Discover Natural Fibres Initiative

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Update on Cotton Production Research




Contents

Introduction

Organic cotton production is usually promoted as a sustainable production system, which is certainly true in terms of impact on the environment. As a cotton production system, organic cotton not only provides but prohibits the use of commercially available synthetic agrochemicals, herbicides, fungicides, insecticides, fertilizers, growth regulators, defoliants and desiccants. Elimination of all these agrochemicals is replaced with natural products and their formulations. Biotech cotton which not eliminates but reduces the use of insecticides is also forbidden for certification as an organic produce. Concerns about the environment have only grown over the years but organic production has declined for the last few years after reaching a peak production of 242,000 tons in 2009/10. India and Turkey became more active in organic production while most other small organic cotton producing countries maintained but did not exert on boosting organic production. Turkey being closer to the organic consumer market has certain advantages over other organic producing countries. The first article is an in depth analysis of organic production system and how it has developed in Turkey, one of the pioneers to initiate organic cotton production. The experience in Turkey showed that weeds usually do not constitute a major problem in organic cotton farming once proper crop rotation is established. Funnel traps and Delta traps are used to control bollworms. Read more in the first article.

The 2nd article ‘The Slow Changing Sector of Technology Transfer’ analyses the extension systems and various non-traditional approaches tried around the world in cotton production. The three important pillars of a successful production system are development of a technology package, effective dissemination and implementation/practice by farmers. Effective dissemination or technology transfer provides a link between research and verification segment and farmers who actually benefit from improvements in technological packages. Technology can be developed locally, borrowed from external sources and even purchased or licensed, however, the success in the commercialization of the recommended technology is not guaranteed, especially if the in-house technology transfer capabilities are not capable to convince growers to change their practices. Rapid development of information and transfer to growers using the Internet services is presenting a new challenge for extension specialists to device approaches that match the speed in development of technology. There is a need to motivate growers to come out and look for new technologies, rather than wait and see when a technology transfer agent will bring him a message.

Drs. Brendan Kelly and Eric F. Hequet of the Fiber and Biopolymer Research Institute, Lubbock, Texas, USA have contributed the third article ‘Breeding for Improved Yarn Quality: Importance of Non-HVI Fiber Properties.’ Variability in cotton fiber quality makes it a challenging natural raw material for transforming into a consistent industrial product i.e. yarn, fabric and garments. The authors emphasize the importance of predictability in performance, which, according to them, can be achieved by breeding for improved distribution in fiber quality. HVI testing is popular because it is fast and inexpensive but it is designed as a marketing tool. The authors advocate that breeders should base their selection of breeding materials on improved spinning performance and not merely on fiber quality parameters. This paper showed that AFIS fiber quality parameters provided a substantial improvement over HVI classification alone for screening breeding lines. Even though AFIS does not provide a direct parameterization of fiber tensile properties, AFIS parameters are able to increase the amount of explained variation in yarn tensile properties. It is imperative to augment HVI fiber quality parameters with non-HVI fiber quality parameters when selecting lines with reduced imperfections. For purposes of ranking lines in cotton breeding programs, a 1-replication measurement protocol may be adequate, thereby reducing the time and expense associated with adding the AFIS data to the programs. The authors showed the same from a large data set that non-HVI fiber property measurements are needed to achieve future genetic breakthroughs for lowering variation in predictability.

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Reliability in spinning performance is necessary to strengthen cotton's competitiveness vis a vis the large and growing array of synthetic fibers vying to serve the global yarn spinning industry.

Two New Publications

The Technical Information Section of the ICAC is currently working on the following two reports for the 72nd Plenary Meeting of the ICAC to be held in Cartagena, Colombia from September 29 to October 4, 2013.

- *The Planting Seed Industry*
- *Cost of Production of Cotton – 2013*

2013 Technical Seminar

The 2013 technical Seminar will be held on October 2, 2013 on the topic 'Overcoming the Period of No Growth in Yields.'

13th Meeting of ALIDA

The 13th Meeting of he Latin American Association for Cotton Research and Development will also be held during the 72nd Plenary Meeting of the ICAC. The ALIDA meeting will be on October 3, 2013, all day. Dr. Jorge Cadena jcadena12000@gmail.com of the Colombian Agricultural Research Corporation (CORPOICA), Colombia will serve as the Coordinator of the Meeting. Spanish-English translation is expected to be available.

Organic Cotton Production System in Turkey

Organic cotton production is thousands of years old, but certified organic production is about two decades old. Unlike some other production initiatives, organic cotton is a comprehensive production system requiring technological knowhow on a level, if not greater, at least equivalent to that required by conventional production. A farmer producing organic cotton must also understand all the other crops that are grown in a cropping system. Any production system requires research, guidelines and continuous updates. This article is an attempt to convey an understanding of organic cotton production technology as it is employed in Turkey, including management options for efficient control of weeds, insects and diseases. The article also provides information on the nutrient needs of an organic production system and how to meet those needs. Expert recommendations are meant to provide a sound foundation for Turkish farmers to guide their decision-making process. As the circumstances of farmers vary from country to country and from region to region, so too must the recommendations designed for them. Unfortunately, technical guidelines to support organic production are not coming at the same pace as the drive to expand organic production. Consequently, promoters of organic production systems have few tangibles with which to back up their claims.

In Turkey, the earliest certified organic agricultural practices were implemented back in the mid-1980's in the production of dry fruit. The movement was driven by demand from European importers and retailers and, since then, many attempts have been made with other agricultural products, including cotton from the early 1990's. The driving force behind organic cotton was not its safer production methods but the search for a rotation crop to produce in conjunction with organic dry fruit and nuts. A typical farm production system in Turkey (in the regions where cotton is grown) included winter cereals like wheat, barley and rye, which are planted during November and harvested in June. The summer crops are cotton, corn and sunflower, sown in April/May and harvested in September-November. There is an overlap in this conventional system that hampered achievement of optimum yields. The quest for new cropping patterns applied to organic cotton and its rotation crops is an additional reason to support adoption of the organic system.

The organic pattern had to be followed in a way that reduced sowing and harvesting bottlenecks within the limited availability of field working days by fostering a longer vegetation period, good yields, high quality, lower cost of production and premium prices.

Certification

Production can only be labeled as organic if a third-party certifier verifies that the specified certification requirements have been met, both in the field and in processing. Requirements vary slightly among certifying companies. The first official regulation on organic farming in Turkey came into effect in June 1995 following the promulgation by the EU of its Organic Regulation EEC 2092/91, which was in force for years. With the emergence of certain marketing issues, not only in cotton but also in other crops, the Turkish Association on Organic Agriculture started calling for a revision of Turkey's original 1994 organic legislation. The new law, passed in 2004, removed several obstacles that had been written into the earlier law. It also enabled village cooperatives to be certified as a group, thereby spreading the cost among several farmers. Changes in old regulations had to wait 2-3 years for parliamentary approval, making it all but impossible for Turkey to remain in step with the dynamic European regulations. In 2004, however, the new law empowered the Ministry of Agriculture and Rural Affairs (MARA) to make further changes. The Ministry also negotiated with the state agricultural banks to gain additional benefits for the organic sector, including lower interest rates on loans, and a 60% subsidy for producers of organic inputs. As a result of the new legislation, many independent control and inspection companies emerged in Turkey. Now, even some regions have their own region-specific organic production standards. The law was revised again in 2011, but the most commonly adopted standard is still EEC 2092/91. The US National Organic Program Standard and the Japanese

Agricultural Services' JAS standard are also followed to a great extent.

In the 1980's, all production, whether for food or fiber, adhered to EU standards for a number of reasons. One of them was the fact that organic production was tied in with high-end supermarket chains in Europe. Thus the bulk of the economic returns accruing from Turkey's organic production did not remain at home, a fact that still holds true for most organic cotton producing countries, except the USA. In Turkey, it may be claimed that at least a part of organic production is no longer tied to export contracts. This is one of the reasons why certifying companies have to be familiar with more than one standard. One thing that has not changed is that the lion´s share of organic production price premiums flows to off-farm owners of organic production and products.

Countries Producing Organic Cotton in 2011/12

Very few of the countries that originally started producing organic cotton have subsequently given it up completely, but it is also true that most countries have not made substantial increases in organic production. India, Turkey and lately China, have made huge increases in organic cotton production. Syria also produced over 20,000 tons of organic cotton for a few years. Its insecticide-free cotton production system provides excellent conditions for organic production and, in 2007/08, the country's output exceeded 25,000 tons. But ever since it started producing organic cotton, Syria has had to deal with marketing problems. Similar difficulties are facing other countries, most of them in connection with marketing and premium prices, but interest in organic cotton production has not diminished. Sustained interest in organic cotton also prevailed thanks, largely, to international support for specific organic projects.

The following countries produced organic cotton in 2011/12:

Africa:	Benin, Burkina Faso, Egypt, Mali, Senegal, Tanzania, Uganda, Zambia and Zimbabwe
Asia:	China, India, Israel, Kyrgyzstan, Syria, Tajikistan, Turkey and Pakistan
South America:	Argentina, Brazil, Nicaragua, Paraguay and Peru
Europe:	Greece
North America:	USA

Planting and Weed Control

The quality of planting seed for organic production has to be as high as for conventional cotton. Acid delinting, fungicide use and all applications of insecticides on planting seed—usually used to control sucking insects and pathogens—are prohibited on planting seed intended for organic cotton. Planting can be done manually or mechanically, but farmers must make certain that field stands remain high as a prerequisite for high yields.

Timely weeding is more important than either fertilization or pest control in maintaining or increasing cotton yields. Going without weed control causes greater reduction in yields than doing without fertilization or insect control. This phenomenon has been observed in conventional production as well as organic. When herbicides cannot be applied, the most important techniques for successful weed management in cotton are proper crop rotation and timely soil cultivation. However, this is not enough to ensure that the cotton fields will be free of weeds throughout the season. In the initial stages of crop growth, weeds take up nutrients, which would otherwise be lost through leaching. Then, when these weeds are slashed and left to decompose in the fields, the nutrients are returned to the soil and made available to the cotton plant. Slashing has to be done in a timely manner to ensure that the weeds have not formed seeds yet. Once the cotton crop has developed a dense stand, weeds usually remain below a level where they become significant competitors with the main crop. Careful monitoring of weed populations and the use of shallow soil cultivation, combined with selective hand weeding, usually allow experienced organic cotton farmers in Turkey to minimize losses due to weeds. In order to prevent the spread of weed seeds through composting, it is important that composts containing weed seeds go through a heat phase, to destroy the germination capability of most seeds. The experience in Turkey has shown that weed populations may increase during the transition/ conversion period, especially when switching from an herbicide-treated conventional cotton production system to mechanical weeding in organic production. It is important to keep the organic fields as free from weeds as possible, but the experience in Turkey has shown that weeds are not usually a major problem in organic cotton farming once a proper crop rotation is established.

One of the definitions of crop rotation is: a farming system whereby soil fertility and farmers' profits are least affected. Rotation is an important means of controlling a number of cotton pests, including nematodes. In Turkey, in addition to controlling weeds, cotton intercrops such as maize, sorghum, beans and peanuts provide a balance between pests and their natural enemies. However, the timing of planting intercrops, trap crops and border crops should coincide with the flowering of the cotton crop. Turkey has opted for a mixed cropping system and some of the more important products that may be grown together with cotton are leguminous crops. The option is not uniformly exercised on a large scale thus giving rise to fertility issues. Some of the crops that are commonly grown in multi-year crop rotations include corn, wheat, vetch, soybeans, sunflowers, vegetables, chickpeas and lentils. The important point is that organic cotton has to be produced as a component of a production system. The crops rotating with cotton must also be organic, and the cropping system has to be followed for a long enough period of time for the ecological balance to upgrade to a level that diminishes the need for emergency applications of herbicides and conventional insecticides.

Fertilizer Recommendations in Turkey

Regions	N kg/ha		P_2O_5 kg/ha		K_2O kg/ha		Total	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Aegean Region	140	160	30	70	130	90	240	380
Cukurova (Mediterranean)	160	170	30	60	130	90	250	390
Southeast Anatolia GAP	140	150	30	60	130	100	230	380

Fertilizer Needs

Proper growth of the cotton plant requires nutrients and there can be no doubt that synthetic fertilizers can best match the plant's nutrient needs in the field. However, nitrogen evaporation and nutrient leaching play are important in many ways. If proper crop rotations are followed, and if farmers can afford to reduce cropping intensity to some extent, the nutrient needs of plants that require external fertilizer sources decline significantly. On average, the following quantities of nutrient elements (above table) are recommended by the Ministry of Food, Agriculture and Livestock for conventional cotton growers in various cotton regions of Turkey.

A production system requiring lower doses of NPK is certainly more suitable for organic production. In Turkey, organic cotton fields received applications of about 110 kg/ha of nitrogen in the form of certified organic fertilizer sold under the commercial name of 'Agrobiosol' (NPK = 7:1:1.5). Unfortunately, this product is no longer commercially available and nowadays 'Bio-Farm' is the most common form of NPK= 3.5:3:3. Wherever possible, green manuring is done with *Vicia villosa L.* (commonly known as hairy vetch, fodder vetch or winter vetch). It has been found in the Aegean Region that green manure fixes 80-100 kg N/ha/year and any additional N requirements are met with certified organic fertilizer. Varieties requiring lower doses of nitrogen are more suitable for organic production. Excess nitrogen can easily produce an imbalance between reproductive and vegetative growth.

Insect Pest Control

The main insects in Turkey are cotton aphid (*Aphis gossypii*), red mites (*Tetranychus urticae* and *T. Cinnabarinus*), whitefly (*Bemisia tabaci*), thrips (*Thrips tabaci*), jassids (*Empoasca* spp.), American bollworm (*Helicoverpa armigera*) and pink bollworm (*Pectinophora gossypiella*). On a region-wide level, the distribution of arthropods is as appears in the following table.

Leafhoppers (*Asymmetrasca decedens* and *Empoasca decipiens*) became significant pests on cotton in Turkey only in the 1990's. Leafhoppers may appear in the early stages of development of the cotton plant in some regions and not show up until close to the peak boll formation stage in other regions. No strict control measures are taken to target leafhoppers directly. Thus, when favorable conditions allow the population to multiply and reach 10 hoppers per leaf, significant losses in yield may occur. The threshold that is usually recommended in organic cotton, 10 adults or nymphs per leaf, is rarely reached.

Major Arthropods Affecting Cotton in Turkey

Region	Early Season	Mid/late Season
Aegean		
	Aphis gossypii	*Tetranychus utricae*
	Thrips tabaci	*Helicoverpa armigera*
	Emphoasca decipiens	*Bemisia tabaci*
		Pectinophora gossypiella
Mediterranean		
	Aphis gossypii	*Emphoasca decipiens*
	Thrips tabaci	*Helicoverpa armigera*
	Spodoptera exigua	*Aphis gossypii*
		Bemisia tabaci
		Tetranychus utricae
Southeast Anatolia		
	Thrips tabaci	*Helicoverpa armigera*
	Agrotis spp.	*Earias insulana*
	Spodoptera exigua	*Tetranychus utricae*
	Aphis gossypii	*Asymmetrasca decedens*

The following are some action threshold levels for various arthropods (Anonymous, 2011).

Sucking insects

Tetranychus urticae	5 adults or nymphs/per leaf early in the season in Mediterranean regions, 10 adults or nymphs/ per leaf along the Aegean and in Southeast Anatolia
Bemisia tabaci	5 adults or 10 larvae per leaf at mid- and late season
Thrips tabaci	1 nymph or adult per leaf at early season
Aphis gossypii	50% seedlings infested at early season, 25 adults or nymphs per leaf at mid- and late season
Empoasca decipiens and *Asymmetrasca decedens*	10 adults or nymphs per leaf at early season

Bollworm insects

Helicoverpa armigera	2 larvae per 3-meter row
Spodoptera exigua	10 larvae or 2 egg pockets per 100 plants
Earias insulana	2 larvae or 4 eggs or 10 % infested bolls per 3-meter row

Turkey was once one of the most extensive insecticide users in the world. Some areas in some regions have required as many as 10 sprays, but insecticide use in the country has declined, thus creating more favorable conditions for organic cotton production. Currently, only about 20% of the insecticide used in the country is applied to cotton. Some parts of all three regions are not sprayed at all and the average number of sprays may range from 2-6. In the 2010/11 season, 55%, 70% and 53% of the cotton area in the Aegean, Mediterranean and Southeast regions, respectively, received less than two sprays per season (Technical Information Section, 2011). Lower insecticide use has been achieved without resorting to insect-resistant biotech cotton.

Funnel traps are used for the American bollworm and Delta traps for the pink bollworm, spiny-worm and cotton leaf-worm. Pest scouting is done on a regular basis to determine larvae and egg populations and once the counts exceed the threshold levels (2 larvae per plant per three-meter row), certified organic preparations, such as *Bacillus thuringiensis* (Bt) and pyrethrum are applied (Personal, Ulfet Erdal, Turkey). Lately, pyrethrum has been banned for use on organic production, so only Bt is used when required. Catches in the traps are closely monitored to assess the field situation. When catches in the traps reach 60 adults per trap, field scouting for larvae becomes necessary. Bt sprays are applied based on the larvae count in the field and not on catches in traps. Control measures are definitely needed in the first year of transition from conventional to organic, but no such applications are needed in the second and the third years because of reduced insect populations. Funnel and Delta traps are among the pheromone traps that are commercially available in farm markets in Turkey (Anonymous, 2011). The recommended rate of application is one pheromone trap per two km^2. Organic growers can alternate Bt with neem-derived azadirachtin, which is more popular in India, but rarely needed or used in Turkey.

The pink bollworm is also monitored with pheromone traps, but it is no longer a significant problem in conventional production, thus requiring no control measures in organic fields. No special preparations are recommended or available on the commercial market for use against the pink bollworm. Total reliance on the pheromone traps is the only available option. Different kinds of pheromone traps are available in Turkey, and the main upkeep operation is replacement of the pheromone every 15 to 30 days. Resistance to Bt is not an issue since the number of applications is one of the lowest and they are enough to tackle smaller populations of *Spodoptera exigua* and *Earias insulana*.

Sucking insects, particularly spider mites, require good control on organic cotton in Turkey. Sulfur is a naturally occurring element available in abundance in many countries. In elemental form, sulfur has insecticidal properties and is used on cotton in Turkey to control spider mites *Tetranychus* spp. Powdered sulphur stripes are applied around all organic fields as a protective measure. It is difficult to keep sulfur dust on leaves for very long. This accounts for its lack of toxicity as compared to wet sulphur. In Turkey, crystalline sulfur is used to spray on leaves. Four hundred grams of crystalline sulfur is mixed in 22 gallons of water and sprayed on the cotton plants to control the red spider mite, *Tetranychus urticae*. A thin layer of sulfur applied in wet form also provides protection against other sucking pests.

Diseases and Picking

Some of the diseases reported in Turkey are: verticillium wilt, seedling disease and bacterial blight (Anonymous, 2011). None of these diseases reach a stage requiring special control measures.

In Turkey, labor is expensive and is not conveniently available. Conventional cotton farmers can switch to machine harvesting to lower the cost of picking. Currently, almost ¾ of production is machine picked. In the last few years, the number of picking machines reached around 1,000. All organic cotton is hand picked, but when defoliation is required, excess doses of sulfur are applied to terminate growth and enhance leaf abscission.

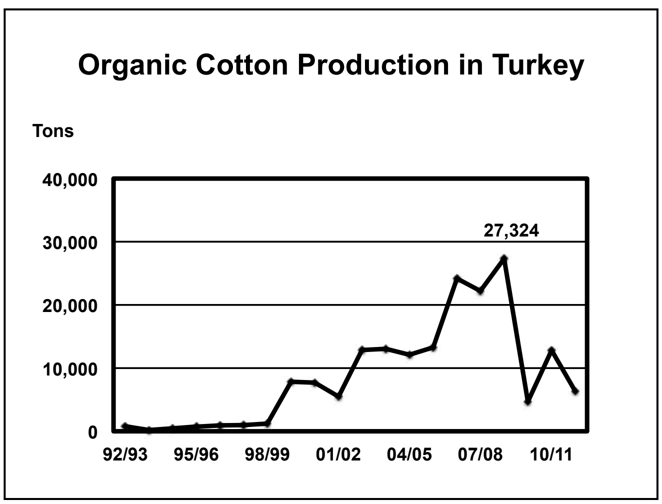
Reasons for Decline in Production

Turkey is one of the countries that pioneered organic cotton production. Turkey was second only to the USA, having produced 789 tons of organic cotton as early as 1992/93, only the third year of organic cotton production. Turkey produced 27,324 tons of organic cotton in the 2008/09 season. Compared to the more than 20 other countries that produce organic cotton, Turkey has some advantages and favorable circumstances that facilitate organic cotton production. The additional benefits are:

- Cotton yields in Turkey are among the highest in the world. Higher yields automatically indicate that the production technology is good and use of the technology is optimal. It is assumed that better growers of conventional cotton will be more capable and better prepared to handle organic production, a system that requires good judgment on the part of growers.
- Insecticide use has been dropping in Turkey for many years. Lower pest pressure leading to lower insecticide use provides an environment that is more enabling for organic production.
- India, Syria, China and the USA, in that order by volume, are some of the other major producers. Most of the cotton area in China, India and the USA is planted to biotech varieties, thereby creating the risk of contaminating the organic seeds during transportation, ginning and storage. In Turkey, biotech cotton is still prohibited, which precludes the risk of planting seed contamination.
- Most organic cotton consumption takes place in Europe. Turkey's proximity to the organic cotton consuming countries in Europe gives it privileged access to the greater part of the organic cotton market, in addition, of course, to local consumption.
- India is the largest producer of organic cotton, most of

which is produced under rainfed conditions; in Turkey, however, all cotton is irrigated. Moreover, although the recommended nitrogen application doses in India and Turkey are similar, i.e., about 120-150 kg nitrogen/ha, elimination of fast acting nitrogen by rainfall under rainfed conditions can have devastating effects that are not an issue in irrigated conditions. Additional irrigation in Turkey might compensate for some nitrogen deficiencies.

- The average farm in China and India is very small. Most farmers plant less than one hectare of cotton and such small farm size inhibits the adoption of organic practices, particularly in connection with insects. In Syria and Turkey, the average farm size is about five hectares, sufficient for individual farmers to implement their own organic production systems. Turkey was the largest producer of organic cotton in the world for eight consecutive years, from 1999/00 to 2006/07. Organic cotton production in India increased three fold from 2006/07 to 2007/08, thus pushing Turkey down to second position. Turkey maintained this ranking in the world and continuously increased production until 2008/09. Organic cotton production declined drastically to less than five thousand tons in 2009/10, increased in 2010/11, but halved again in 2011/12. Production is not expected to recover in the next few years.



There are some generic constraints that are limiting expansion of the organic cotton area in the world. The constraints include: lack of technical information on the organic production system, lack of suitable varieties, lack of transparency (particularly with regard to marketing), lack of reliable data, and so on. The main reasons for the decline in organic production in Turkey are the following:

- There have been some changes, but most organic cotton production in Turkey basically depends on demand from foreign countries. Lower demand is driving production down.
- Organic farming is leading to a predominance of contract farming conditions. Small farmers cannot afford to produce organic cotton on their own and then go looking for interested buyers. This inherent problem has always crippled the organic cotton production sector. Farmers have not been able to produce organic cotton and sell it competitively in the open market. Organic cotton remains a demand-driven initiative, a fact that needs to be changed.
- Companies' demand for organic cotton is known sufficiently in advance to give farmers the flexibility to alter the area to be planted to the organic system. The organic cotton industry in Turkey and elsewhere lacked the sustained commitment by consumers to buy their produce, thus creating imbalance and uncertainty in the market.
- Organic producers expect premium prices, irrespective of any other price level. Price premiums over conventional cotton have always been an issue.
- Insecticide use on conventional cotton is on the decline, thus affecting the cost of production in conventional vs. organic cotton. In Turkey, the cost of labor operations, picking in particular, is increasing. Organic cotton has to be picked manually because of the inability to defoliate the crop properly. Hence, it is becoming more expensive to grow organic cotton in Turkey.
- Not often, but occasionally, Turkish cotton growers have faced difficulties in connexion with planting seed for organic production. This may be due to the complete transfer of planting seed production to the private sector in the last 10 years.

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The Slow Changing Sector of Technology Transfer

The goal of research is to develop technology capable of improving productivity, lowering production costs, devising safer methods by which to produce high quality cotton and making cotton production a sustainable undertaking for all allied industries. The specific objectives of research may differ for different production systems; they may focus on just one aspect at a time, and the priorities will certainly change over time. Whatever the focus or priorities may be, the objective is to develop a technological package that is both viable and easily implemented by farmers. It is a well-known fact that farmers around the world have only minimal direct communication with researchers. When a technology package, or an element of a package is developed, it has to be thoroughly tested before it is transferred to farmers. Technology transfer systems are responsible for disseminating the package to the growers. Thus the three key pillars of a successful production system are: development of a technology package, efficient dissemination to producers and successful implementation by them.

The Technology Development Aspect

The development of technological recommendations is a long process involving well-coordinated cooperation among various disciplines of production research. Knowledge development has traditionally been undertaken by the public sector, and the development and improvement of technology packages continue to be in the hands of the public sector. This trend is not going to change in the foreseeable future because there is no direct and visible remuneration for the recommendations developed by experts. At this stage, most experts expect that the public sector will continue to be largely responsible for knowledge management, i.e., articulating national needs, matching them to often unidentified needs of farmers, and taking every opportunity to serve the farm community. Researchers often have to adjust components of a package to effectively meet farmers' needs at specific regional and zonal levels. In some countries, universities play a strong proactive role but, in most, it is the national agricultural research system that is in charge of identifying farmers' needs and adjusting research accordingly. University systems generally provide higher flexibility than national agriculture research systems to adjust to local conditions. State and provincial research networks working together with the universities have also succeeded in meeting the applied research needs of farmers.

The most important aspects of technology development where the private sector has played an important role, have been: the use of fertilizers, the use of pesticides and the introduction of biotech cotton. Fertilizer use proceeded without requiring much advocacy due to the extremely high cost/benefit ratio and the minimal requirements for dose adjustment and time of application. The use of pesticides gave rise to a real partnership beyond mere profitability. The main interest of the pesticide companies may have been motivated by the quest for higher sales or the promotion of their own products, but in so doing, they chose to educate growers, to teach them the differences among various products and, afterward, to promote the wise use of insecticides. The pesticide companies bridged the gap between researchers and farmers, something agriculture extension systems were often unable to do. Pesticide companies were not expected to develop research systems as strong as the national agricultural research systems. Agronomic research was limited; for example, there was no research in breeding, but their entomological research went far beyond economic motives and they were quite thorough with respect to various products.

The contraction of pesticide use forced the industry to reorient its strategies. Some producers availed themselves of the opportunity offered by the commercialization of biotech cotton and the growing awareness of the need for higher quality planting seed to go into the planting seed business. China privatized the production of planting seed; in India and Pakistan hundreds of seed companies appeared, and in Turkey, planting seed production and distribution by the private sector soared from less than 20% to 100% in less than 10 years. A similar trend developed in the USA, where public sector breeding was limited to the development of registered breeding lines.

In many countries, the public sector continues to compete with the private seed companies, but that competition cannot continue for very long. Weak implementation of intellectual property rights protection keeps public sector researchers from reaping the benefits of their achievements. The private sector can, however, afford to develop varieties and sell planting seed. Those varieties come with a technology package designed to ensure that particular varieties will produce maximum yields. As a result, the private sector is now formally assisting in the development and dissemination of technology indispensable for success.

Cotton at a Disadvantage

Technology development requires a thorough review of the work done by other cotton teams in the country. The legitimate motivations include, of course, the desire to learn from each other's experience, efforts to identify better options and the drive to surpass others. International collaboration with researchers in other countries has proven to be very productive. The international research centers participating in the Consultative Group on International Agriculture Research (CGIAR) have developed technologies for major food crops such as wheat and rice, in particular, and later for corn, cassava, potatoes, millet and beans. Germplasm distribution was liberal and the national agriculture research systems were able to use applied research to adjust these technologies to fit their own ecological and production conditions. The international centers provided unconditional cooperation, which the national agriculture research systems were able to use to a greater or lesser extent as a function of their particular circumstances. The national and international centers together shared knowledge and frequently invited scientists to participate in visits and seminars. Thus the expertise acquired by the national centers allowed them to provide advice and counseling to local farmers with the goal of infusing the new knowledge into production systems throughout their countries.

The system described above worked especially well for disseminating improved crops and new production techniques. The results are apparent. For example, the plant breeding work of the International Maize and Wheat Improvement Center (CIMMYT) developed a new family of short-stature wheat varieties in the early 1960's, which 10-15 years later were already being planted by the majority of wheat growers in the world. Furthermore, the national and international research institutes set up in the developing world during the 1960's and 1970's were largely responsible for substantially increasing yields. The success story of rice was similar to that of wheat, and the global cereal yield doubled between 1960 and 1985 (Piñeiro, 2007). Technology is still being transferred to developing countries this way, but recently, public funding for agricultural research has diminished, thus emphasizing the need for collaborative joint venture research. This research is becoming more expensive and, in certain areas, public sector involvement is severely limited.

Cereal crop yields doubled in 25 years (between 1960 and 1985) but it took over 40 years for cotton to double its average world yield from 313 kg/ha in 1960/61 to 646 kg/ha in 2001/02. The slow pace of development in cotton can be attributed to many factors, but the lack of international technical and germplasm support for cotton made a big difference between cotton and other crops. If equal international support had been made available to develop cotton technology, the distance would have been travelled in a much shorter time. The situation still persists, and cotton continues to suffer.

Access to literature and well-equipped libraries is another factor that plays a significant role in helping researchers enhance their technology skills. Being able to maintain an ongoing review of the relevant literature and to redirect investigative approaches accordingly is vital for researchers. Fortunately, the availability of information on line has to some extent eased the job of keeping up to date. ICAC provides an opportunity for cotton researchers to meet face to face through the four regional networks and world cotton research conferences it has been supporting for over 20 years.

Technology Transfer

A technology package must be effectively transferred to the end users (the farmers) if it is to be useful. In most countries, a network of experts provided by states and provinces is responsible for technology transfer. In some countries cotton companies replace the public sector while in others they are responsible for facilitating the information transfer. The private consultant system is popular in large-scale farming systems. One of the traditional approaches used by the public sector, based on the theory that 'seeing is believing,' has been to run demonstration plots. This principle still holds true, but in most countries it is just one among many tools. Information brochures, radio programs and television have long been used to transfer technology. Ironically, initial research and development requires a great deal of time and resources, but the actual transfer and distribution of technology entails relatively modest expenses. Many new approaches have been tried at various levels, but there are several constraints that limit easy dissemination of messages to farmers.

Limitations to Technology Transfer

Technology can be developed locally, borrowed from external sources and even purchased or licensed; however, success in the commercialization of a recommended technology is not guaranteed, especially if the in-house technology transfer capabilities are insufficient. This is particularly true in the case of comparatively advanced technology.

- In many countries, technology transfer experts, usually known as extension workers, experts, consultants or technical advisers, are called upon to be experts in all crops, including vegetables, fruits and horticulture. It is a tough task for general extension specialists in developing countries to have expertise in all crops.
- The number of extension workers is usually spread very thinly among the mass of farmers. Unlike larger growers who can afford to hire experts for various kinds of advice, small farmers cannot afford to pay consultants.
- Extension staff members usually lack the resources needed to reach farmers. Technology transfer becomes even more difficult because extension workers have to convince the famers that they should be doing things they are not already doing. Technology transfer is a specialized subject, and extension workers are often not given an opportunity to update their knowledge about new developments.
- Recently, the rapid development of information and of its transfer to growers provided by the Internet is presenting a unique problem of adaptation, not only in cotton but in all crops. Decision-making activities and procedures have changed altogether.
- One can outsource certain technology development aspects and enhance emphasis through additional funding, but extension workers must be familiar with local culture and traditions. While production systems prohibit importation of dissemination techniques, in some cases, local language limitations may further complicate the problem.

- Intellectual property rights have not been a big hurdle but could become an obstacle when breeders' rights and proprietary gene ownership become the norm.
- A technology package covers not only the use of resources such as varieties, fertilizers, pesticides, etc. but also, and very importantly, an understanding of their interaction.

Technology Adoption and New Technology Transfer Norms

Technology transfer in the public sector originally focused on timely planting and selection of suitable varieties. Agronomic recommendations like proper row-to-row distance, removal of weeds, and a number of other customary recommendations remained constant. However, with the commercialization of synthetic fertilizers, the focus shifted substantially to input use. Farmers received blanket fertilizer application recommendations that left them little margin to adjust doses. In most developing countries doses were commonly measured in terms of bags of fertilizer rather than kilograms of N, P or K per hectare. Then, with the adoption of pesticides, the technology transfer message became more intense and absolutely necessary. Many countries were quite able to improve the skills needed by farmers to grow cotton successfully.

Now the transfer of technology is at a new junction where it needs to reorient its efforts. Farmers are highly cautious when selecting varieties. Agronomic recommendations are always in a continuous process of fine-tuning, while fertilizer use in most countries has been optimized. A diminishing demand for insecticide to be used on cotton has substantially affected the extension services provided by pesticide companies. All segments of the cotton industry are carefully devising strategies to deemphasize reliance on chemical control—a common goal for partners in the production chain, including growers-- and developments in the Internet and the media have provided a new forum to be exploited.

The world average cotton yield peaked at nearly 800 kgs per hectare in 2007/08 and it is low now, and it is not expected to increase in the near future. Analyzing the current situation, it would seem that the message to be disseminated among cotton growers needs to be updated. The situation may be different with other crops but, in cotton, it has become necessary for farmers to understand the physiology and resultant interaction of the inputs used. The system of applying inputs at the right time and in the recommended quantities has been employed in many countries, particularly in those countries where yields increased and have subsequently stabilized. Countries that have not taken advantage of the benefits of using inputs will certainly need to adopt and employ them. Cotton growers in a number of countries are slowly beginning to depend on information available on line or through direct contacts with experts via telephone and e-mail.

Crop Clinics

The Centre for Agricultural Bioscience International (CABI) has applied a novel electronic approach called 'Crop Clinics.' The experts whose services are available through the clinics are called 'Plant Doctors.' According to CABI, they have already set up plant clinics in over 20 countries in Asia, Africa and Latin America. All plant clinics are not specialized in cotton. The plant clinics advise farmers on pests and diseases in the way a health center does for humans.

The clinics are run by local specialists who have been trained and certified as plant doctors. These specialists may be regular extension workers from the surrounding area, but they are provided with additional training that allows them to make technical "prescriptions" for the local growers. Farmers drop by with samples of diseased plants to get the problem identified and to learn what to do about it. CABI works with existing plant science organizations, agricultural ministries and extension systems to create a sustainable local plant healthcare system in support of the clinics, which, in turn, provide support for the farmers. The program, called by CABI 'Plantwise,' supports local grassroots organizations; it also sets up and runs local plant clinics in their areas. The plant clinic answers farmers' individual questions, and when the national diagnostic laboratories need additional support, samples can be sent to CABI laboratories in the UK for expert diagnosis.

India tried a similar approach, using electronic media to transfer technology to farmers. The country established over 150 kiosks in cotton market yards in 11 cotton-growing states. The kiosks were stocked with detailed information on every aspect of cotton production. Data covering the package and practices relevant to each particular area were collected from state agricultural universities and the central government institutions under the Indian Council of Agricultural Research. Information on production practices as well as on cotton prices prevailing at the international, national and state levels and in nearby markets was updated regularly. Interactive Voice Response Systems were also established whereby farmers could access information about cotton from their own homes. The program has not been extended to all the cotton areas in India, but some of the new uses of electronic media currently in the planning stage are designed to benefit marketers and ginners to help them produce lint with minimal trash content.

The Department of Agriculture, Punjab, Lahore, Pakistan is finalizing arrangements for the automation of agricultural extension services by means of web-based applications in collaboration with CABI. The Department has also proposed to the provincial authorities a plan to provide modern instruments with which to improve delivery systems and accessibility, as well as to extend accountability to the lower tiers of extension agents. The plan includes supplying every unit of extension staff, even the smallest, with laptops and multimedia tools and to give them the mobility they need to be able to demonstrate technological materials in village meetings or at even smaller gatherings in farmers' fields. The department has also provided easy access systems for farmers to reach their local extension staff and every link in the extension chain all the way up to the highest level. The department already maintains a huge database currently comprising over 300,000 cotton growers and their mobile contact phone numbers, but total coverage may take some time.

Farmer Field School System

The 'FAO-EU IPM Program for Cotton in Asia' is one of the largest and most expensive technology transfer programs implemented in the world. Six countries -- Bangladesh, China, India, Pakistan, Philippines and Vietnam -- which together accounted for 57% of world production in 2012/13, worked together on a harmonized media set for transferring technology in a five–year project that finished in December of 2004. The project developed a cadre of IPM cotton trainers from among current extension staff to train farmers in Farmer Field Schools. They promoted cooperation among public and private sector technology transfer agencies, staff and researchers with a view to improving farmer access to information. They also worked to foster the creation of national plant protection policies to support IPM development rather than relying entirely on insecticide use. Highly skilled training facilitators were prepared in all the participating countries. The primary learning process was implemented through Farmer Field Schools (FFS). Graduates of the Farmer Field Schools who had the potential to become farmer facilitators underwent an extensive Farmer Training of Facilitator (FToF) program so that they would be capable of organizing farmer-to-farmer field schools (F2FS). In the end, the farmers themselves wound up training their own colleagues and neighbors.

The program succeeded in demonstrating that farmer education through the FFS approach can encourage growers to adopt a sustainable pest control system. The full version of the project impact report is available at http://www.vegetableipmasia.org/docs/Cotton/PPP_Cotton_IPM_Asia2-CD.pdf, but there is a concise version that was published by ICAC in September 2003 (Ooi, 2003). The project made a long-lasting impact on cotton production in the region, particularly in China, India and Pakistan. ICAC is currently implementing a slightly different but related project, 'Improving Cotton Production Efficiency in Small-scale Farming Systems in Kenya and Mozambique,' with financial support from the EU and the Common Fund for Commodities. The project started in November 2009 and will conclude in November 2013. The aim of the project is to introduce an integrated crop management (ICM) package, to promote adoption of the ICM package, and to build stakeholder linkages for sustaining ICM. At the very outset, the project did a baseline survey and, at its conclusion, it will perform a thorough evaluation of the impact of ICM adoption. CABI Africa, Nairobi, Kenya is implementing the project on behalf of the Fund and ICAC.

Reaching Out to All Growers

There is no doubt that a message conveyed by an extension worker carries a lot of weight, but occasionally, an experienced farmer may know more about a certain aspect than an extension worker. Reaching out to every grower has always been a challenge. Technology transfer staffers usually have an impossibly high number of growers to reach out to individually. There are only two technology transfer systems in the world where every farmer is reached: in Australia and in the West African countries. Australia has a unique large-scale farming system where every farmer can afford to hire a general consultant or specialized consultants in agronomy or pest control. The Australian Cotton Research and Development Corporation and Cotton Australia maintain a list of cotton growers with their e-mail contacts. Cotton Australia circulates a fortnightly e-newsletter to growers. Their target audience includes private agronomy consultants, industry people and researchers. The content is principally farm-orientated research and development and contains a selection of topics from 6 to 8 in each issue. The Australian Cotton Research and Development Corporation also performs a media-liaison function, which allows for re-distribution of media articles in agricultural and other targeted media whenever appropriate. Australia's extension services have the advantage of reaching out to a comparatively smaller number of cotton producers, fewer than 1,500 in most years. In the West African countries, farmers are organized in farmer unions that cover from the village level all the way to the national level. The cotton companies supply farmers with seed, fertilizer and insecticides, along with expert advice. The database on farmers is complete, accurate and always up to date because the cotton companies have to collect the credits extended to all growers. The system is very well organized and should work for technology transfer, as well as for input distribution. However, this is not the case judging from the performance of the system in terms of impacts on yields. National average yields in the West African countries have not increased in more than 25 years, which makes it evident that there is a need to identify the weaknesses in the system and heal them. Contract farming, which enjoys a measure of popularity in India and is employed in a number of countries in the Southern and Eastern African regions, is another way of reaching all growers, but price volatility has often resulted in breaches of contracts on both sides.

Mass media approaches have been tried and are practiced in every country, but, there are also some specific efforts that have been designed to reach growers in a given region or area. In a project that was undertaken in the 1970's and 1980's in Pakistan, it was mandatory to reach every grower in an area. The number of extension specialists in each area was increased and they were exceptionally well trained by direct sessions with researchers on a regular basis. Researchers also followed up with the extension specialists in the field. That project had a huge impact on cotton yields at the national level. A similar project was implemented in Iran with the difference that farmers were given all kinds of help, including financial support, to implement the recommended technology. In this case, yields in the project areas almost doubled. The Government of India invested heavily in technology transfer via Mini Mission II of the Technology Mission on cotton that started in 2000. There were three other mini missions, but the extension mini mission received greater emphasis than the rest. In India, the increases in cotton yields during the last decade can be attributed to technology transfer, in addition to other factors.

In the USA, cotton was produced on 18,600 farms in 2012, and growers always used a broad range of methods to acquire new technologies. The most scientific of all the methods and the one imparted directly by researchers is the series of Beltwide Cotton Conferences, which are held every year in early January. Attendance has been dropping off for some time but, not many years ago, over 5,000 people would often attend the Conferences. About half of the attendees used to be farmers. Public sector programs, including the Cooperative Extension System at the federal, state and county level are used but they are not relied on as the only source of information. Private consultants are hired, and farmers, on their own initiative, explore every aspect of technology acquisition. They also contact state agricultural services, research stations and input suppliers. Farmers in the United States are under high pressure to produce cotton economically, so they do not wait for the information to come to them; they are constantly reaching for better ways to produce cotton.

Summary

Research has progressed at a much faster pace than the means used to transfer new technologies to growers. The technology packages recommended for adoption are no longer limited exclusively to material issues such as varieties, machinery, fertilizer, insecticides and, more recently, biotech cotton. It has become more important to understand the interactions among the different inputs and the adjustments that have to be made in quantities and frequencies so that farmers can get the best return on their investments. Newer methods of mass communications must be developed and tested. Methods have to be developed to reach all growers, or at least most growers. Unfortunately, public funding for agricultural research is declining and the science has grown more complex. Technology transfer, as such, has lacked innovation. Many approaches have been tried but the issue remains that the processes involved in the development and dissemination of new technologies are no longer an individual undertaking but an institutional effort that requires strong collaboration among various disciplines. On the receiving end, farmers are receptive, but reaching each and every one of them remains a challenge in the transfer of technology. Growers have to be motivated to come out and look for new technologies instead of waiting to see when a technology transfer agent gets around to bringing him/her the message.

New technologies embodied in material products resulted in rapid and exponential expansion of private companies that research, develop and make new technologies available. The public sector institutions are slowly adapting to these new circumstances by redefining their priorities, but the process must be expedited.

The philosophy of technology transfer also needs to be changed. The message must be cost effective and the focus has to shift to the resultant interaction among the materials before a new materials-based technology can be developed and commercialized. Optimum utilization must also take into account the sustainability aspect of materials. The new economic and scientific context requires a new, more complex model for transferring technology.

The development of electronic media, both for access to information on line and for personal outreach via mobile phones is revealing new challenges and opportunities. Further technology development demands a review and restructuring of the existing cotton extension systems.

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Breeding for Improved Yarn Quality: Importance of Non-HVI Fiber Properties

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Upland cotton, *Gossypium hirsutum* L., ranks fourth in planted area in the United States, behind corn, wheat, and soybeans. The cotton industry in the United States, from field to fabric, has direct business revenue that exceeds $27.6 Billion [1] and has an estimated total economic impact in excess of $120 Billion [2]. The United States is the world's largest exporter of raw cotton fiber, followed by Australia, Brazil, India, Uzbekistan, and African Franc Zone. Almost all world trade of cotton is for spinning yarns used in making woven and knitted fabrics. In response to the demand for cotton fabric, worldwide consumption of cotton fiber has more than doubled from 1960 to 2011 (Figure 1). Though cotton fiber consumption has increased, cotton has lost half its market shares to competition from synthetic fibers [3]. It should be noted that the cotton's share of U.S. apparel imports is currently about 55% [4]. While consumers desire the comfort of cotton fabrics, spinning mills enjoy the predictability of manufacturing yarns from synthetic fibers. In order to remain competitive with man-made fibers, cotton fiber must exhibit reduced variability so that it may perform predictably at the mill. This can be achieved by breeding for an improved distribution in fiber quality using non-HVI fiber qualities.

While consumers demand cotton yarns, variability in cotton fiber quality makes it a challenging natural raw material to transform into a consistent industrial product. Natural variability in cotton fiber quality can translate into imperfections in spun yarns [5-8]. Imperfections in the yarns, in turn, result in imperfection in the finished textiles. Textiles that exhibit imperfections are less desirable and must be discounted if they are to be sold. Discounts from imperfections in cotton yarns result in lost profits for the spinning industry. In addition to impacting the value of finished yarns and textiles, variability in cotton fiber impacts processing [9]. Yarn imperfections translate into weak points which increase yarn breakages and lower productivity at the mill. In order to mitigate the risk to profits from a naturally variable fiber, spinning mills try to purchase cotton bales that exhibit a fiber quality profile sufficient for their needs. In turn, growers depend on breeders to provide varieties that produce cotton fiber that meets the quality profiles needed in the markets they serve.

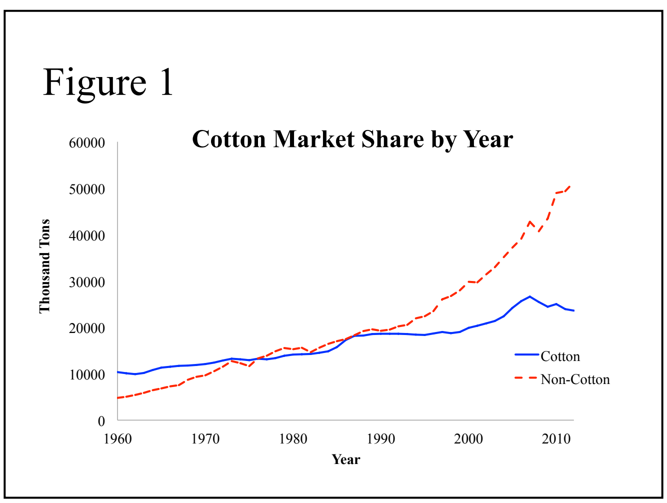

Figure 1: Cotton Fiber Market Shares vs. Non-Cotton Fiber Alternatives [3].

Breeding for improved spinning performance and yarn quality poses a formidable challenge. Spinning trials demand a great deal of time and money, making them impractical in a sizeable breeding program. Therefore, breeding lines are not screened based on their spinning performance. Instead, breeders interested in selecting cotton varieties with improved spinning performance make their selections indirectly, based on fiber quality parameters. The most common source of fiber quality parameters is the High Volume Instrument (HVI). HVI is a classification tool originally developed to replace hand classers in cotton marketing. Despite their origins in cotton marketing, HVI fiber quality parameters are used as an evaluation tool in most breeding programs worldwide. HVI results are popular because the test is relatively fast and inexpensive. However, selections based on fiber quality parameters should be done with the aim of improving yarn quality. It is important to ask if fiber quality parameters provided by HVI testing, a tool designed primarily for marketing cotton, are adequate for selecting elite cotton lines for improved spinning performance.

The speed of HVI classification depends on following the tradition of hand classing. HVI fiber quality testing methods are designed to mimic the bundle testing used by hand classers. Much like a hand classer holding a bundle of fibers between his fingers, upper half mean length and length uniformity are both measured from a beard of cotton fibers held in the HVI comb [10-12]. After being evaluated for length, the beard is clamped and broken to evaluate the strength and elongation of the fiber bundle. HVI is only able to measure the length and strength of fiber extending from the comb and does not characterize the complete distribution of fibers within the sample. In addition, HVI testing is unable to separately evaluate maturity and fineness of the fiber within a sample, two of the most important cotton fiber properties for producing quality yarns. In order to expedite testing, a flow of air through a plug of fiber is used by HVI to obtain micronaire, a composite measure of maturity and fineness [13, 14]. While these measurements are fast, they cannot characterize the important within-sample variations in cotton fiber quality. Yet, capturing within-sample variability of a bale is critical for predicting spinning performance [15]. In effect, high-speed HVI fiber quality assessment is achieved at the expense of a more complete characterization of within-sample variability of fiber quality.

Yarn Strength

The shortcomings of HVI bundle testing have been masked by some historical success in improving fiber bundle strength and upper half mean length. Weak yarns in the textile mills reduce profits by breaking and slowing production levels. Therefore, the primary emphasis of yarn quality improvement has traditionally been placed on improving yarn strength. Many bundle fiber quality parameters, including HVI tenacity, are useful for explaining variability in yarn strength [5, 6]. In turn, advancements in yarn strength have resulted from improved breeding efforts based on HVI length and strength. Therefore, the increasing averages since 1980 of HVI length and strength for the USDA cotton classing office in Lubbock, Texas (Figures 2 & 3) are a real success story. Nevertheless, the inability of HVI to capture the within-sample variability in these fiber properties limits potential improvements. Fiber-to-fiber variability within the cross section of the yarn can cause weak points in the yarn structure where breaks can occur, slowing production. However, bundle strength from HVI does not capture the strength distribution of individual fibers within the sample [16]. Breeding based on within-sample variability in fiber strength can enable improvements beyond what is possible with HVI bundle strength.

Another important yarn tensile property is the total work-to-break (i.e., the total force required to rupture the yarn). Work-to-Break is a function of both yarn strength and yarn elongation. Yarn elongation is highly correlated with fiber

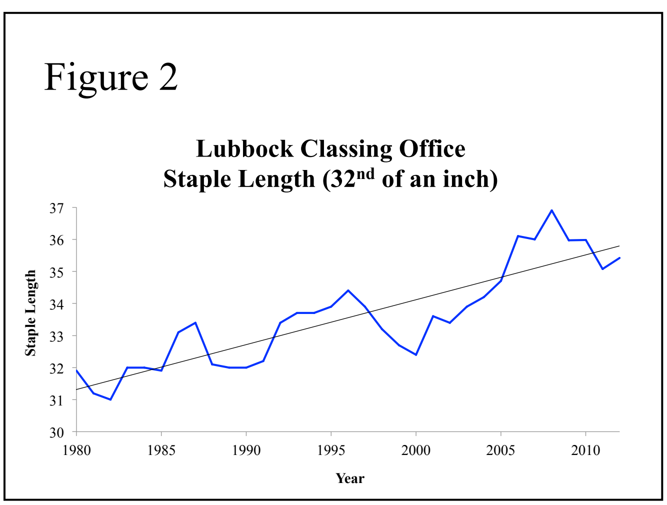

Figure 2: Increase in HVI Length (upper half mean length) at the Lubbock Classing Office from 1980-2012.

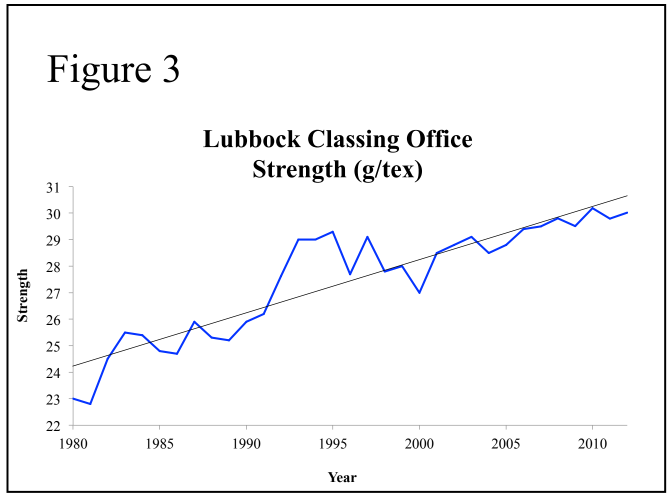

Figure 3: Increase in HVI Strength (fiber bundle strength) at the Lubbock Classing Office from 1980-2012.

bundle elongation [7], yet this property has been neglected by the cotton breeding sector, and a mechanism for further improvements in spinning performance has been forfeited. This forfeiture is due, in large part, to the lack of a widely available elongation calibration standard for HVI systems.

Yarn Evennes

The market value of cotton yarns is impacted by more than just tensile properties. Variability in yarn evenness properties (i.e. coefficient of variation of the mass per unit length, numbers of thin places, thick places, neps, and hairiness) has a large impact on the value of the yarn. These imperfections degrade fabric appearance and/or feel, which limit the fabrics to lower-value markets. Yarn imperfections such as these are largely caused by within-sample variability in fiber quality that is not revealed by HVI classification.

While most breeders depend on HVI fiber quality parameters exclusively, many spinning mills have long known of the need for distributional data to augment the HVI data [15]. The Advanced Fiber Information System (AFIS) was originally developed to provide spinning mills with additional information about within-sample variability [17]. The AFIS individualizes fibers and utilizes a sensor box, containing two electro-optical sensors, in order to evaluate length, maturity, and fineness of individual fibers within the sample. In addition, AFIS uses an airflow and electro-optical sensor to characterize trash particles and other contaminants within the sample that are aerodynamically dissimilar to the fibers. The within sample variability of each fiber property is summarized by AFIS in a set of fiber quality parameters and individual histograms. In this way, AFIS provides a much more complete characterization of fiber quality within the sample.

An Illustration Using Fiber Length

The difference between HVI and AFIS is stark when seen in graphic form. Figure 4 is a graphical representation of all

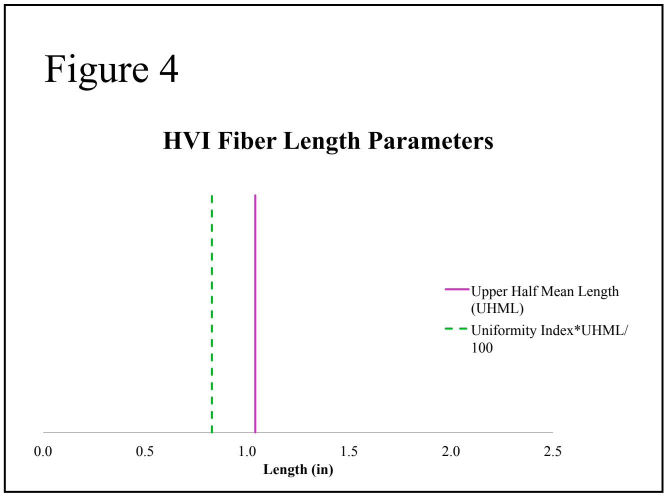

Figure 4: Graphical Representation of HVI fiber length classification data. HVI provides 2 standard parameterizations of fiber length, Upper Half Mean Length and Length Uniformity. Length uniformity is defined as a ratio of the mean fiber length to the Upper Half Mean Length. Therefore, mean fiber length is depicted in this graph instead of the uniformity ratio.

length related parameters characterized by HVI classification while Figure 5 illustrates all of the fiber length attributes characterized by AFIS testing. HVI provides two parameters that describe the longest fibers in the sample while AFIS provides 45 unique parameterizations of the complete distribution of fiber quality within a sample. These charts highlight the potential for significant differences in spinning performance from cotton varieties developed using only the HVI and those developed using both the HVI and the AFIS.

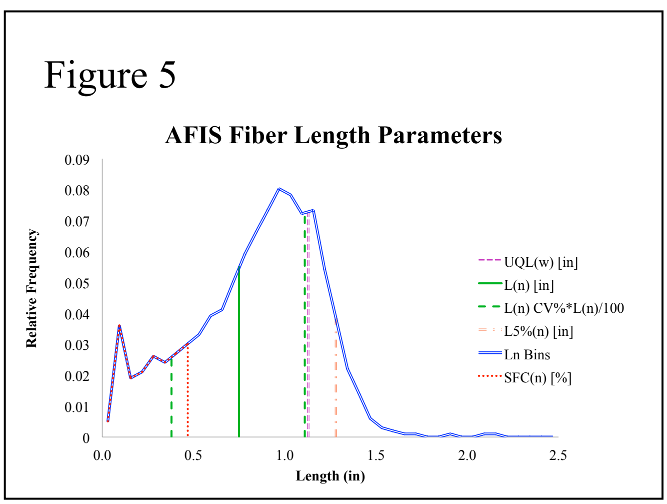

Figure 5: AFIS fiber length parameterization of fiber length by number. The complete frequency distribution of fiber length by number is reported in 40 discrete length bins (Ln Bins) along with 5 additional parameterizations of fiber length. Length CV% is defined as the ratio of the standard deviation of fiber length to the mean fiber length, expressed as a percent (L(n) CV%*L(n)/100). Therefore, L(n) CV% is represented by the standard deviation of fiber length in this figure.

Implications for Cotton Breeding Programs

Cotton producers require varieties which have the potential to produce fiber of a quality that enables them to sell into the highest-valued markets possible. The basic objective of this paper is to present the limitations of bundle testing while highlighting the efficiency of alternative fiber quality evaluation systems in breeding programs. This will be done through three experiments designed to reveal the practical advantages and limitations of augmenting HVI data with additional fiber measurements. The first experiment will demonstrate the practical limitations of HVI classification. The second will present a statistical evaluation of the improvements provided by augmenting the HVI data. The third experiment will explore the feasibility of a cost-reducing protocol for obtaining AFIS data that serves the needs of cotton breeders.

Experiment I – Practical Limitations of Fiber Quality Evaluation Systems

In the first example, two sets of 4 bales (each set is made of 4 bales from the same field but separate modules) are used to demonstrate the practical limitations of screening breeding lines with HVI parameters. Both sets in this example were sampled and evaluated for both HVI and AFIS fiber quality parameters. Table I summarizes the HVI fiber quality parameters for the bales used in this example.

Based on HVI classification, set A and set B appear to be very similar. Both sets exhibit a combination of good length and less than ideal micronaire. Based on these conventional HVI parameters, these two sets of cotton would be expected to produce similar quality yarns.

Table II contains a summary of the AFIS fiber quality parameters for the same two sets as Table I. While HVI length is based on the length of the longest fibers extending from the fiber clamp, AFIS mean length is derived from the complete distribution of fiber length in the sample and includes the short fibers. The AFIS fiber quality parameters reveal that the average fiber length in set B is slightly shorter than set A, and that set B has slightly higher percentage of short fibers. AFIS also provides additional measurements of contaminants, which reveal that set B has many more neps and more trash when compared to set A.

These apparently conflicting results lead to a natural question. Which of these fiber quality evaluation systems is capturing the true spinning potential of these bales? To evaluate spinning performance for carded yarns, fibers from each bale were used to produce ring-spun yarns from 12Ne through 30Ne, with a step-wise increase toward finer yarns of 2Ne. (Note: 4 bales per set = 4 replications for fiber testing and spinning). The results of the spinning trial are summarized in Figures 6-8.

HVI fiber quality parameters should at least relate well to yarn tensile properties. The work-to-break of the yarns produced

Table I. HVI data on the 2 sets of 4 bales selected for Example 1

Set	Micronaire	Length (inch)	Uniformity (%)	Strength (g/tex)	Elongation (%)	Rd (%)	+b
A	3.5	1.18	82.7	29.2	9.8	81.2	8.6
B	3.2	1.17	81.9	28.4	9.8	78.8	8.8

Table II. Main AFIS data on the 2 sets of 4 bales for Experiment 1

Code	Neps (Count/g)	L(n) (inch)	SFC(n) (%)	VFM (%)	H (mtex)	IFC (%)	MR
A	333	0.76	30.6	1.71	152	8.8	0.81
B	566	0.74	32	3.38	148	9.9	0.81

L(n) = Length-by-Number
SFC(n) = Short Fiber Content-by-Number
VFM = Visible Foreign Matter
H = Fineness
IFC = Immature Fiber Content
MR = Maturity Ratio

by each cotton bale at each count is summarized in Figure 6. These results show no substantial differences in yarn strength between Sets A and B for any count.

Now consider the results for yarn evenness and imperfections. While often overlooked in breeding, these fiber quality parameters significantly impact the value of spun yarns. Yarn evenness is commonly expressed as the coefficient of variation in the yarn mass, or CVm%, while the total imperfection index, IPI, provides a summary index of the aforementioned yarn imperfections.

Figure 7 summarizes the CVm% of the yarns produced with these two sets of bales at each count. Despite the similarity in HVI characteristics, the yarns produced by the bales are not the same quality. In both cases there is a level shift, with the bales exhibiting superior AFIS fiber quality parameters having lower variations in yarn mass for every count.

Figure 8 summarizes the IPI results. The bales with superior AFIS characteristics had consistently fewer imperfections, with the differences increasing along with the yarn counts. The difference in IPI for the two sets increases with finer yarn counts.

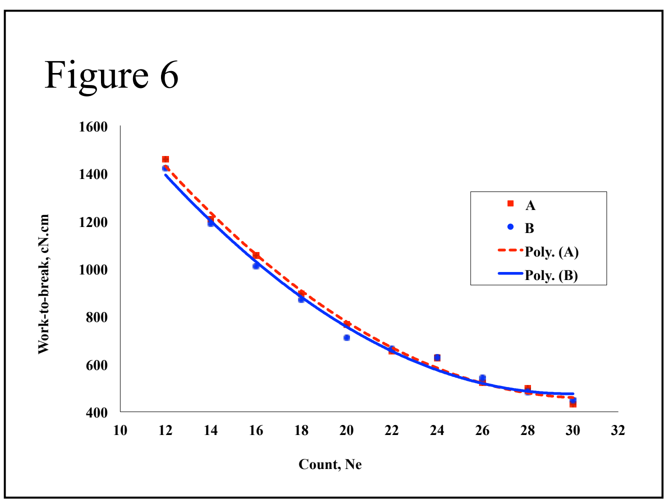

Figure 6. Work-to-break vs. Yarn Count (carded ring spun yarn, knitting twist) for the Sets A and B

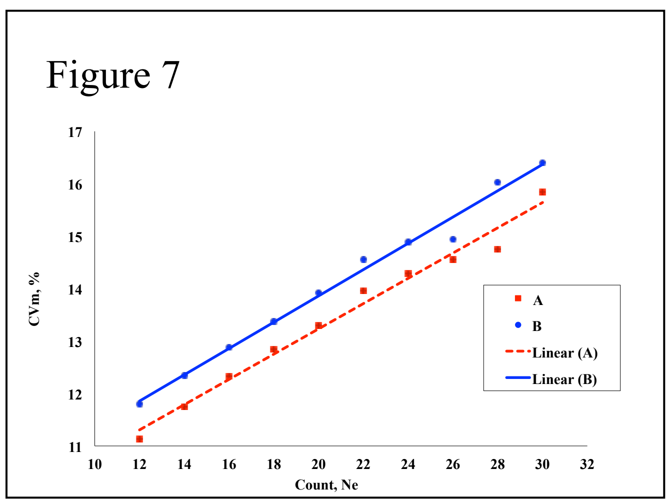

Figure 7. Uster CVm vs. Yarn Count (carded ring spun yarn, knitting twist) for the Bales Set A and Set B

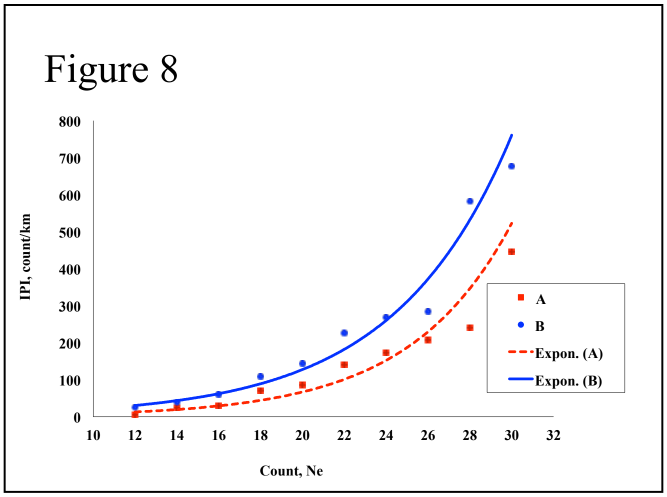

Figure 8. Uster IPI (total imperfections) vs. Yarn count (carded ring spun yarn, knitting twist) for the Set A and the Set B

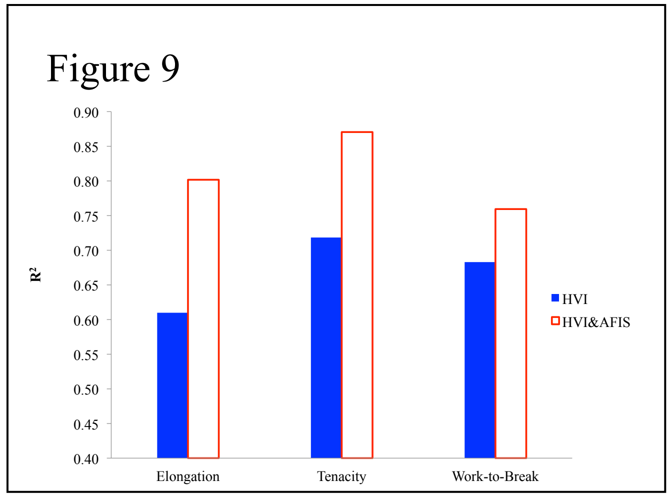

Figure 9: Explained variation in yarn tensile properties. R^2 of 1 indicates the fiber quality parameters used in the model explain all of the variability observed.

These results indicate that exclusive use of HVI does not entail much risk when selecting bales to produce yarns with improved strength. However, for selecting bales that can be used to produce yarns with a low variation in mass, and with small numbers of imperfections, the AFIS can greatly reduce the risk of failure. The risk of relying exclusively on HVI for bale selection increases for finer yarn counts desirable in high value markets. This example indicates that breeding for spinning performance in high-value markets requires information about the within-sample distribution of fiber quality in addition to HVI classification.

Experiment II – The Efficacy of Fiber Quality Evaluation Systems For Improving Yarn Quality

In this second example, 110 cotton bales were selected to represent a wide range in variability of fiber quality within and between bales. The commercial bales represent several years and locations from across the United States cotton belt. Each commercial bale was tested on HVI to obtain the standard bundle properties. In addition to HVI testing, each bale was tested for within-sample variability in fiber quality on the AFIS. The tests confirmed that the bales covered a wide range of fiber properties. Each bale was spun into carded 30Ne ring spun yarns, which were tested for tensile properties on the Uster Tensorapid and for evenness and imperfections on the Uster Tester 3.

The relationship between the fiber quality profile for each bale and yarn quality produced was investigated with a partial least squares regression (PLSR). First, the fiber quality attributes were grouped into two subsets. The first subset, HVI, is composed of the most commonly used HVI fiber quality parameters. The second subset, HVI&AFIS, also includes the basic HVI parameters with the addition of AFIS fiber quality parameters. Each of the two fiber quality subsets were then used to separately characterize the fiber and yarn quality complex.

Because HVI data are so widely available, both regression models of the fiber and yarn quality complex include HVI fiber quality parameters as predictor variables. In this way, any differences in the two models must be attributed to the addition of non-HVI fiber quality parameters in the second model.

The amount of variation in yarn tensile properties explained by both sets of fiber qualities is compared in Figure 9, where the improvements provided by the non-HVI fiber properties are apparent. There are clear differences in the performance of HVI and non-HVI fiber quality parameters when predicting yarn tensile properties. The model constructed with HVI bundle parameters characterizes anywhere from 61% of the variation in yarn elongation to 72% of the variation in yarn strength. However, augmenting the model with non-HVI fiber qualities provided by AFIS helps explain from 80% of variation in yarn elongation, up to 87% of variation in yarn strength. The augmented model explains 31% more variation in yarn elongation than the traditional HVI classification parameters. This translates into 76% of the variation explained in yarn work-to-break.

The differences are even larger when considering explained variation in yarn imperfections (Figure 10). The model constructed with HVI fiber quality parameters alone fails to explain even 50% of the total variation of two critical yarn imperfection parameters, thick places and neps. In contrast, the model augmented with non-HVI fiber quality attributes explains 82.8% of the variation in yarn CVm% and at least 78% of the remaining yarn imperfection parameters considered in this study. The model augmented with non-HVI fiber qualities explains 79% more of the variation in yarn neps over traditional HVI parameters.

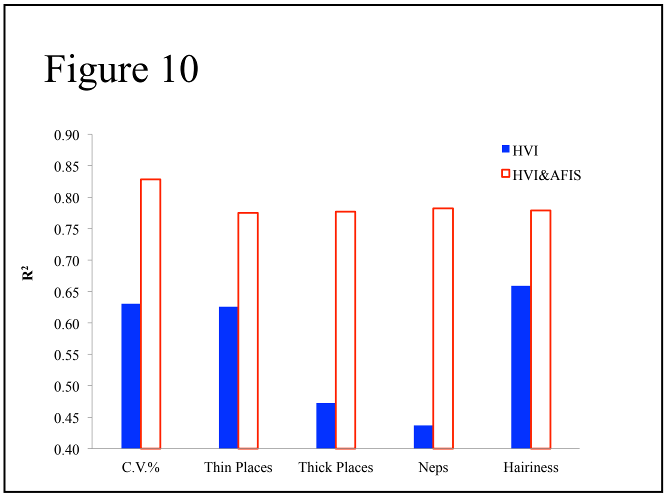

Figure 10: Explained variation in yarn imperfections. R^2 of 1 indicates the fiber quality parameters used in the model explain all of the variability observed.

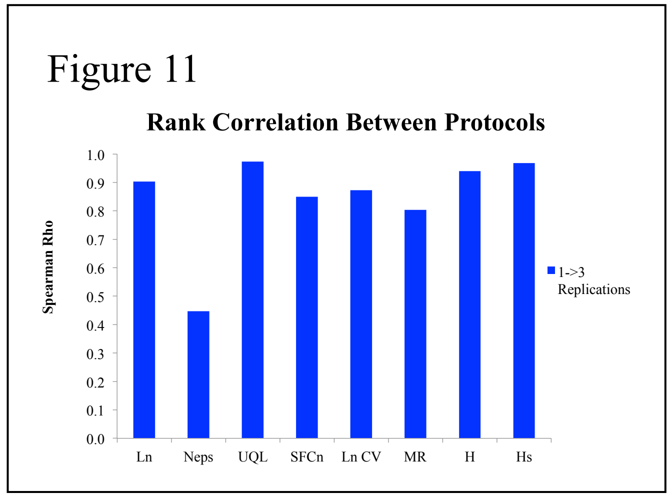

Figure 11: Rank correlations between protocols. (Ln - Length-by-Number; Neps – Neps per Gram; UQL – Upper Quartile Length; SFCn – Short Fiber Content-by-Number; LnCV – Coefficient of Variation in Length; H – Fineness; MR – Maturity Ratio; Hs – Standard Fineness).

Experiment III: AFIS As a Breeding Tool (1 vs. 3 reps)

The third experiment presented in this paper investigates a protocol for using AFIS testing as a tool for screening in a breeding program. It has been determined that accuracy and repeatability with AFIS measurements normally requires 3 replications of 3,000 fibers. Breeding lines are often screened by selecting the top lines based on their rank in the breeding population. The purpose of this section is to evaluate the feasibility of reducing the number of replications with the AFIS, while still achieving an adequate ranking of the breeding lines.

Under the standard AFIS 3-replication protocol, about 50 samples can be tested in a day after checks have been run. Therefore, AFIS typically runs at a rate of about 7.14 samples per hour. The rate of AFIS testing can potentially be tripled under a single replication protocol, to about 21 samples per hour. If this is feasible for purposes of rankings lines in breeding programs, the cost of AFIS testing could be significantly reduced.

260 breeder samples were selected to represent the variability expected in the average breeding program. Each breeder sample was tested with the standard AFIS protocol of 3 replications of 3,000 fibers. The samples were then ranked based on the individual AFIS fiber quality attributes. After ranking, an alternative AFIS protocol was run with 1 replication of 3,000 fibers. The rank of the samples identified by the alternative protocols was then compared to the rank of the samples identified by standard AFIS protocol. The results are used to investigate the potential of single AFIS runs for ranking selections for screening in a breeding program.

Spearman's correlation coefficient can be used as a measure of how well rank is preserved from one measurement to the next. Under this interpretation, a high Spearman's correlation coefficient between the two protocols is desirable in a breeding program in order to provide sufficient selection pressure. Genetic gain in a breeding program depends on selection pressure. A higher rank correlation for particular AFIS parameters implies that little selection pressure is lost from implementing the alternative protocol for those parameters.

The rank correlations for several AFIS fiber quality parameters measured under the two protocols are reported in Figure 11. The length parameters measured under the two protocols, mean length by number and coefficient of variation in length, have a rank correlation of 0.87 and 0.9 respectively. This reveals that much of the rank is preserved among these two length parameters moving from a 3-replication protocol to a single replication. Measurements of short fiber content under the two protocols also exhibit a high rank correlation of 0.85. However, a rank correlation of 0.45 indicates that the measurement of neps requires more replications.

Of heightened interest is the loss in selection intensity incurred by implementing the single replication protocol. The selection intensity is demonstrated for the cotton used in this experiment by identifying the top 10% of the breeder samples tested under the separate protocols. An example of selection intensity is shown for maturity ratio, length-by-number, and standard fineness in Figures 12 through 14 respectively. In each of the figures, the standard 3-replication protocol is considered the true rank order of the samples. The top 10% of the breeder samples under the 3- replication protocol are represented by hollow circles, while the 10% threshold measured by the single replication protocol is indicated by a solid line. If the two protocols provide the same selection pressure for the samples, the solid line will demarcate the hollow circles from the filled circles.

Figures 12 through 14 show the comparisons for maturity ratio, length-by-number, and standard fineness, as measured by both the 3 replication protocol and the single replication protocol. When measuring maturity ratio, the alternative protocol properly identified almost 60% of the top 10% of the breeder samples identified by the standard protocol (Figure 12). For both mean length-by-number and standard fineness, the single replication protocol identified 81% of the top 10% of the breeder samples identified by the standard protocol (Figures 13&14). These results indicate that AFIS testing without replication may be able to provide suitable selection pressure while increasing fiber quality evaluation throughput.

Figure 12

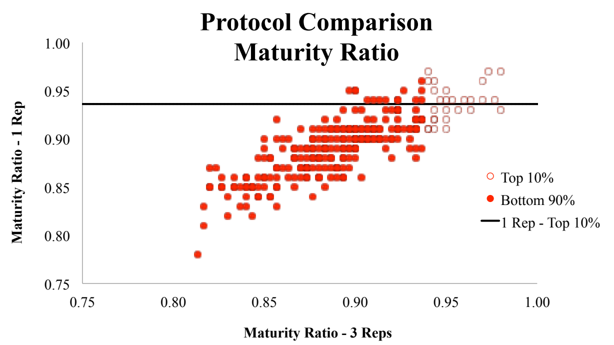

Figure 12: Comparison of AFIS maturity ratio under the current 3 replication AFIS protocol compared to results from a single replication AFIS protocol. The top 10% of the samples identified by the standard 3 replication protocol are identified by hollow circles. The 10% threshold identified by the single AFIS replication protocol is indicated by the solid line.

Figure 13

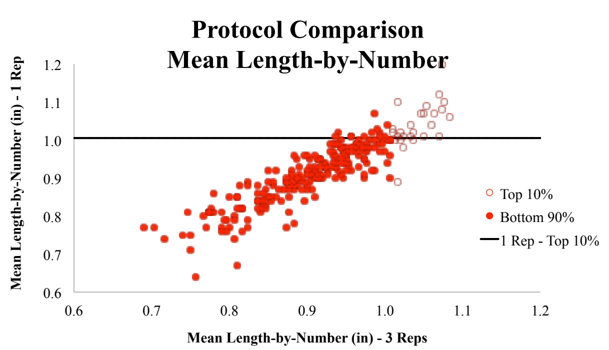

Figure 13: Comparison of AFIS mean length-by-number under the current 3 replication AFIS protocol compared to results from a single replication AFIS protocol. The top 10% of the samples identified by the standard 3 replication protocol are identified by hollow circles. The 10% threshold identified by the single AFIS replication protocol is indicated by the solid line.

Figure 14

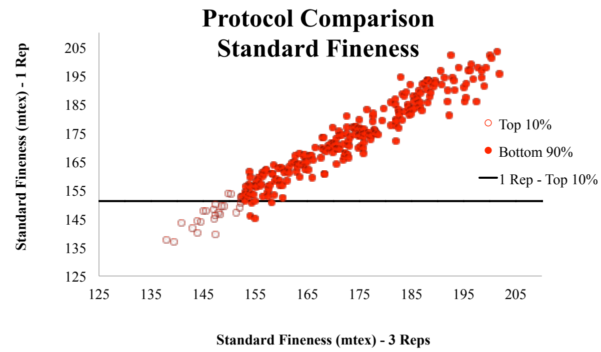

Figure 14: Comparison of standard fineness (calculated from AFIS results) under the current 3 replication AFIS protocol compared to results from a single replication AFIS protocol. The top 10% of the samples identified by the standard 3 replication protocol are identified by hollow circles. The 10% threshold identified by the single AFIS replication protocol is indicated by the solid line.

It is important to note that the gains in speed for this testing are at the expense of statistical power. While it may facilitate selection of lines with the potential for improved yarn quality in a breeding program, reducing replications of AFIS testing is unlikely to have the same usefulness in most scientific research.

Conclusion

This paper has shown the following:

- HVI classification may not be sufficient for detecting substantial differences in the spinning performance of cotton bales. HVI classification data should be augmented with non-HVI fiber qualities in order to select lines that perform well in high-value spinning markets.
- The lack of an elongation calibration standard severely limits the potential of HVI fiber qualities for improving yarn tensile properties.
- Including AFIS fiber quality parameters provides a substantial improvement over HVI classification alone for screening breeding lines. Even though AFIS does not provide a direct parameterization of fiber tensile properties, AFIS parameters are able to increase the amount of explained variation in yarn tensile properties. It is imperative to augment HVI fiber quality parameters with non-HVI fiber quality parameters when selecting lines with reduced imperfections.
- For purposes of ranking lines in cotton breeding programs, a 1-replication measurement protocol may be adequate, thereby reducing the time and expense associated with adding the AFIS data to the programs.

The experiments related here are part of a large and growing body of data showing that non-HVI fiber property measurements are needed to achieve future genetic breakthroughs in fiber quality. These breakthroughs will be necessary to strengthen cotton's competitiveness vis a vis the large and growing array of synthetic fibers vying to serve the global yarn spinning industry.

Acknowledgement

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