 25% of world cotton production with just over a 12% share of the world area planted to cotton. Enhanced cotton production, particularly the high yield, is largely due to the country's adoption of a series of intensive farming technologies and cultural practices. The main intensive farming technologies employed include double cropping,

transplanting of seedlings, plastic mulching, plant training and super-high plant density, all of which have played an important role in increasing yields and production. Although such intensive farming technologies help to meet the needs of a large population with limited arable land, they are labor-intensive and involve large volumes of inputs of various kinds of chemical products, such as fertilizers, pesticides and plastic film. The low profitability of cotton production compared to competing crops has inevitably caused the planted area to decrease year after year. Thus, there arose a need to undertake a series of comprehensive countermeasures to increase the benefits of cotton production by simplifying field operations, mechanization, cropping system reform and reduced soil pollution through rational use of plastic film and chemicals. Cotton production in China can be sustainable and has a bright prospect if supported by new farming technologies.

Introduction

China is the largest cotton producer and consumer in the world (Chen *et al.*, 2015; Wang, 2009). The area planted to cotton in China was 4.35 million hectares in 2014/15 with an average lint yield of 1,484 kg/ha and a total output of 6.53 million tons. Based on cotton type, distribution and growth environment, the cotton growing area in China can be divided into three major agro-ecological areas: Northwest Inland Cotton, Yellow River Valley and the Yangtze River Valley regions (Table 1). According to Yang and Cui (2010), these three main cotton regions account for over 99% of cotton area and production in China.

Cotton cultivation has a long history in China, but science-based cultivation methods were adopted only after the founding of the People's Republic of China in 1949. Great progress in cotton production was achieved during the more than six decades since 1949, with an average annual yield increase of 3.1%, from 160 kg/ha in 1949 to 1,280 kg/ha in 2009 (Fig. 1). China has emerged as one of the highest yielding countries in the world. In 2014/15, the average lint yield was 768 kg/ha in the world, while it was 1,484 kg/ha in China, i.e., higher by 58%, 189%, 90% and 93% than yields in the USA, India, Pakistan and the world average, respectively (Table 2). Many factors contributed to increased yields, including adoption

Table 1: Cotton Production by Region in China - 2014/15

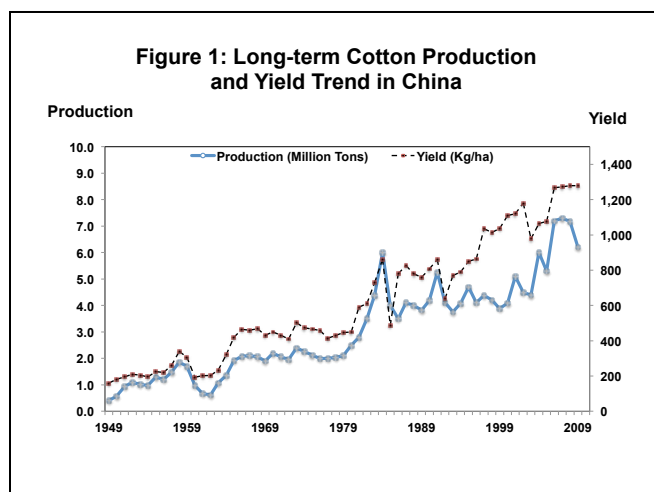
Cotton Region	Provinces	Area (million ha)	Production (million tons)	Yield (kg/ha)
Northwest Inland	Xinjiang, Gansu	1.76	3.64	2,068
Yellow River Valley	Shandong, Hebei, Henan, Shanxi, Tianjin	1.45	1.61	1,110
Yangtze River Valley	Hubei, Hunan, Anhui, Jiangsu, Jiangxi, Sichuan	1.11	1.25	1,126

*Source: China Cotton Production Prosperity Index (<http://www.ccppi.com.cn/>)

Table 2: Cotton Area, Average Yield and Production in the World – 2014/15

Country	Area (million ha)	Average yield (kg/ha)	Production (million tons)
Brazil	0.98	1,546	1.51
China	4.31	1,495	6.44
India	12.25	534	6.54
Pakistan	2.84	812	2.31
United States	3.93	903	3.55
World	33.51	781	26.18

*Source: International Cotton Advisory Committee



of improved varieties and innovative farming technologies. These technologies include double cropping, transplanting of seedlings, plastic mulching and plant training, which have played more important roles than cotton varieties and other factors that contributed to the significant increase in lint yield over the past sixty years. The following is a summary and review of these intensive farming technologies with Chinese characteristics, and how they not only furthered the improvement of China's cotton production technology, but also that of other countries.

Intensive Farming Technologies and Achievements

Double Cropping

The cotton-growing regions in China are also the main food crop growing regions; hence the competition for land between grain crops and cotton has become increasingly intense. Double cropping of grain and cotton, which improves the soil, and a greater efficiency in the use of solar energy have become the mainstays of the cropping system. It ensures higher total output than single cropping, particularly the cotton-wheat double cropping system (Zhang *et al.*, 2008), because it meets the need of farmers to grow a profitable cash crop while securing their food supply (Zhang *et al.*, 2007). Based on the time (season) when the cotton is planted, the double cropping system is classified into ‘spring cotton double cropping’ and

‘summer cotton double cropping.’ Due to its shorter growth period, summer cotton double cropping has the obvious advantages of earliness and reduced susceptibility to plant diseases and insect pests through use of short-season cotton varieties (Lu, 1991). In the past, from the 1980s to the 1990s, it was once prevalent in the Yellow River Valley and Yangtze River Valley cotton regions. However, double cropping of summer cotton and wheat began to be replaced by spring cotton and wheat due to the relatively lower lint yield and poorer fiber quality of short-season cotton (Smith and Varvil, 1982). Currently, double cropping of spring cotton and wheat occupies a dominant position in the cropping system in both the Yellow River Valley and the Yangtze River Valley cotton regions (Fig. 2a, 2b). According to the different cotton-wheat planting modes, China’s Huang-Huai-Hai plains generally adopted three different planting modes: the 3-1 planting mode (3 rows wheat and 1 row cotton); the 3-2 planting mode (3 rows wheat and 2 rows cotton); and the 4-2 planting mode (4 rows wheat and 2 rows cotton) (Fig 3).

Compared with solid cotton planting, wheat-cotton intercropping significantly increased multiple crop indexes and reduced competition between grains and cotton for land use in China. For example, the average yield of seedcotton under the wheat-cotton system in the Huang-Huai-Hai Plain since 1959 was 2,836 kg/ha, i.e., roughly 88% of the yield with the solid cotton cropping system. It should be noted that an extra harvest (3,861 kg of wheat per hectare) was also obtained compared to single cropping (CRI, 2013). Consequently, the gross income was greater. However, the planting area and the ratio of cotton-wheat double cropping system to conventional cropping system were sharply reduced owing to certain limitations. Those disadvantages include: a) low lint yield and

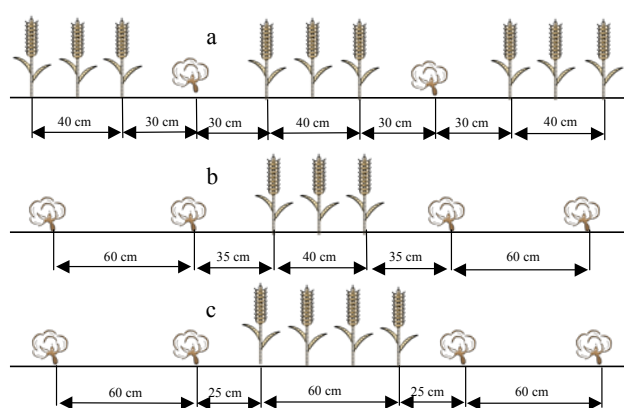
Figure 2: Intensive Cotton Farming Technologies in China



Legend:

- (a) Double-cropping of cotton and wheat
- (b) Multi-cropping of cotton, wheat and watermelon
- (c) Manual seeding in the nursery bed
- (d) Transplantation of seedlings
- (e) Seedlings manually freed from mulch
- (f) Mechanized plastic mulching
- (g) Mechanized plastic film coverage (mulching) before sowing
- (h) Furrow seeding and plastic mulching
- (i) Manual removal of vegetative branches
- (j) Manual removal of growth terminals of the main stem
- (k) Drip irrigation under plastic film
- (l) Narrow row planting in the Northwest Inland Cotton area

Figure 3: Double Cropping of Cotton-Wheat



Legend:

- “3-1” mode: 3 rows of wheat and 1 row of cotton
- “3-2” mode: 3 rows of wheat and 2 rows of cotton
- “4-2” mode: 4 rows of wheat and 2 rows of cotton

poorer fiber quality due to delayed seedling growth during the wheat-cotton intergrowth stage and late senescence, both in the spring and summer cotton double cropping systems; b) reduced profitability because of increased demand for manual labor resulting from the lower degree of mechanization of the sowing and harvesting operations of wheat and cotton under the double cropping system.

Transplanting of Seedlings

Although the wheat-cotton double cropping system significantly increased profits relative to solid planting, the conventional process of cotton production also had some disadvantages. In that system, winter wheat is harvested in early or mid June, while cotton is sown in late April. Both crops overlap in the field for almost two months, from April till June (Zhang *et al.*, 2007). Since cotton is sown approximately seven weeks before the harvest date for wheat, strips are left open in the wheat crop at sowing (October/November) to provide space for the cotton plants during their seedling stage (April-June). After the wheat is harvested in June, the cotton plants can exploit the full space, aboveground as well as belowground. A cotton-wheat relay intercropping system is thus characterized by three main phases: a) winter wheat (vegetative stage) grown in strips from November till April; b) intercropping of wheat (reproductive stage) and cotton (seedling stage) from April till June; and c) cotton only from June to October (Zhang *et al.*, 2007). The two component crops in the system interact directly during the second phase, thereby delaying plant growth and maturity, as well as reducing cotton yield due to shading and competition between the two crops for water and nutrients (Zhang *et al.*, 2008; Pan *et al.*, 1994). An investigation to determine the relationship between boll weight in wheat-cotton double cropping, on the one hand, and meteorological factors, on the other, showed that the number of hours of sunshine was the key meteorological factor in most wheat-cotton double cropping patterns and in the positioning of the greatest number of bolls on the plant. In double cropped short-season cotton, the temperature that had an important impact on upper and top bolls (Zhou *et al.*, 2000; Hodges *et al.*, 1993). In 2006, Wang *et al.* found that competition for nitrogen absorption between wheat roots and cotton roots, as well as the translocation of absorbed nitrogen from the wheat roots to the cotton roots, occurred in the wheat-cotton double cropping system and that the nitrogen absorbed by the cotton roots was mostly allocated to the aboveground parts, and less to the roots. The findings also underscored the negative effect of wheat on intercropped cotton during the overlapping period. Although a wider cotton belt might reduce the negative crop interaction, it would undoubtedly decrease wheat yields and therefore cannot be adopted by farmers. Direct-seeded short-season cotton after wheat is harvested can avoid the negative effects of wheat shading on cotton seedlings, but the resulting poor fiber quality and yield stemming from the short growth period is not acceptable to farmers nor encouraged by experts (Smith and Varvil, 1982). Therefore, transplanting the cotton

seedlings just before or after the wheat harvest provides an effective way to prevent or alleviate the interaction effects of both crops (Song, 2010).

The practice of transplanting cotton seedlings began in China in the 1950s, but was not widely adopted until the 1980s, especially in the Yangtze River Valley and the Yellow River Valley regions (Cao *et al.*, 2015). The ratio of total transplanted cotton area to the total area planted to cotton in China amounted to about 0.93 million hectares or 18% in 1980s. The seedling transplanting process consists essentially of three steps (Fig. 2c, 2d): 1) cultivation of the seedlings in the nursery bed, 2) transplanting seedlings to the fields and 3) field management after transplantation (Dong *et al.*, 2007). For cultivation of seedlings, “columned soil blocks” (4-6 cm in diameter by 8-12 cm high), made of soil and organic fertilizer at a ratio of 9:1 (by weight) with the corresponding mold sizes, were prepared in early April, before planting. The soil blocks were then tidily placed into a eutrophic soil bed (10-15 cm deep and 2-3 m wide). After watering, each block was sown with a single cotton seed. The seedling bed was then covered with plastic film, which was supported by bamboo sticks arranged in the manner of a 50 cm high arched hut. Since the temperature inside the greenhouse-like hut was much higher than outside the hut, it provided quite favorable conditions for emergence and growth of the seedlings during the earlier part of the season. The seedlings were allowed to grow in the hut until they were ready to be transplanted. The huts were kept open for at least a week before transplanting to ensure the acclimation of the seedlings to cold temperatures. The soil blocks, together with the seedlings, were then transplanted to the fields manually. Seedling transplantation can generally be conducted about 35 days before harvesting the wheat when spring or full-season cotton is used, or soon after the wheat harvest when summer or short-season cotton is used, as soon as the mean soil temperature at the 5 cm depth reaches 17-19°C and the cotton seedlings have 2-4 true leaves on the main stem. Soon after transplanting, each field plot was watered to enable the seedlings recover their normal growth quickly (Dong *et al.*, 2007). Inter-tillage and irrigation are conducted in a timely manner after transplanting (Sun *et al.*, 1999).

Transplantation has several advantages, over direct seeding before or after the wheat harvest, as follows (CRI, 2013):

- Sowing can be conducted at the precise time in the seedling bed by adjusting soil temperature and humidity; bed cultivation of seedlings can also reduce the quantity of planting seeds consumed, as well as the incidence of diseases and/or insect pests on cotton seedlings. Cotton seedlings in open fields are easily attacked by *Rhizoctonia solani* Kuhn, *Colletotrichum gossypii* Southw, *Alternaria tenuis* Nees and *Phytophthora boehmeriae* Saw, but they are rarely attacked in nursery beds (Shen, 1992);
- Thanks to the optimal/efficient use of light and temperature by transplanted seedlings, the growing

process is accelerated and the blooming and boll-setting periods are prolonged. Thus, the blossoming rate before frost sets in and total seedcotton yields are both greatly increased. The blooming period peaked about five days earlier and lasted about one week longer. The retention rate of early-season blooms and bolls per unit area was significantly greater with the transplanting system than with direct planting (Dong *et al.*, 2005);

- Water and nutrient uptake improved as a result of promoted lateral root growth. Furthermore, root weight and the number of lateral roots in the transplanted soil cubes were 43.4% and 18.8% higher than that in direct seeded cotton (Mao *et al.*, 2008);
- Cotton germination, emergence and early seedling growth are sensitive to salinity stress. Stand establishment was greatly improved by seedling transplantation when non-saline soil was used as nursery substrate; conversely, stand establishment was greatly diminished with direct seeding in saline soils (Zhang *et al.*, 1982). Thus, seedling transplantation may be considered an efficient practice to increase the stand establishment of cotton in saline soils.

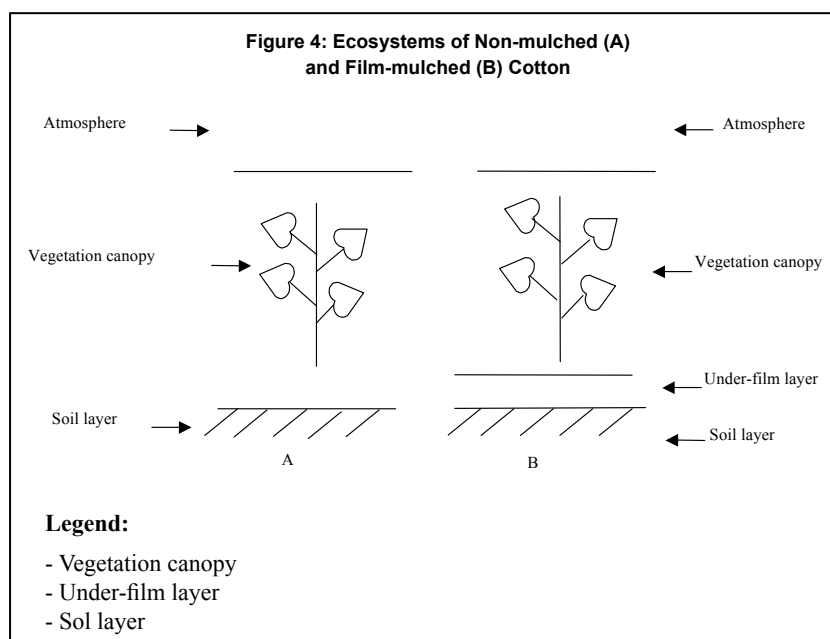
Compared with direct-seeded cotton after the wheat harvest, the yield of transplanted seedlings was found to be 20 to 30% higher (Gao and Shang, 1982). Moreover, seedcotton yield and quality parameters improved as a result of the increased number of bolls per square meter and earlier blooming; the net revenue for producers also increased relative to direct planting (Dong, 2012a; Dong *et al.*, 2005). About two million hectares were planted with the seedling transplanting technology in the 1990s (CRI, 2013). It is true that traditional cultivation of seedling nurseries for later transplanting is labor-intensive. However, the process can be simplified by replacing nutrient soil clay with medium, by transplanting naked seedlings rather than combined with soil-clay, and by mechanizing the transplanting operation instead of doing it manually (Mao *et al.*, 2012). Simplified transplantation of seedlings would decrease labor costs and increase efficiency.

Plastic Mulching

Cotton is widely cultivated in China and, consequently, the ecological conditions such as uneven rainfall distribution and varying temperatures differ among planting regions or locations. Lower temperatures and drought at sowing, as well as soil salinity stress and diseases during the seedling stage, usually decrease the rate of seed emergence and stand establishment. Meryl *et al.* (1986) indicated that lower soil temperatures slowed germination, altered normal root development and caused cell damage, thus

rendering seedlings more susceptible to diseases. Accumulated salts in the soil inhibit seed germination, emergence and plant growth and development through osmotic stress, nutritional imbalance and/or toxicity of salt ions, consequently reducing lint yield and quality (Ahmad *et al.*, 2002). Lower temperature combined with salinity stress can further reduce cotton emergence and stand establishment in saline fields (Dong *et al.*, 2008a). Although later sowing may reduce the environmental stress of early season chilling and disease incidence, shortening of the growth period decreases cotton yields (Dong *et al.*, 2005). Fortunately, all these problems can be solved through the use of plastic mulching, i.e. covering the rows with polyethylene film (Fig. 2e, 2f), because this practice increases soil temperature, water conservation, salinity control in the root zone and weed control (Mahmood *et al.*, 2002; Mahajan *et al.*, 2007; Stathakos *et al.*, 2006).

Plastic mulching of cotton fields in China began in 1979 and has been widely used since then (Lu, 1985; Xu and Liu, 2001). Currently, about 70% of the total cotton area, some 2.7 million hectares, are covered with plastic film each year, especially in the arid and semi-arid regions of northern China and in saline-alkali soils of the coastal areas (CRI, 2013). Compared to the ecosystem structure of non-mulched cotton fields, which comprises the soil layer, the vegetation canopy and the atmosphere, film-mulched cotton fields consist of four ecosystems: soil layer, under-film layer, vegetation canopy and the atmosphere (Fig. 4). The under-film layer has multiple effects, including the increase in soil temperature through the greenhouse effect and moisture conservation by preventing direct evaporation of moisture from the soil, all of which ultimately lead to improved seedling establishment, enhanced plant growth and greater economic returns (Dong *et al.*, 2010a, 2009a, 2008a, 2007; Tarara, 2000; Cao, 1987). Moreover,



plastic mulching in saline fields can effectively reduce the accumulation of salts in the surface soil by suppressing evaporation, thereby decreasing salinity stress (Dong *et al.*, 2007, 2008; Dai *et al.*, 2010; Bennett *et al.*, 1966).

Plastic film coverage (mulching) is usually conducted soon after sowing, manually or mechanically, in the Yellow River Valley and Yangtze River Valley regions (Fig. 2f). Seedlings are uncovered from mulching by cutting the film above hills at emergence (Fig. 2e), and thinned to the planned population density by leaving one vigorous plant per hill at the two-leaf stage (Dong *et al.*, 2009a). It should be noted that under post-sowing mulching, it is critical to free the seedlings of the film in time to avoid suffocation and poor seedling establishment. Generally, the polythene mulch can be retained during the whole growth season (especially in arid areas planted to special early maturing cotton) to improve soil temperature and decrease the loss of moisture through evaporation. In areas with ample water and heat sources, plastic film should be removed at full squaring stage in late June, and then inter-tillage, weeding, ridge forming and earthing up can be done in time to prevent lodging and premature senescence of cotton late in the season (CRI, 2013). Conversely, with the development of the whole-course mechanization of cotton, the laying of the plastic film coverage (mulching) before sowing can be done in a single integrated sequence of mechanized operations in the Northwest Inland Cotton region (Fig. 2g), thereby avoiding the process of freeing the seedlings in the rainless sowing stage.

In addition, plastic film mulching can also be done before sowing. Pre-sowing coverage is particularly beneficial for cotton planted in saline fields (Dong *et al.*, 2009a). A great deal of evaporation usually occurs in bare land before sowing in spring, causing significant additional accumulation of salts on the surface layer of saline soils. Research showed that row covering with plastic film 30 days before sowing (early mulching) improved stand establishment (38.7%), biomass (26.5%), lint yield (19.0%) and earliness (14.7%) of cotton compared to conventional post-sowing coverage. Compared with mulching after sowing, early mulching reduced leaf Na^+ levels by 8%, increased stand establishment by 11%, plant biomass by almost 10% and lint yield by 7% in the saline soils of the Yellow River Delta (Dong *et al.*, 2009a). Furthermore, furrow seeding with plastic mulching (Fig. 2h) was also found to be a suitable cultural practice to enhance stand establishment and increase cotton production in saline fields, especially fields with moderate to high concentrations of saline-alkaline soils. Compared with flat-seeded cotton without mulching, stand establishment and lint yield of cotton planted in furrows under plastic mulching increased by 92% and 22% in saline fields with ECe of 12.8 dS m^{-1} (Dong *et al.*, 2008a).

Plastic film mulching in combination with transplanting was recommended because it possesses the dual advantages of increasing soil temperature and promoting early maturity

(Sun *et al.*, 1999). Under this system, cotton seedlings from the nursery bed are transplanted to plastic-mulched fields rather than to open fields. It was demonstrated that plant growth and development, together with yield and earliness, improved significantly when mulching and transplanting were combined instead of implementing either transplanting or plastic mulching alone (Liu *et al.*, 1997; Wu, 1996). With the combined implementation of plastic mulching and transplantation, it was found that lint yields increased by 17.4% and 14.6% over the use of the two techniques by themselves (Dong *et al.*, 2007).

Plant Training

Plant training is also an intensive cultivation technique that is widely adopted in China. It mainly involves removal of vegetative branches, topping the plants, and excision of old leaves and empty fruit branches. Plant training can efficiently optimize the relationship between vegetative and reproductive growth by regulating the distribution of nutrients in cotton plant tissues and reducing nutrient consumption by surplus organs (CRI, 2013). Plant training can also improve the microclimate of the cotton plant, reduce boll abscission and rot, while increasing cotton yield and fiber quality (Zhou and Yang, 1999).

Removal of vegetative branches

The cotton plant does not bear fruit directly on vegetative branches. Vegetative branches grow vigorously, consume excessive amounts of nutrients, aggravate competition between vegetative and reproductive growth and often lead to field shading and increased abscission of squares and bolls, especially at a mean plant density of $4.5\text{--}7.5 \text{ plants/m}^2$ (CRI, 2013). Removal of vegetative branches is usually done manually after the first fruiting branches appear in mid June (Fig. 2i). Compared to plants with intact vegetative branches, the boll-shedding rate of cotton plants freed of vegetative branches decreased by 9%, whereas boll weight increased by 7% and seedcotton yield increased by 8.7% (Yuan, 1982). The removal of vegetative branches improved the number of fruiting nodes per leaf area (31.1%) and dry mass of fruiting parts per leaf area (88.9%), thereby increasing seedcotton yield by 17.7% (Dong *et al.*, 2008b).

Plant topping

As an indeterminate crop, cotton can grow continuously and bear more fruit and branches as long as suitable temperature, light, water and fertilizer are provided (CRI, 2013). Removal of growth tips on the main stem by hand (topping) inhibits apical dominance and vegetative growth, allowing more nutrients to be redirected to the reproductive organs, thus leading to more squares, flowers, bolls and lint yield (Li *et al.*, 2006). Identification of the best topping time is of vital importance. Topping too late always causes a proliferation of ineffective fruit branches and ineffective flower buds on the upper fruit branches; topping too soon increases the abscission of squares and bolls on the upper fruit branches. It is recommended that

topping should be done around mid- or late July, when the number of fruiting branches has reached 8-10 per m² ground area (CRI, 2013). It is recommended that plant topping be carried out on clear and windless days to facilitate wound healing (Fig. 2j). Bennett *et al.* (1965) showed that topping increased lint percentage, fiber length and micronaire relative to non-topped cotton. Renou *et al.* (2011) reported that the populations of bollworms, *Helicoverpa armigera* Hübner (56%), *Earias* spp. (68%) and *Diparopsis watersi* Rothschild were fewer in plots of topped cotton than in plots of non-topped cotton.

Removal of old leaves and empty fruit branches

During the middle of the growing period, removal of old, yellow and diseased leaves and the empty fruit branches can remarkably improve ventilation and light penetration, as well as decrease soil humidity and boll rot (CRI, 2013). Removal of older leaves and empty fruit branches should be done as a function of plant growth after full flowering.

Removal of apical points of vegetative and fruiting branches

Removing the apical points of both vegetative and fruiting branches can delay canopy closure by limiting the horizontal growth of branches (CRI, 2013). Removal of apical points of vegetative branches can also enhance root growth and mitigate premature senescence of the plants, and thus increase lint yield (Dong *et al.*, 2003). Researchers found that pruning the side branches improved cotton yield, lint percentage and earliness while reducing boll rot (Bennett *et al.*, 1965). The apical points of vegetative branches are usually removed in mid-July, while those of fruiting branches can be removed in early August.

Removal of early fruit branches

Fruit shedding or loss appears to be necessary to ensure normal development of retained bolls that are carried through to maturity because the cotton plant produces many more fruit than it can possibly bring to maturity (Malik *et al.*, 1981). Loss of early fruiting forms can elicit compensatory growth (Sadras, 1995). Early-fruit removal enhances vegetative growth and development. Thus it can be used to coordinate the relationship between vegetative and reproductive growth (Dong *et al.*, 2009b). Removal of early fruiting forms is currently done in early squaring cotton to mitigate premature senescence because it increases the level of total nitrogen (N), soluble protein, as well as glutamic-pyruvic transaminase (GTP) activity in leaves (Zhang *et al.*, 2009), thereby increasing lint yield (Dong *et al.*, 2008c, 2009b). It was also reported that removal of early squares reduced the incidence of *Verticillium* wilt disease and early senescence indices (Zhu *et al.*, 2008). Removal of early fruiting branches is usually performed five days after squaring. The lowermost two or three fruiting branches on the main stem are removed by hand.

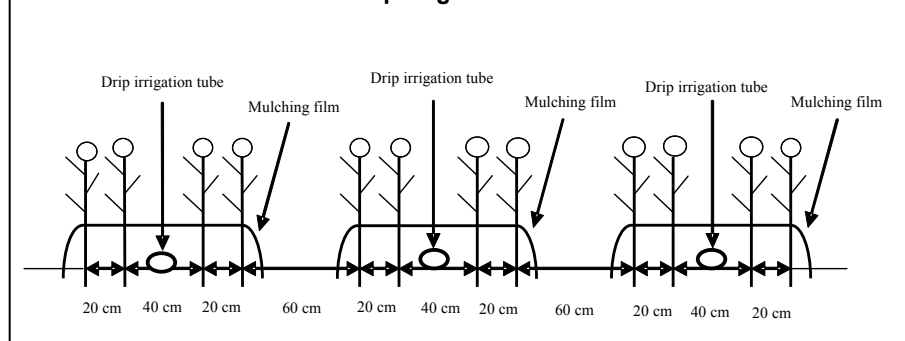
Super-high Plant Density Technique

Light and heat resources in the Northwest Inland Cotton region are abundant, but cotton productivity is low due to the limited duration of the effective growing season in this region. In order to make the most productive use of the light and heat resources available in the region and, particularly, to avoid the adverse effects of the limited growing season, a high-yielding cultivation pattern called “short-dense-early” has been widely adopted in that area. This pattern is achieved by increasing plant density, keeping plant height low and inducing early maturity with the support of drip irrigation under plastic mulching (Zhang *et al.*, 1999). Close planting is one of the most important aspects of the “short-dense-early” planting technique (Fig. 2l). Close planting is suitable in the Northwest Inland Cotton area because of the favorable climate conditions, such as: higher temperature difference between day and night, longer duration of daylight and less rainfall. These climatic conditions are favorable for effective control of excessive growth, even at high plant density. The planting density is always in the range of 200,000-300,000 plants/ha, and plant height is controlled to a range of 60-75 cm through chemical regulation and water and fertilizer management (CRI, 2013). Additionally, other cultivation measures, such as using early-maturity varieties, early planting and especially drip irrigation under plastic film mulching are also used to promote early maturity and lint yield (Cao and Lin, 2007; Zhou *et al.*, 2012). The average lint yield in this region reached 1,927 kg/ha, and a total of 3.18 million tons of cotton fiber was produced in 2014/15 as compared to 1.65 million tons in Xinjiang in 2012/13. It is easy for most farmers in Xinjiang to achieve yields of 2,250 kg/ha with the “short-dense-early” scheme (Wang, 2009). It was also reported that a record lint yield of 4,900 kg/ha was obtained in a small part of Xinjiang in 2009 (Maimaiti *et al.*, 2012).

The Northwest Inland Cotton area of China is located in an arid inland region with low rainfall. Because cotton flowering and boll-setting stages are sensitive to water stress, the technique of drip irrigation under film mulching (Fig. 2k) is commonly applied in the area (Ma and Yang, 1999). Based on the number of cotton rows per irrigation tube, the drip irrigation system was divided into double rows per tube and four rows per tube. At present, the pattern of four rows per drip irrigation tube (Fig. 5) is commonly used in the Northwest Inland Cotton region. There are multiple advantages to drip irrigation under film mulching, such as effectively reducing moisture loss and improving water and nutrient use efficiency by increasing the coverage rate (Liu *et al.*, 2006; Zheng *et al.*, 2000). Compared to flood irrigation, drip irrigation under film increased water economy and yields by 20-50% and 10-30%, respectively (Ma and Yang, 1999, and Liu, 2008), and water and nitrogen efficiency also greatly improved in Southern Xinjiang (Liu and Tian, 2007).

On the other hand, drip irrigation effectively alleviates weeds, diseases and insect pests, decreases the incidence of boll rot

Figure 5: Drip Irrigation System with Four Rows of Cotton Per Drip Irrigation Tube



and improves seedcotton yield and fiber quality (Liu *et al.*, 2005; Hu and Zhang, 2005). Liu *et al.* (2007) also found that damage by *Aphis gossypii* and spider mite on cotton was reduced with drip irrigation under plastic mulching. In saline fields, drip irrigation under film induced low salinity distribution around the root zone, which significantly alleviated salinity stress and enhanced seedling establishment and plant growth (Liu and Tian, 2005; Zhou *et al.*, 2006). Yan *et al.* (2009) reported that cotton roots were mainly distributed in the mulched area, occupying about 61-73% of total root biomass, while only about 27-39% was distributed in the uncovered area. Compared with equal salt distribution in the root zone, unequal salt distribution could decrease Na^+ concentration in leaves owing to higher root Na^+ efflux in the low salinity side, increased leaf photosynthesis, transpiration

vital roles in supporting China's drive to become the largest cotton producer in the world. However, cotton production in China is currently facing significant challenges, such as soil pollution by plastic film and chemicals, labor shortage due to urbanization of the population and intense competition by food crops for land. The most realistic approach to these challenges would be to reform traditional intensive farming technologies, i.e., reducing soil pollution through rational use of plastic film and chemicals, economizing on labor by simplifying management and intensifying mechanization, and increasing benefits by reforming the cropping system and the management mode. We are convinced that reformed farming technologies (Table 3) will play a more important role in sustainable cotton production in China than the traditional intensive farming technologies.

and water and nutrient uptake, all of which enhanced the cotton biomass, lint yield and earliness (Kong *et al.*, 2012; Dong *et al.*, 2010b).

Countermeasures and Prospects

Intensive farming technologies, including double cropping, transplanting of seedlings, plastic mulching and plant training, as well as the “short-dense-early” high-yielding cultivation pattern in the Northwest Inland area have played

Table 3: Current Status and Prospects of Cotton Cultivation Measures in China

Measures	Present	Prospect
Planting and thinning	Conventional seeding, 30-45 kg seed per hectare, and manual freeing and thinning of seedlings.	Precision seeding, 15-19 kg seed per hectare; no manual freeing or thinning.
Inter tillage	8-10 times during the whole growth season.	2-3 times at the full post-emergence and full squaring or flowering stage.
Fertilization	3-4 times with rapid release fertilizers at planting, squaring or flowering stage and after topping. This implies more labor and lower fertilizer use efficiency.	One time at planting with slow- or controlled-release fertilizer. Labor saving and higher fertilizer use efficiency.
Plant training	Manual removal of vegetative branches, old leaves and redundant buds and growth terminals on the main stem.	Retention of vegetative branches at lower plant density, inhibition of growth of vegetative branches through increased plant density, plant growth regulators, or through use of chemical substitutes for topping.
Plastic mulching	Film thickness of 0.004-0.006 mm, lower residual film recovery.	≥ 0.012 mm thick film for better recovery; use of film substitutes instead of conventional plastic film.
Planting pattern	Double-cropping through direct seeding or transplanting before harvest of wheat/rapeseed.	Direct seeding of short-season cotton after harvesting or transplanting seedlings after wheat/rapeseed harvest
Management mode	Scattered distribution and small-scale plantations.	Concentrated distribution and scaling up plantations
Mechanization	Currently 40%: including tillage, sowing, fertilization, inter tillage and stalk mulching.	Ten years hence: $\geq 70\%$, including tillage, sowing, fertilization, inter tillage, picking, and stalk mulching.

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