MAPPING OF IN-FIELD COTTON FIBER QUALITY UTILIZING JOHN DEERE'S HARVEST IDENTIFICATION SYSTEM (HID)

by

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(Under the Direction of Wesley Porter)

ABSTRACT

Currently, the most popular type of cotton harvester is a roller cotton picker/stripper that creates round plastic wrapped modules on the go during the harvest process. Because each of these modules are wrapped on the machine, they can be better managed and tracked. The option of adding John Deere's Harvest Identification (HID), installed on roller pickers such as the CP 7760 or CP 690, has allowed the cotton industry to introduce more integration of technology. Using yield maps to do post-harvest analysis of in-season production on most major crops is becoming common practice. Though for a crop such as cotton, the quality of fiber is the deciding factor for the final received price for growers. For a full understanding of crop production, a useful method for growers to use to visualize this field metric is necessary. The main objective of this project is to understand, demonstrate, and utilize HID data to create a useful grower tool to aid in the decision-making process for cotton growers through the development of net profit, fiber quality, yield, and other field parameter maps. A handheld RFID reader, a grower connected MyJohnDeere account, and GIS software were used to record and develop these maps. Once modules are created on the harvester, they are scanned and given a label for the project that is used as a reference once the gin's unique label is also applied to each module. The module average fiber quality is obtained through averaging all bales associated to a specific module. This average fiber quality is then linked to timestamped points in the field that are acquired from the machine's generated yield map and travel path. This in turn can allow for the visualization, at a module level resolution, of the fiber quality. These maps contain a wide variety of fiber quality parameters such as micronaire, strength, trash, and reflectance. Parameters such as the price in cent/kg and loan value per bale are available from these data sets. Further statistical analysis was required to validate the average module fiber quality. An analysis of the standard deviation for each module's fiber parameters was performed. Also, an uncertainty analysis was performed to provide an understanding of the inner module perspective by parameter. Through both of these analyses it became clear which parameters were accurately representing the parameter variability by a single module average point. Methodology has been developed and utilized in the creation of fiber quality maps now for two growing seasons. Through the development of this methodology, a process for utilizing HID data to pair fiber quality data with the travel paths has successfully shown that tracking and mapping of fiber quality is possible. To fully satisfy the objective of this project, further work must be done to add the visualizations of the economic analysis of net profit and to develop a user-friendly tool or interface.

INDEX WORDS: Cotton, Cotton Harvest, Cotton Fiber, Fiber Quality

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DEDICATION

I would like to dedicate this to thesis to the late Martin Acevedo. Many knew him in the tight knit community of Pendleton, SC and surrounding areas. He was a kind soul, a community figure, the life of the party, and so many more accolades. To me though, his was so much more. He was a caring friend, he was a teacher, a loving son to his parents, a helper, and a big brother. Though he was taken from us too soon, his time spent with us left quite the impact. To many he was called the happy farmer. I began my interest in agriculture later than some, but he always happily explained things or allowed me to work alongside him to cultivate not only the fields but my interest in agriculture. He taught me not only agricultural knowledge, but also many life lessons. Memories with him and our friend group are held dear to my heart. So please keep the gold tops cold, and the hay fields growing till we meet again one day. Always loving Martin.

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I next would like to thank my past mentors and advisors along the way. I have had many people who were instrumental in their involvement in my life who have gotten me to where I am today. Their support has helped foster growth in my academic career as well as my life to where I am today.

I lastly need to thank my family and friends. My parents have supported me in life through thick and thin. Without their love and support I would not be half the man, student, or person I am today. They have always challenged me to reach for the stars and pursue my goals. Everything they have done and sacrificed for me is unmatched and I could not thank them enough in a lifetime for all they have done. To my brother Will, I thank you for being my lifelong friend. Though you did not have much say in the arrangement, I would not choose another. We have had our fights, and have been at each other's throats, but we have also shared laughs, talks, advice, and memories that I hold dear. To you I say thank you, and to continue aiming high with those goals and I know you will go farther than you could ever dream. To my friends, I thank you for all the memories throughout my life. I cherish each and every one of them. Though as many of you have moved away or are beginning careers, families, and walks of life I still enjoy the late-night talks or laughs we spent. You all helped me through hard times, taught me to laugh and live some, and have walked with me through life. To you all I thank you for molding me and leaving your unique impression on me.

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CHAPTER 1

INTRODUCTION

Cotton is the single most important textile fiber in the world, accounting for about 35 percent of all fibers produced (AGMRC, 2017). Of this, American Upland cotton (*Gossypium hirsutum*) currently dominates the United States' cotton belt, representing 95 percent of cotton grown. A second variety grown for its' longer staple fibers is the American Pima variety (*G. bardadense*), which accounts for the other 5 percent of the cotton grown in the United States (Cotton Inc., 2018). With current work in crop genetics, cotton has continued to see growth in yield and crop quality. Cotton is held in high standing across the country as one of the major crops grown. Numerous advancements have been made in the cotton harvest industry. From the development of yield monitors, autosteer systems, and now the round module accumulators. These strides in technology have greatly impacted how cotton harvest is carried out. Yield monitoring has allowed growers an even greater understanding of their fields. With the development of these monitors and paired with an autosteer system, a grower can finally link a georeferenced numeric value to crop productivity. Whereas prior to this system crop yield would have been a visual estimation. The tracking of yield can also be used in the development of future field and farm decisions. Being able to show areas of varying production levels allows growers to plan ahead and potentially even do on-farm trials to determine what works best for their unique situation. Also, within recent years John Deere has revolutionized cotton harvest with their round module builder cotton harvester lines. This allows for the growers to build round modules on the go and drop them at the ends of fields. This advancement in harvest equipment has equated to the saving of time, labor, and machinery efficiency. The introduction in 2012 of the round module harvesters also provided a new system to be integrated for module data tracking. This system is John Deere's Harvest Identification or HID system. Utilizing the machine's GPS, different module characteristics are linked to the serial number in the embedded RFID tags in the module wrap. Eighteen unique data parameters are recorded onto the RFID tag of each module and those parameters can be displayed on the machine monitor or post processed in the MyJohnDeere online account. Pairing both the HID system and yield monitor, a system for both production levels and fiber quality tracking becomes possible. To date, cotton fiber quality could only be visualized and tracked in small research plots, but not on the production level. Through this project, the procedure for fiber quality tracking was developed and explored to utilize these new datasets to their full capabilities.

Hypothesis

- Cotton fiber quality data can be tracked and mapped, at the module level resolution, to known geo-referenced areas of a field similarly to yield data for making farm decisions

Project Objectives

In order to thoroughly test the above hypothesis, the following objectives will be met.

- Develop a procedure for the identification and labeling of modules to allow for their tracking through the ginning process.

- Create a methodology for the handling of both Harvest Identification and fiber quality data to generate geospatial maps depicting the variability of cotton fiber quality.

- Evaluate the validity of module averaging, in its ability to accurately represent fiber parameter variability for single modules.

CHAPTER II

REVIEW OF LITERATURE

In Field Portion

Cotton Production

Cotton production begins with the planting of seeds as is the case for most major row crops. This seeding rate varies, but a typical average rate is near 30,000 seeds per acre. This operation will typically occur between April and May. Current studies conclude there is no significant variation in yield, regarding planting date within this planting window. The variability in yield will be due to both cultivar and post-planting field conditions such as precipitation, soil and environmental temperatures, disease, pests present, and weather conditions and events. It is recommended that soil temperatures be at least at 65º F for optimal emergence. Recommended planting depths are suggested from depths of ½ inch to 1½ inches deep. As seen on many of the commercially available planters, downforce is also being used in the planting process. Downforce is a set amount of force on the row unit above that of its original weight. This has recently been studied and found that additional downforce at planting does aid in crop emergence (Virk et. al, 2018). It is then critical to irrigate the planted crop. This is commonly known as irrigation scheduling. Irrigation scheduling is the method by which someone determines when to irrigate a crop. This scheduling can be based on many different systems including sensor readings, computer models, and checkbook to name a few methods. Of course, the necessary irrigation schedule will change due to weather conditions, and throughout the developmental stage in which the cotton is. According to a study done by Cotton Inc., it verified there are varying levels of evapotranspiration

(ET) produced by the plant throughout the developmental stages (Cotton Inc., 2017). This water requirement is crucial for the establishment of a crop stand, plant stress management, and aids in the overall maintenance of yield. It is also important to understand when irrigation must be terminated for harvest preparation. With recent understandings pointing at earlier irrigation termination resulting in cost savings, decreases in water use could lead to decreases in fiber degradation. A final irrigation event is often applied when the cotton bolls begin to open. Commonly, NO additional irrigation is applied once the crop reaches 10% open boll to minimize problems with boll rot, hard lock, light spot, and other fiber quality issues (Hand et. al, 2021). It is important to allow the plant to finish fruiting but also can cause delays, pest problems, and higher input costs for no increases in revenue. With the plant's need for water and nutrients, a well-developed root system is also a key component to plant success. Cotton plant root growth finishes in the late bloom to early boll production stage (Schwab et. al, 2000). Schwab goes further to show the varying levels of nutrients taken up by the plant. These levels of uptake for both macronutrients and micronutrients vary depending on the plant development stage. During the vegetative growth stage leading up to boll development, plants will require larger amounts of those nutrients. These levels then decrease as the plant begins to fruit, as shown in Table 1

Table 1. This table depicts the average daily influx of various nutrients Schwab observed. (Schwab, 2000)

Sampling interval		Macronutrients ($\mu mol\ m^{-1}\ d^{-1}$)						Micronutrients ($pmol\ m^{-1}\ d^{-1}$)			
Days after planting	Heat units	N	K	P	S	Ca	Mg	Cu	Fe	Mn	Zn
37-49	211-291	3.41	0.73	0.19	0.01	0.91	0.17	0.18	5.42	0.83	0.80
49-64	291-469	14.4	2.90	0.57	0.04	3.66	0.62	0.49	35.5	10.5	1.66
64-87	469-764	10.7	2.65	0.67	0.05	2.98	0.62	0.57	14.3	9.48	1.94
87-99	764-912	5.06	3.33	0.92	0.33	3.15	0.68	0.54	17.2	12.7	2.04
88-112	912-1063	6.12	0.05	0.16	0.22	0.36	0.11	0.03	0.67	3.62	1.05
112-122	1163-1174	-2.63	0.83	0.05	0.54	-1.35	0.07	0.03	-12.2	-4.43	-0.59
122-134	1174-1317	2.47	1.17	0.26	0.23	0	0.11	-0.02	2.55	3.23	0.42
134-151	1317-1495	-1.99	-0.41	0.13	-0.09	0.57	-0.16	-0.01	-4.15	-2.55	1.05

For cotton to do well, it must also be grown in soil with a proper pH range. Much of the South Eastern regions of the United States see more acidic soil problems. This is typical due to the soil types present and volumes of rain received. To correct this a liming agent is normally applied to bring the soil pH to a more suitable value. A pH of 6.5-7 is the optimal range and best for nutrient absorption. Another potential problem that can hinder the success of a cotton crop is the presence of weeds or undesired plants. Cotton does not compete well with weeds, especially early in the season, a given number of weeds will reduce cotton yield more than corn or soybean yield. Weeds also may interfere more with harvesting of cotton and can reduce lint quality because of trash or stain (Whitaker et. al., 2019). One of the prevalent and difficult to manage of these weeds is *Palmer amaranth* or more commonly known as pigweed. There are other weeds such as sickle pod, Bermuda grass, and morning glory. Herbicide programs can greatly benefit crop stands and performance if used and implemented correctly. This is accomplished with the monitoring of fields and identifying weed location. Cotton will grow throughout the season developing nodes, fruiting branches, and squares or fruiting buds. There will be 20-25 of these nodes that develop fruiting branches, which will later develop bolls along each branch. As seen in table 2 below, a general developmental schedule based on Days after planting (DAP) and growing degree days-60 (GDD-60) shows the progression of the plant.

Table 2. This table depicts the various growth stages and their respective days post-planting. (Whitaker et. al., 2019)

	GDD-60’s	Days after planting (DAP)
Emergence	50	4 to14
Pinhead Square	550	35 to 45
First Bloom	940	55 to 70
Peak Bloom	1700	85 to 95

First Open Boll	2150	115 to 120
Harvest	2500 to 2700	140 to 160

Growing degree days are an estimated amount of heat units a crop has accumulated based on the day's maximum and minimum temperature. Because cotton is actually by nature a perennial crop, it will continue to see vegetative growth even when the plant has begun to develop reproductive growth. When the plant begins this reproductive period, it will begin producing flowers. The day of flowering is referred to as anthesis and the term "days post-anthesis' (dpa) is often used to describe cotton fiber development (Abidi et. al., 2010). These flowers as seen in table 2 will typically be present on the plant for 40-60 days. The location of the flowers will vary based on the node location and dpa. Different stages of cotton squaring, or a pyramid shaped structure consisting of three bracts, will surround the flower during development. As the flower develops and is pollinated it eventually becomes a boll, where cotton fiber will begin to develop. Once a plant enters the reproductive period, cotton seeds will begin to develop small finger-like outgrowths called fibers. The cluster of these fibers is encapsulated by a vegetative casing referred to as a boll. After boll development and maturation, a process known as defoliation is performed. Defoliation has become widely practiced and carried out using chemicals to cause leaf dropping from the plant prematurely and uniformly. Chemical defoliation is a cultural practice that induces the abscission of cotton foliage earlier than normal (National Cotton Council, 1949; Cathy, 1987). Plant defoliation is a natural process that will normally result from plant maturity or senescence due to cotton's perennial lifestyle. Thus, abscission is controlled by an interaction of hormones. These hormonal interactions cause cells within the abscission zone to secrete hydrolytic enzymes that degrade the cell wall, especially the pectic substances of the middle lamella and cell walls, to permit the leaf to fall from the plant (Cathey, 1987). Defoliation is a key component in harvesting high-quality cotton.

Cotton Harvest

Currently in the cotton harvest industry there are two machinery categories that accomplish the task of seed cotton harvest. One machine, known as a cotton stripper, strips the plant of much of the remaining plant material, branches, and bolls. This is completed by using rotating cylinders, brushes, and bats. The brush and roller unit can be seen in figure 1 below.

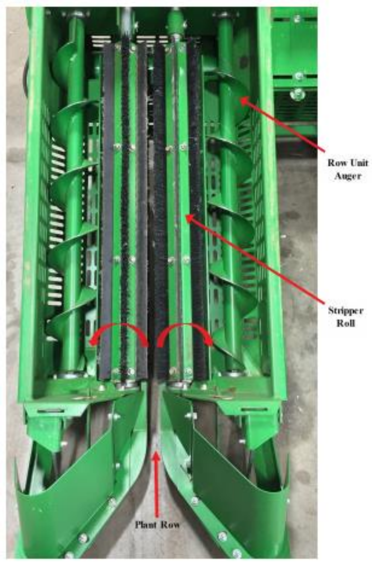


Figure1: Depiction of a cotton stripper row unit with brushes and rollers. (Wanjura et. al., 2017)

Cotton strippers using the brushes and rollers will harvest all bolls, ripe or unripe, from the plant along with considerable amounts of plant material. The trash content of stripper harvested cotton may be as high as 25-40% (Williford, 1992). Though cotton strippers are typically associated with higher trash contents, they also harvest more fiber and seed quantities than pickers. In a test done by Boman et AL. (2011) lint yield averaged 1739.6 kg/ha for the stripper system and 1647.7 kg/ha for the picker system (P>|t| 0.0002), a difference of 92 kg/ha. The test did also conclude the economic value of the ginned fiber for the cotton picker was slightly higher than the stripper. This is in part to how cotton pickers operate. The cotton stripper's popularity in the United States is primarily limited to the High-Plains regions of Texas and Oklahoma. Stripper harvesting is predominately confined to the Southern High Plains due to several factors including: low humidity levels during daily harvest intervals, tight boll conformations and compact plant structures adapted to withstand harsh weather during harvest season, and reduced yield potential due to limited rainfall and irrigation capacity (Porter et. al., 2012). The other more commonly used cotton harvester in the United States is the cotton picker. As seen in much of the state of Georgia and along the cotton belt, many producers utilize cotton pickers for the harvest of the crop. Cotton pickers as stated above harvest cotton fibers and seeds differently than a cotton stripper. A cotton picker uses rotating spindles with sharp edges to wrap cotton fibers around the needle-like spindles and pull the seed cotton from the boll. The cotton fibers are then separated from the spindles using a counter-rotating doffer. The doffer removes the cotton and uses a vacuum system to pull the harvested fiber and seed up to the basket or module builder. The spindles and doffers can be seen in figure 2 below.

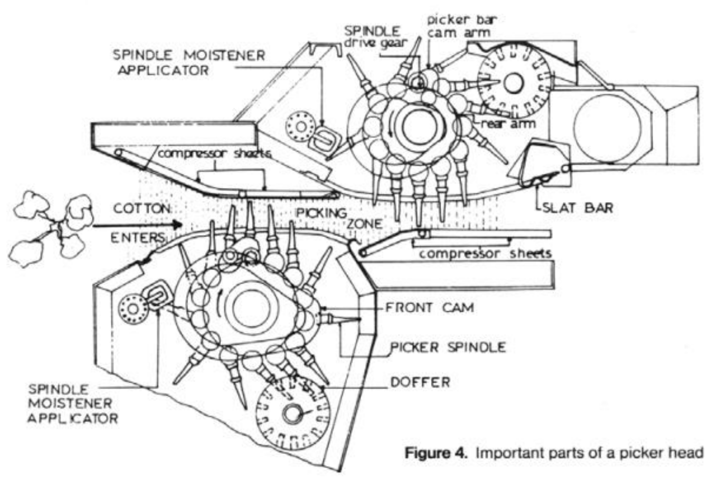


Figure 2: Depiction of a cotton picker's row unit. (Christenbury,1996)

Spindle pickers are more selective and remove only the seed cotton from open bolls plus small amounts of leaf and bur trash. The trash content of spindle harvested cotton is typically in the range of 5-10% (Williford, 1992). Spindle pickers are associated with cleaner and higher quality cotton due to the lack of harvesting immature or unripe bolls and the plant material with the fibers. The spindle picker is able to achieve a cleaner picked fiber by being inserted into the boll without pulling much undesired plant material with it. Normally growers will make a single pass when harvesting allowing the machine to pick all of the available cotton at that time. However, cotton pickers can be used in a two-pass harvesting if weather conditions are less than ideal. Producers will harvest when a portion of bolls are open and make a second harvest pass when the rest have opened. Older model machines will harvest into a basket on the back of the machine. This basket when full is then dumped into a boll buggy to be transported to a module builder. Module builders are a large rectangular press used to compact harvested seed cotton into a large, 2.3 m wide by 9.75 m long and common height of 2.59 m, rectangular shape to be taken to the gin (ASBAE,2005). However, with John Deere's incorporated module builder, this large multiple-step module building is a fading practice. Boman listed these five agronomic aspects about using a cotton picker " 1) not substantially increase micronaire, but can somewhat improve it, 2) substantially reduce or eliminate bark contamination, 3) many times result in higher Loan value for lint, 4) leave seed cotton in the field, which can be a significant income loss (both lint and seed) and will likely increase volunteer cotton challenges in the next crop, 5) likely reduce expenditures for harvest aid chemicals as no sequential application of paraquat is generally needed beyond the typical ethephon plus defoliant initial applications generally used for stripper harvesting."(Boman et. al., 2011).

Yield Monitors

The most essential component of precision farming is the yield monitor — a sensor or group of sensors installed on harvesting equipment that dynamically measures spatial yield variability (Vellidis et. al., 2003). Yield monitoring which began around the 1990s, has gained tremendous popularity since then and is utilized by most growers of major row crops. These monitors use various systems such as impacts plates, optical sensors, or microwave units to determine the volume of the crop being harvested. John Deere currently uses microwave mass flow sensors to monitor and record yield on the round module cotton pickers. The sensors are modified ground speed radar devices that measure the velocity and mass components of the flowing material. The mass measured at a particular reading is proportional to the power of the microwave signal reflected back from the flowing material (Wanjura et. al., 2014). These data if used with GPS coordinates can be used to create yield maps of the harvested field. These maps provide growers a visual depiction of crop performance across their field. This can allow them to notice the varying levels of performance. The variation could be linked to a variety of infield characteristics, irrigation, weather, and plant health and performance. Yield maps, in conjunction with other field's parameters or maps, can also be used in the delineation of management zones throughout a field. With more knowledge of a field's performance, growers are able to make better or more informed decisions for the next growing season. With the wide implementation of yield monitors, growers are also able to do on-farm tests to determine what options are best for their unique farm's situation. There are sources of error that must be addressed by growers. Rain et. al. (2002) addressed this and explained how different varieties could affect the accuracy of the monitors. To mitigate problems such as these, calibrations and system checks can be done to fix this and hone the accuracy of the monitor.

John Deere

John Deere has revolutionized the cotton harvesting industry with the development of on-board on-the-go round module builders. This machine, similar to round hay balers, uses a system of belts and rollers to roll the harvested fibers into a round cylinder module. The on-board module development has eliminated the need for an external module builder and crew to press the modules into shape and tarp the module. As classic basket pickers are getting older, many farmers are switching to the round-module pickers to make the harvest process more efficient. The new pickers not only make the module, but also wrap it in plastic to help minimize contamination or fiber quality degradation. This plastic wrap also has four integrated Radio Frequency Identification (RFID) tags with individualized serial numbers for each module. With four tags imbedded in the tag, a RFID reader will have the greatest opportunity to come within range and receive a return signal from the tag. This allows the utilization of the harvest identification system (HID). This system tracks several data points about each module and links them back to the serial number. Some of these points are start and finish coordinates, moisture, weight if taken, and time stamp of when the module was made.

Ginning

Cotton fiber and seeds once harvested from the field and compressed into a module are transported to a gin. It is the gin's responsibility to separate the cotton fibers from the seed through the ginning process. Modules which are either large rectangular blocks, weighing between 7,257-9,072 kilograms or round modules, weighing between 1,814-2,268 kilograms, are transported to the gin yard. Modules are normally loaded onto a bridge or conveyor and fed through a module feeder. The module feeder breaks apart the modules from their long rectangular or round shape. If needed fiber is dried to bring the cotton to ideal moisture for ginning, which is 6-7 percent. Cotton fiber and seeds are then processed through various cleaning cylinders and stick cleaners to remove any trash or debris. At this point, the seed and fiber are still connected and need to be separated. The seed and fibers are then conveyed to the gin stand. Gin stands come in two major types, either a roller-style or a saw type gin stand. The roller-style gin stands, uses a series of rotating knives and a roller bar. The rotary knife helps guide, with the roller, seed cotton directly to the ginning point, then sweeps away seed from the ginning point, and removes any seed cotton unable to be ginned (carryover) (Armijo et. al., 2017) as shown in figure 3

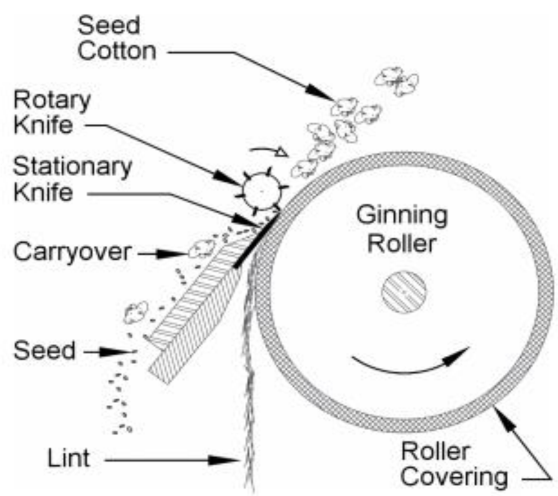


Figure 3: Depiction of a rotary knife roller gin (Armijo et. al., 2017)

The saw gin passes cotton through the gin stand where there are circular saws used in separating the lint from the seed. The lint is pulled through the grid bars under the saw as to not allow the immature seeds and trash material to pass through separating it. The pitch and shape of the saw teeth are important in maintaining capacity and cotton quality (Hughes et. al.,2017). As seen in Figure 4 below, this is a diagram for the configuration of a saw gin stand.

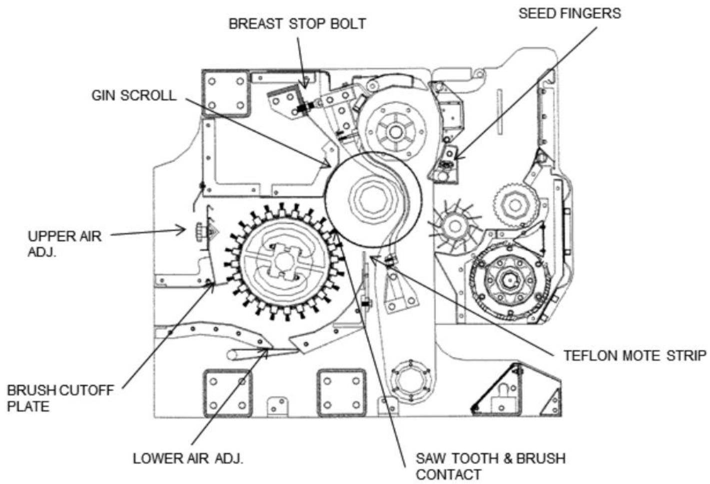


Figure 4: Depiction of a saw gin stand (Hughes et al., 2017)

Roller gin stands are associated with less damage to the ginned cotton, and is most commonly used for pima cotton. The separated lint is then conveyed through lint cleaners. The lint cleaning process is necessary to remove any leftover trash or debris that made it past the previous cleaners. The ginned cotton is then conveyed into a bale press that uses a hydraulic ram to compress the cleaned lint into bales and then wrapped with cords to retain shape. Each of these ginned bales will weigh approximately 480 lbs or 217.7 kg, which is the industry standard for ginned cotton bales. Ginned bales are then typically stored in warehouses until needed for production. Armijo had this to say about the difference in handling of fiber, “roller ginning does less harm to the fiber because it is a much gentler process than saw ginning.” He goes further to say “Roller-ginned Upland cotton also contains fewer fiber entanglements (neps) than the saw-ginned cotton.” (Armijo et. al., 2017)

Computer Data Analysis

Radio Frequency Identification

Radio Frequency Identification (RFID) is a heavily utilized tracking method throughout the industrial world. RFID is a form of automatic identification and data capture (AIDC) technology that uses electric or magnetic fields at radio frequencies for identification, authentication, location, or automatic data acquisition and transmission, and support a wide range of applications—everything from asset management and tracking to access control and automated payment (Sabbaghi and Vaidyanathan, 2008). The development of RFID applications in precision agriculture makes it possible to increase efficiencies, productivity, and profitability while minimizing unintended impacts on wildlife and the environment, in many agricultural production systems (Garcia and Lunadei,2011). RFID can be used to tell various points of data about a product. RFID implemented in off-road vehicles, such as tractors or combine harvesters, can allow exchanging data with static infrastructure or with other vehicles, creating mobile RFID systems and helping fleet management (Sjolander et. al., 2011). The John Deere HID system is utilized by implanting various module data onto tags that are incorporated into the module plastic wrapping. These tags then can be read by a reader and allow the transfer of information about the object to be received. RFID tags can range in their capabilities. The functionality of the tags needed greatly depends on the job. They can have varying data capacities, costs, and reading ranges. As opposed to barcodes, RFID tags do not have to be in visible site of the reader due to the use of radio waves to transfer the implanted data. This allows the RFID tags in the modules to be incorporated into the cotton module wrap and still be read. The tags can be also attached to products (seeds, fertilizers, pesticides, etc.) and the readers installed on the machinery, detecting what is transferred into the implement's hopper or tank. Transparency is gained for the purpose of quality assurance, knowing which fertilizer was spread or when, and which pesticides or insecticides were used (Watts and Miller, 2002, Peets et al., 2009, Garcia and Lunadei, 2011). The tag must only come within certain proximity with the reader and the data is transferred. With the modules having three to four tags, this allows the modules' information to be collected by the reader no matter the position of the module on a truck, gin yard gate, or module feeder. In the case of this study, module identifiers are stored on the module tags allowing for increased traceability of the module as the growers will have records of each module's serial number through the harvester's data log and can be tracked when gins use RFID readers to show the progress of each module or link bale data back to a specific module. Pushes for RFID technology in the industry began in the early 2000s and has continued to grow. For the larger industry, this is not a problem. Many smaller businesses are slower to adopt due to the cost of readers, software, and maintenance, though the cost, especially of stationary readers, has begun to be quite affordable. In 2018, USDA-ARS equipped a gin in Lubbock, TX with RFID readers at the gin's gate and gin stand. This project was used to show the unique serial numbers and RFID tags of the HID could be used in the tracking of modules from the field through the ginning process.

Cotton Fiber Quality

Cotton fiber quality is the combination of several fiber quality parameters-measurements of various attributes, and is to determine a standard grading process by which cotton is classed. Cotton fiber development consists of five major overlapping developmental stages (Wilkins and Jernstedt 1999): differentiation, initiation, polar elongation, secondary cell wall deposition, and maturation (Abidi et. al., 2010). The stage of secondary cell wall development commences in general around 21 days post-anthesis (dpa) and continues for a period of 21– 42 dpa. This phase is marked by a massive deposition of a thick cellulosic wall (Wilkins and Jernstedt, 1999; Abidi et. al., 2010). The period between anthesis and the thickening of the secondary cell wall is when fiber elongation occurs. This period is critical for the plant's yield potential and is considered as an important time to have appropriate levels of available water and nutrients for the plant. Fiber properties are mostly determined by internal and external cues perceived by cotton plants during fiber development, which affects physiological, metabolic, and cellular activities

(Allen and Aleman, 2011). Originally cotton fiber was graded by human graders at each USDA-Agricultural Marketing Service (AMS) location. The original fiber grading method was highly subjective, leading to a very inefficient and inconsistent system. With fiber being produced at a higher rate than ever, the grading machines and standards had to evolve as well. The three common methods for testing fiber quality parameters are Advanced Fiber Information System (AFIS), Fiber Classing System (FCS), and High-Volume Instruments (HVI). AFIS which was originally developed around the 1980s produces measurements by single fiber testing and measures parameters such as complete length and diameter distribution, trash content, nep content, fineness, and maturity (Negm et. al., 2015). HVI was developed in 1969, and uses automated sampling techniques and measures fiber properties from a bundle of fibers. This system remains popular today for both marketing and breeding because it is efficient in terms of time and cost (Negm et. al., 2015). HVI was developed for measuring large quantities of bale cotton within a minimum time frame. Typical HVI measurements include fiber length, length uniformity, bundle tenacity, elongation, micronaire, color, and trash content. The last system is FCS. Texechno developed a new system for classification which is considered to be a medium volume instrument. The modular FCS system determines the quality of the incoming raw cotton fibers and cotton slivers in order to optimize the spinning process. It considers cotton testing from a different point of view, taking the spinning method into account in order to assess the spinability of fibers within the spinning process (Negm et. al., 2015). HVI is still the most popular system and is the system used by the USDA AMS classing facilities all along the cotton belt. While cotton fiber yield is easily quantified, fiber quality is a complex parameter (Bradow et. al., 1997). “The USDA’s Universal Cotton Standards Agreement is an agreement between the USDA, the U.S. cotton industry, and 23 foreign cotton associations from 21 countries. The Agreement serves as a means for providing recommendations to the USDA regarding the Universal Cotton Standards. The Agreement covered only color and leaf grades until 1995 when approval was given by the Secretary of Agriculture to expand the Agreement to include calibration cotton and moisture conditioning standards for instrument classification. The current agreement includes standards for length, strength, length uniformity index, micronaire, moisture conditioning, and a reference to the USDA publication “Guidelines for HVI Testing” (Knowlton, 2005). The USDA’s cotton program is responsible for this united classing program. This classing system is commonly referred to as the AMS classification. This classification is divided into several grading criteria. These grading areas are color grade (reflectance and yellowness), leaf grade, length, micronaire, strength, length uniformity index, and trash percentage (USDA AMS, 2018). Premiums and discounts associated with several quality factors can have a significant impact on the price producers receive for cotton (Dumler and Duncan, 2004).

Color Grade

The color grade is determined using both the reflectance (Rd) measurement and yellowness (+b) measurement. As seen in Appendix I, there is a color grade assignment depending on the intersecting area of the sample’s reflectance and yellowness. The reflectance is a percentage measurement of how light or dark a sample is. The +b or yellowness is a scaled measurement (4-18) on the degree of yellow the sample is. To correct the yellowing of cotton fiber, a bleaching step is normally necessary to achieve the desired white color used in yarn spinning. The necessary level bleaching required will depend on the fiber’s assigned color grade.

Length and Uniformity

Fiber length and uniformity are important metrics to measure in ginned cotton as different lengths or uniformity cotton bales are used for different purposes in spinning. This is due to the possibility of fiber breakage or damage during the ginning process. HVI uses a fibrosampler to grab a portion of cotton from the whole sample. This subsample is used to create a beard of approximately parallel fibers that is optically scanned for relevant measurements such as upper-half mean length (UHML) and uniformity index (Kelly et. al.,2012). This measurement is the average of the longest 50% portions of the fibers commonly referred to as the upper half mean length or UHML. Length can be measured either using 32nds or 100ths of an inch. Fiber length is typically determined within the first few weeks after flower. There are also environmental stresses that can cause length variation. Length uniformity is the percentage of length uniformity between the upper half mean and total length mean. This uniformity allows graders to understand the fiber length distribution of the bale. The uniformity is then described on a range from very high to very low. The uniformity indexes can be found in appendix II. Both fiber length and length uniformity play a role in yarn spinning. Both parameters affect yarn characteristics such as yarn strength and evenness. Low uniformity or short/ broken fibers will cause yarn fibers to vary and produce a low-quality product with greater possibilities of defects.

Micronaire

The next major parameter is the measurement of micronaire. This is the measurement of fineness of fibers. Micronaire is affected by both maturity (degree of secondary cell wall development) and fineness (weight per unit length) of the fibers (Paudel et. al., 2013). Micronaire is measured using the HVI machine to measure the permeability of air through a cotton sample of specific density. Depending on how well the air permeates through the sample, it is then assigned a value ranging from less than 2.4 through greater than 5.3, falling into categories of G0 to G7. The ideal range is 3.5-4.9 which correlates to a category G5. The received measurement will then fall into a range such as discount, base, and premium. Each of the ranges represents values that correspond to added or lost value to the cotton fibers. The index ranges can be seen in appendix III. This would account for fibers that are either coarse or too fine. Fiber's micronaire is affected by external factors and plant nutrition. Micronaire will affect the speed of processing and the quality of the yarn produced. It is intuitively obvious to hypothesize that immature fibers (having a thin, poorly developed secondary wall) will be fragile. Thus, they are likely to break during multiple mechanical stresses involved in transforming the fibers from the field to the yarn (Hequet et al., 2006).

Strength

Another industry parameter is fiber strength. This is measured by applying a pulling force on a sample until fibers break. Using a gauge length of 3.175 mm two sets of jaws clamp the beard at a position towards its base. The breaking force is measured directly and normalized using an estimation of the mass of fiber from the optical sensor (in combination with the Micronaire value) to give the strength in cN/tex (Naylor et. al., 2014). The strength indexes can be seen in appendix IV. Strength is measured in grams per tex. A tex is equivalent to the mass in grams of 1,000 meters of fiber. Strength has five classes with their respective ranges. These classes range from weak to very strong. Strength of the fibers is normally affected by weather and nutrient availability, but can also be manipulated with varieties. Yarn strength will depend greatly on the strength of the fibers.

Leaf Grade and Trash

Mechanically harvested cotton contains some degree of plant-related contaminants and other irregular foreign matter. Considerable efforts have been made to remove foreign matter (e.g. botanic trash) as much as possible during subsequent ginning and cleaning practices. However, it remains a challenge to remove all trash from lint fiber without damaging fibers (Liu and Foulk, 2013). Leaf grade is the measurement of leaf content in a bale of ginned cotton. This was originally done by a person at the quality lab but has now transitioned to being incorporated with the HVI machine. Leaf content is affected by plant cultivar, harvesting method, and harvest conditions. An estimate of trash is also provided, and it should be noted that the leaf grade is not a part of the trash measurement. Trash content is the measurement in which the percent area of a sample has trash present. Trash can come from multiple sources. These sources of trash can range from plant matter such as bark or leaf litter but can also be of inorganic sources from the field or wrapping. Trash percentage is estimated using a camera, and the image is taken and analyzed to identify the trash content. The size of the trash particle and the percent area of the trash are studied. HVI trash and color measurements are based on two-dimensional images of the surface of the cotton samples and are not capable of providing information about trash thickness, density, or mass (Whitelock et. al., 2016). For yarn producers' smaller particulate trash, also known as pepper, can be very difficult to remove.

Cotton Fiber Variation Causes

Cotton fiber traits are determined by complex interactions among genetic, environmental, and processing conditions (Krifa, 2012). Cotton classing has historically had a vital impact not only on the economics of cotton production and marketing but also on the efficiency and the ultimate profitability of the textile manufacturing operation. In fact, decision-making in the cotton industry is often, if not always, based on categorizing or clustering cotton bales into relatively homogeneous quality groups using measured fiber properties (Krifa, 2012). These groupings come from the differently classed cotton. Cotton fiber can vary because of many different external factors as well as plant factors. One of the largest in-plant factors affecting fiber quality is fiber maturity. Fiber maturity refers to the thickening of the secondary cell wall. Fiber maturity is one of the most important fiber quality parameters as it has a potential impact on different fiber properties including fiber length, strength, the linear density of fiber or fineness, and other yield components such as cotton fiber density (Ayele et. al., 2017). The effects from fiber maturity will then affect the fiber performance in the spinning process post ginning. Fiber maturity is not the only mechanism that causes fiber variation or degradation. Abiotic stresses, particularly water deficit, salinity, and temperature extremes, are the primary factors limiting crop productivity, accounting for more than 50% reduction in crop yields worldwide (Boyer, 1982). Water stresses or rainfall are both large factors in affecting the final fiber quality. The period of fiber formation occurs within three weeks after the anthesis, thus periods of water stress in this period can compromise the length of fibers formed in these bolls (Abidi et. al., 2010). Cotton producers are greatly impacted by the weather. The longer open bolls are exposed to adverse conditions, the greater the impact on fiber quality there is. There is not only fiber quality difference between areas or even plants but also difference in quality among plants in different areas. According to Belot and Dutra (2015), comparing the bolls from the top and the lower positions within the middle third of the plants, showed great discrepancies in some characteristics such as micronaire, maturity, and percentage of fibers. These differences occurred due to complex interactions among soil properties, soil water and nutrients availability, and plant populations (Bradow et. al., 2000) (Zonta et al., 2017).

CHAPTER III

In Field Module Tracking

Introduction

Cotton harvest in the United States is primarily performed using a machine known as a cotton picker, seen in the state of Georgia and along much of the cotton belt. A cotton picker uses rotating spindles with sharp edges to wrap cotton fibers around the needle-like spindles and pull the seed cotton from the boll. The cotton fibers are then separated from the spindles using a counter-rotating doffer. The doffer removes the cotton and uses a vacuum system to convey the harvested fiber and seed up to the basket or module builder. The previous models of cotton pickers harvested seed cotton and held it in an expanded metal basket on the back of the machine. This seed cotton would then be dumped into a boll buggy to be transported to a module builder or it was dumped directly into a module builder from the harvester. A module builder is large metal container outfitted with several large hydraulic rams manually operated to compact cotton into a large, 2.3 m wide by 9.75 m long and common height of 2.59 m, rectangular shape to be transported to the gin (ASABE, 2005). The release of the John Deere on the go round module cotton pickers in 2009 brought much needed innovation to the cotton harvest industry. The round module picker builds round cylindrical modules in the machine’s on-board accumulator. This on-board accumulator allows the machine to continue to harvest, only needing to stop for a moment to deposit modules at desired field locations. This new harvester style has allowed for even higher field efficiencies, decreased requirements in field labor, and has helped to incorporate technological advancements to the industry. Alongside this new harvester style another crucial piece of equipment used by growers of most major crops is a yield monitor. The most essential component of precision farming is the yield monitor — a sensor or group of sensors installed on harvesting equipment that dynamically measures spatial yield variability (Vellidis et. al., 2003). These monitors vary in design, but all measure the amount of incoming product harvested. Currently John Deere's roller pickers utilize a microwave mass flow sensor to measure the amount of harvested seed cotton. The sensors are modified ground speed radar devices that measure the velocity and mass components of the flowing material. The mass measured at a particular reading is proportional to the power of the microwave signal reflected back from the flowing material (Wanjura et. al., 2014). Another advancement in the cotton industry was John Deere's Harvest Identification, HID system, released in 2012. The HID system tracks 18 data points about each module and links them back to the module serial number. Examples of these points are module creation and drop coordinates, moisture, weight (if collected), and time stamp of when the module was built. With limited work completed on the HID datasets it was unclear if modules could be tracked from the field through the ginning process. Previous attempts at the tracking of modules required the manual logging of georeferenced points or through a group of additional sensors. The HID system paired with the harvest path mitigated the need for additional inputs. Through the process of completing this project, a clear methodology was developed to handle this relatively new and unused harvest data. To complete this project growers across the state of Georgia were selected as collaborators based on the availability of a cotton picker with the Harvest Identification system on board. The HID data is generated from the cotton harvester with the appropriate sensors and license subscription. The HID system could be outfitted to both the CP and CS 7760 models as well as come as a factory option for the CP and CS 690/770 models. This complete system includes the module weighing system, RFID reader within the accumulator, and a moisture meter as seen in figure 5.

Figure 5: A photo of a CP690 representing the equipment associated with the HID cotton system. Number 1 refereeing to the RFID reader present in the accumulator of the picker. Number 2 refereeing to the moisture meter imbedded in the side of the accumulator. Number 3 represents the hydraulic on-board weighting system integrated with the back platform.

RFID is a form of automatic identification and data capture (AIDC) technology that uses electric or magnetic fields at radio frequencies for identification, authentication, location, or automatic data acquisition and transmission, and support a wide range of applications—everything from asset management and tracking to access control and automated payment (Sabbaghi and Vaidyanathan, 2008). With limited current work demonstrating the benefit of RFID implementation at the gin level, the adoption of this technology is minimal. Due to the low use of RFID readers, field work was still required to accurately track modules from their creation, through the ginning process, and assign fiber quality back to the harvested areas. A project label was associated with both the module identifies as well as the gin's label to allow for the tracking of said modules.

Research Question

Can a module tracking methodology be developed to track a module through the ginning process into bale development and tag the fiber quality results spatially back to the module creation locations from the field?

Chapter Objectives

The main objective of this chapter was to develop a procedure for the identification and labeling of modules to allow for the tracking through the ginning process into bale development and tag the fiber quality results spatially back to the module creation locations within the field.

Sub-Objectives

In order to meet the main objective of this study, the following sub objectives will be met.

- Evaluate the performance of two currently available methods of module identification- RFID and Free 2D barcode scanner
- Develop a technological method for tracking modules from selected fields of interest to the gin.

Materials and Methods

The project began by identifying those individuals in the state of Georgia with cotton harvesters equipped with the HID system. UGA's extensive county Extension Agent network, as well as John Deere dealerships were used to determine which growers were optimal candidates for this project. Four growers in Georgia were identified. Three were initially selected as they were all in the Southwestern region. A single grower located in Colquitt, GA was chosen due to resources and scheduling ease. The selected grower was very generous and has provided access to several fields each year which varied in acreage, from 16 - 40 hectares, and production levels. This grower also implemented his own on-farm trials which allowed for the further exploration of cotton fiber quality variation. Before these fields were planted, soil electrical conductivity or EC was collected using a six-coulter Veris 3100 machine (Veris Technologies, Salina Kansas). On the day of harvest, a pull-type module scale was taken to the first field and was used in the calibration of the harvester, following John Deere's recommended procedures. (Plumblee et. al., 2020) Three modules were weighed and entered into the machine's system. This allowed for the correction of the calibration factor. Once the machine was calibrated the grower would harvested the field as normal. Post-harvest it was necessary to scan the modules to make a list of all the modules' serial numbers. The primary method of module scanning involved using a hand-held Trimble Nomad (Trimble, Sunnyvale, California) computer with a Thing Magic RFID reader attachment as seen in Figure 6.

Figure 6: The Trimble Nomad handheld computer with the Thing Magic RFID reader attachment.

The Thing Magic RFID reader attachment (Trimble, Sunnyvale, California) is able to read up to 190 tags per second and has a reading distance of up to 100 cm. The reader boasts a wide range of operating temperatures, drop resistance, and is IP67 rated, all while maintaining a 9600 to 921,600 bits per second baud rate. To use the RFID reader, the RFID Searchlight software was downloaded on the Nomad. This method allowed for the advantage of being able to scan the RFID tags embedded in the module wrap. An example of this passive RFID tag can be seen in figure 7 below.

Figure 7: An example of one of the four imbedded RFID tags present in the John Deere round cotton module wrapping. (photo courtesy of John Deere)

Also, an Android tablet was used with a free 2D barcode scan application. The Android based barcode scan application called “RFID Cotton Module Scan” would read the 2D barcode present on the outside of the module wraps as seen in figures 8 & 9.

Figure 8 & 9: Tama’s 2-D QR code style barcode read by the Android tablet application.

The application was a cheaper option but does pose problems if the barcode is not present or in a bad spot on the module. The RFID reader is able to read the tag’s associated module ID for identification of the module. Whereas the application reads the module serial number which is present on stickers on the wrapping, seen in figure 8 & 9 above. Both methods were only able to identify a single identifier from the module and notate the dropped location using an internal GPS system. The step of scanning modules was still necessary as it was used to associate a module identifier with the order the modules were labeled. The RFID reader and application both exhibited problems that were resolved. If a machine malfunction occurs and two different tags were placed on the same module they will both be read. This is mitigated by recording the serial numbers and cross-referencing the serial numbers of the modules with the output HID file from the MyJohnDeere account. The module scan application would occasionally auto-populate an entry that normally was not the correct length of digits and could be easily deleted. Once the module was scanned, the module was painted, on the plastic wrapping, with a numbered code that related to the field name and overall module number. The module was coded due to the gin not utilizing the RFID tags and serial numbers on each module. Modules would then be staged and hauled to the grower's gin as normal. In order for cotton gin's to efficiently track modules, each typically has a method to label modules for identification. It was necessary to speak with the gin as each gin typically uses its own system for numbering the incoming modules. Currently, Clover Leaf Gin, located in Donaldsonville, GA, labels each module with a number identifier that includes the grower's field code and module number. Once the modules arrived on the gin yard, the gin's labels were then recorded as well as the project label to link the two back to the module's serial number. The code generated by the gin, was recorded and related back to the project label for tracking as seen in figure 10 below.

Figure 10: Both the project label, and gin label present on modules in the gin yard waiting to be ginned.

A module's code is utilized by the gin when collecting samples from all bales, from a specific module, for fiber classing samples. Modules from the project were ginned normally. Once ginned one sample from each bale created per module was collected and were sent to the AMS grading lab in Macon, GA for classing.

The field portion of this project required the following materials:

- Trimble Nomad handheld computer with RFID attachment
- Android tablet with RFID Cotton Module Scan application downloaded
- Module scale
- Spray paint can

Results and Discussion

The module tracking portion of the project did result in the development of a tracking method by utilizing various associated module labels. An example of these labels can be seen in table 3 below.

Table 3: The various module labels and identifiers used in the module tracking methodology from the field through the ginning process.

Module ID	Module SN	Project label	Gin Label
3500B98806110504C12262F0	20420125424	3	18
3500B98806110404C12262EF	20420125423	1	15
3500B98806110304C12262EE	20420125422	11	21
3500B98806110204C12262ED	20420125421	4	25
3500B98806110104C12262EC	20420125420	10	16
3500B98806111804C12262EB	20420125419	9	17
3500B98806111704C12262EA	20420125418	2	8
3500B98806111604C12262E9	20420125417	8	20
3500B98806111504C12262E8	20420125416	12	23
3500B98806111404C12262E7	20420125415	13	13
3500B98806111304C12262E6	20420125414	5	4
3500B98806111204C12262E5	20420125413	7	3
3500B98806111104C12262E4	20420125412	6	10
3500B98806111004C12262E3	20420125411	14	9
3500B98806110F04C12262E2	20420125410	15	22
3500B98806110E04C12262E1	20420125409	17	1
3500B98806110D04C12262E0	20420125408	16	19
3500B98806110C04C12262DF	20420125407	19	5
3500B98806110B04C12262DE	20420125406	18	7
3500B98806110A04C12262DD	20420125405	25	11
3500B98806110904C12262DC	20420125404	24	14
3500B98806110804C12262DB	20420125403	23	6
3500B98806110704C12262DA	20420125402	20	12
3500B98806110604C12262D9	20420125401	21	2
3500B98806110504C12262D8	20420125400	22	24

Through the use of the RFID reader and barcode-scanning application, module labels were linked to identify each module which its fiber quality as well as its harvested area. EC data was also collected to add another layer of data for future project efforts exploring the causes of the spatial variability of fiber quality. Utilizing another GIS software, Spatial Management System (SMS), the EC data was displayed using the contour map tool and placed into three ranges to show soil EC zones. These zones can be seen below in figure 11.

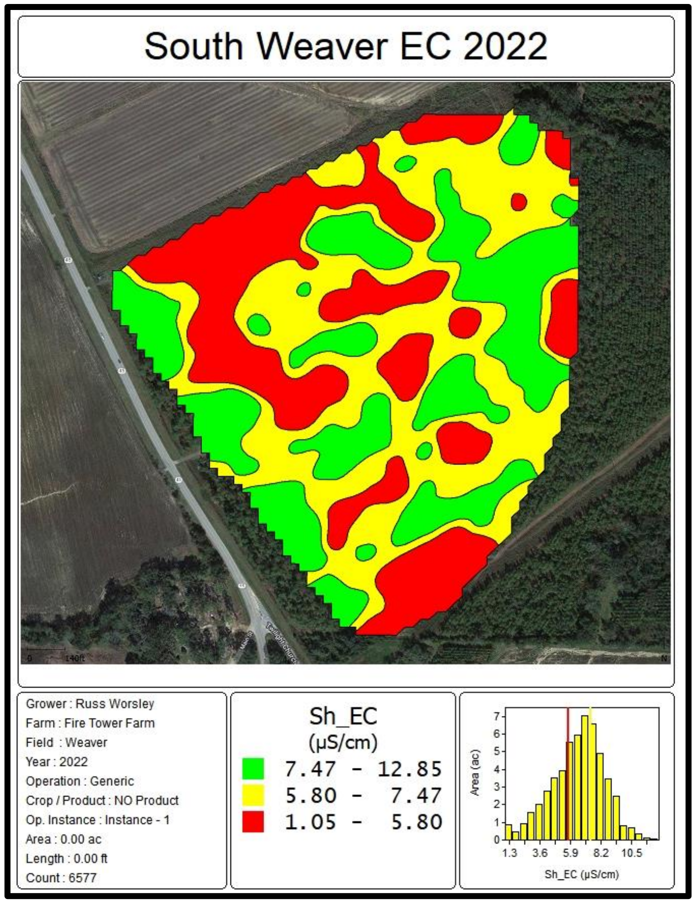


Figure 11: A 2022 collected EC map utilizing SMS to show soil zones from a field tracked through the 2021 season.

Conclusions

Through this portion of the project a methodology for identifying, labeling and tracking round cotton modules was developed. This procedure was necessary as limited work at the commercial scale up to this time has been completed on the labeling and tracking round modules utilizing John Deere's HID system. Two available methods for module identification were tested to evaluate various price point options. Even though it was more expensive an RFID reader was used, utilizing the four RFID tags present imbedded in the module wrap. This option allowed for the user to walk within the reader's specification range and acquire the module identifier without the need to stop. The second option used an android tablet with the free "RFID Module Scan" application. The application scans the 2-D QR style barcode present on the attached sticker on the module wrap as well as on outward facing side of the RFID tag. The user must stop, locate and scan the barcode to acquire the module identifier. The free application works similarly to the RFID reader, but does require the user to stop and operate the application. Once the modules were identified they required a project assigned label because of the lack of use of RFID technology at the ginning location. The module identifiers collected by the readers were correlated back to the project label as well as the gin assigned label. This labeling procedure became the foundation for correctly tracking modules through the entire process. Thus, through the process, round cotton modules could now be identified and tracked to the gin yard accurately.

CHAPTER IV

Python Coding and ArcMap Analysis

Introduction

With the ever-growing amount of technology and machinery aids, growers are given a large selection of avenues to better their production practices, better conserve the land they work, and increase revenue from crops. The release of the on the go round module pickers in 2009 revolutionized the cotton harvest industry. This new harvester style has allowed for even great field efficiencies, decreased required in field labor, and has brought technological advancements to the industry. One of these advancements was John Deere's, 2012 released, Harvest Identification, HID. This system is able capture an array of data including time stamps and georeferenced location tags for each module. These location tags can include module creation location and time as well as module dropping location and time. The idea of module tracking can then be taken further, if combined with gin fiber quality data, by creating module level resolution fiber quality maps. These maps can then be used for several reasons. These maps of course serve their purpose of visualizing the distribution of the fiber quality across the field. It also can be used to analyze fiber data to create net profit maps using the extension enterprise budget. From the start of the project, major improvements were needed to increase efficiency and mitigate the potential for human error. The necessity to clean yield data was made apparent as large quantities of duplicate data and outlier values were noticed. It was determined that a module average fiber quality must be computed, this was due to the current blending that occurs when modules enter the feeder at the gin. Originally the process was done utilizing an Excel calculator and manual input of data. With the implementation of a python code, the process was minimized to seconds and decreases error potential significantly. As the project evolved the methodology for analysis was developed and improved.

Research Question

Once modules are tracked through the ginning process, can the data be cleaned to show the spatial variability of fiber quality?

Chapter Objective

The main objective of this project was to create a methodology for handling of both harvest identification and fiber quality data to generate geospatial maps depicting the variability of cotton fiber quality.

Sub-Objectives

In order to meet the main objective of this study, the following sub objectives will be completed.

- Creation of a work flow to follow in understanding fiber quality and harvest data
- Determine a method to display fiber quality spatially utilizing the machine travel path
- Generate fiber quality maps following USDA AMS grading standards for selected fiber quality parameters

Materials and Methods

Linking a Grower's My John Deere Account

During the harvest process, the harvester is constantly creating data as it traverses through the field. Not only is this machine collecting HID data, but it is also collecting elevation, yield, speed, and heading. These data can be downloaded from either the field computer in the machine or the growers MyJohnDeere operations center. To ensure data access, the growers' account must be shared with the person or entity whom is needing access to the files. A grower can be added as a partner to the organization's MyJohnDeere account allowing varying levels of access across a few different categories depending on the need of a specific project. In the operation center of MyJohnDeere, using the setup tab and team option it shows the individuals linked with the account. While under this team option there is an icon for "add to your team" which allows for the user to create a new partner to the organization. The website will ask for the grower's email, which was used to create their account, to send the access request when finished. The website then asked to confirm the varying levels of access for the different categories of account sharing. To gain access to the grower's files the location category needs to be selected to a level three access which can be seen in figure 12 below.

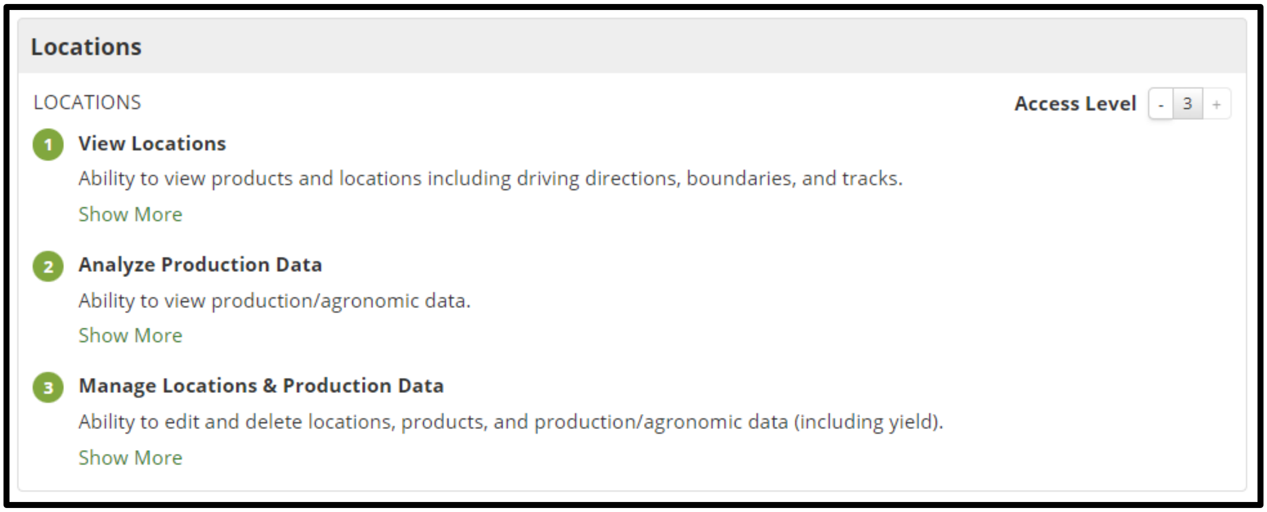


Figure 12: MyJohnDeere interface depicting the location category which requires a level three location access request.

As mentioned above when done, an access request email will be sent to the grower's email address to be accepted. Once accepted by the grower the user can toggle to the grower's account from the home operation center page. Once granted access to the grower's account the user is able to look at various operations in fields of interest. As the grower for this project implemented on-farm trials, with the linked MyJohnDeere account, a visualization of data such as in figure 13 below, can be observed prior to downloading.

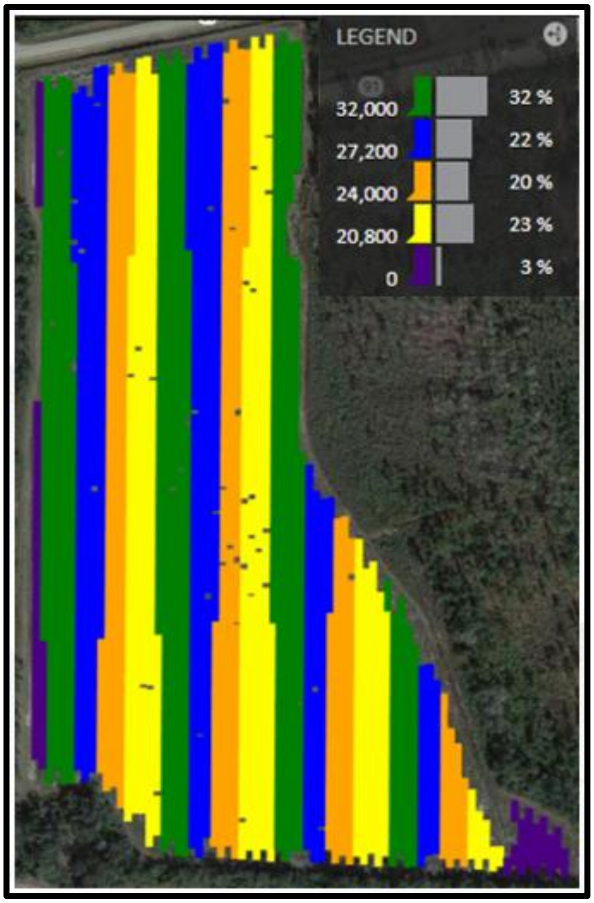


Figure 13: A MyJohnDeere operation center output of an on-farm trial of four planting populations from 2020 season in the Fire Tower field.

Exporting Yield and HID Files from My John Deere

With the grower's account opened in operation center, map tab selected, the field icon on the left side of the page can be opened showing the various field's the grower has logged on their account. With the upper select icon checked, find the desired field and highlight. With the field highlighted an option to export became available. Knowing when the grower harvested the desired field, the pop up allowed for the selection of a date range in which the interface will find the desired operation files. When finished, the software will take a few minutes to create a zip package of the files of the operation selected. The zip package can be found under the more tab and files option.

In the files option the user can select the zip package, when generated, and download as an Excel comma-separated value file or shapefile depending on the operation.

Cleaning Yield Data

The harvest shapefile exported previously was then imported into a geographic information system (GIS) software. In the case of this project, ArcGIS was used. The shapefile contains harvest operation data as well as field parameter data such as elevation, heading, and speed. Each of the data layers can be toggled through to view the basic machine-gathered data. A map of the field elevation from the 2019 season can be seen in figure 14.

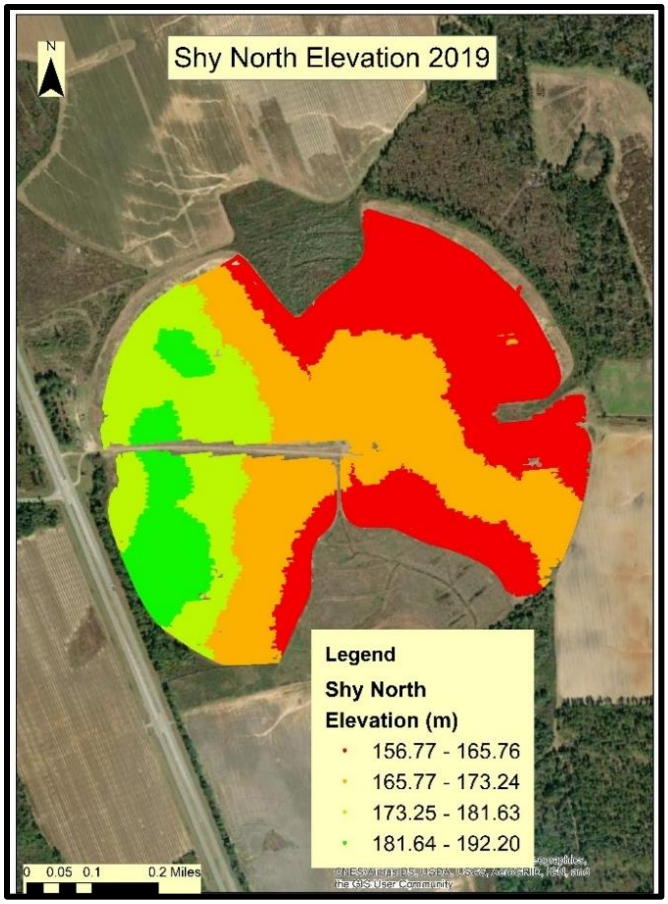


Figure 14: An ArcGIS map of the field elevation from 2019 season, giving growers another layer of data to make field decisions upon.

The CP690 used for this project collected yield data at a rate of 1Hz. This frequency of data logging equates to a data point being logged roughly each second. With the harvest operation taking several hours to days, the quantity of data generated quickly there are a high number of points in the field, thus, to prevent overloading the system and requiring a long time to display the data. An important step when utilizing these styles of data is data cleaning. Data cleaning is the process of deleting or fixing data to better allow for manipulation or use. Cleaning also aids in the reduction of data load.

To clean yield data in ArcMap the harvest shapefile was first added to a blank project. Using the editor toolbar, "start editing" was selected with the shapefile highlighted in the pop-up window. The attribute table was then opened for the layer to begin selecting points. In the table option icon “select by attribute” was selected. This particular tool allows for the selection of points by a specified value, attribute or desired function. To select the points by yield values the “VRYIELDBAL” attribute was first selected and will be displayed in the function box at the bottom of the window. A greater than or less than button was subsequently clicked and expected standard yield value can be entered and outlying points identified. Once applied, the points selected by the built function can be deleted using the “delete selected” button at the top of the attribute table. This process can be repeated for the other operation. In the cleaning of the datasets for this project a range of 0.2 bales per acre to five bales per acre was used as the range representing standard expected yield values. This was later converted into international units of bales per hectare, but the shapefile original contains the data in bales per acres. When the cleaning was complete the edits were saved and stored in the editor tab.

Another form of data cleaning for the harvest dataset deals with the section ID column and duplicate entries. As a John Deere machine or implement is operating in a field, the swath is being divided into equal sections, and are assigned their own ID. As the GPS, yield monitor, and other sensors are operating, a point will be generated for each of the sections at the same time and be provided the same values, causing a massive quantity of duplicated data. Seen in Figure 15, original 2019 season maps were hard to read and could cause software crashes due to the large quantity of data being displayed. With section ID and outlier cleaning performed, it reduced the total points from 142,944 to 46,881.

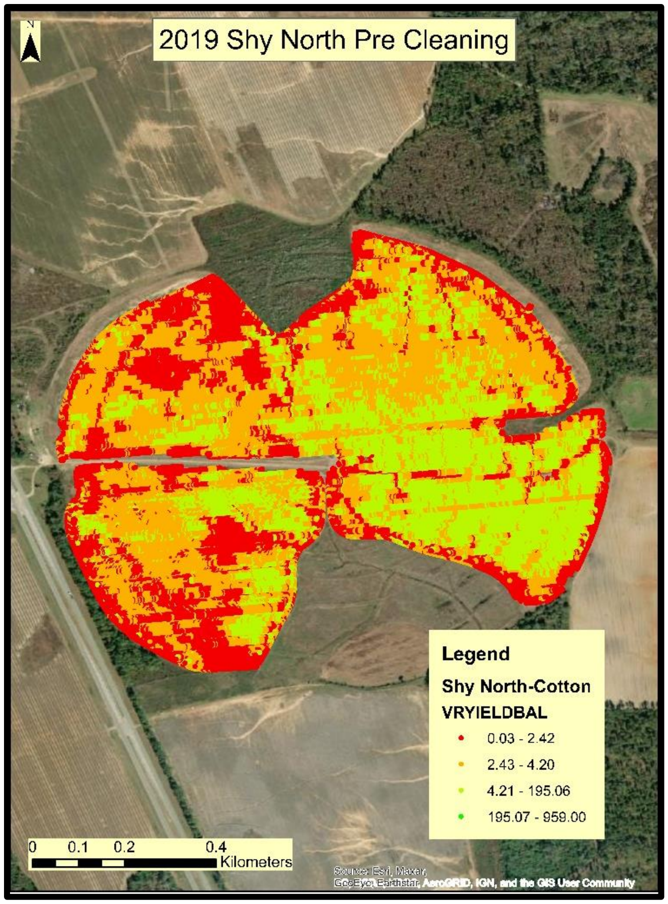


Figure 15: Point map of the 2019 field before data cleaning was performed containing 142,944 data points.

Original visualizations of data had to be captured using screen shots from the computer to get a resolution close enough to make out the field variability. ArcMap exports could not be used due to the issues seen in figure 15 above. In order to clean the yield data of the duplicate sections a similar series of steps were taken as cleaning of outlier yield values. Instead of selecting the "VRYIELDBAL" attribute, the "Section ID" attribute was the foundation of the selecting function. With the "Section ID" column highlighted the "get unique values" button was used to find all values present within the column. The highlighting and obtaining unique section ID values can be seen in figure 16 below.

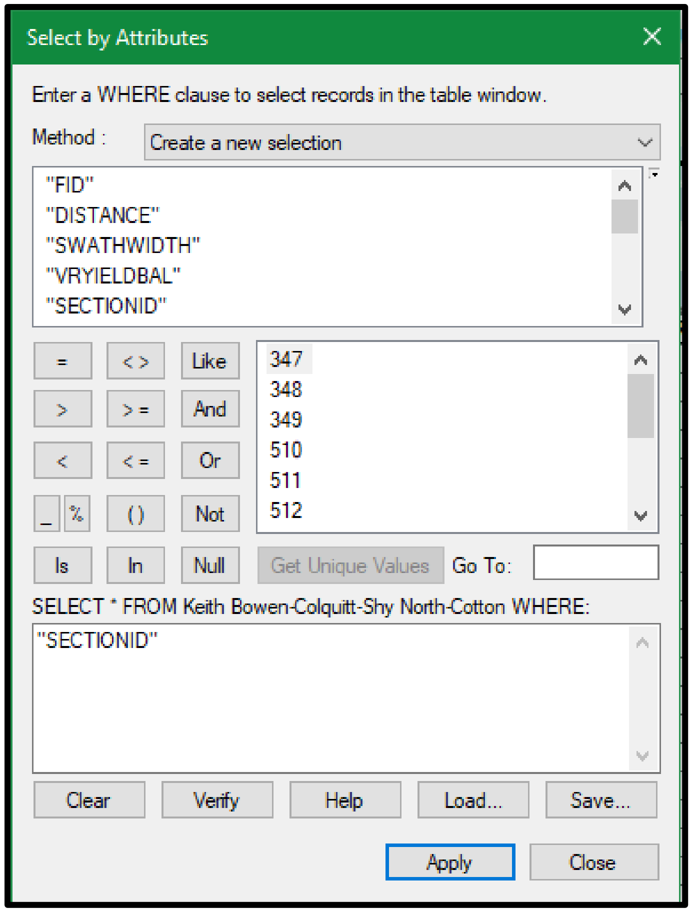


Figure 16: The "select by attribute" function builder in ArcMap displaying section ID unique values which can be used in the cleaning of duplicate data.

The harvest's six row units were broken into groups of two, resulting in three sections made across the header. For each of these occurrences, only the middle section was retained. To build this function, a simple equals sign followed by the outer section values would allow for the selection and deletion of the extra points as outlined above. It is still unknown as to why there are numerous section ranges created. Once cleaned, the maps readability increased significantly as seen in figure 17 below.

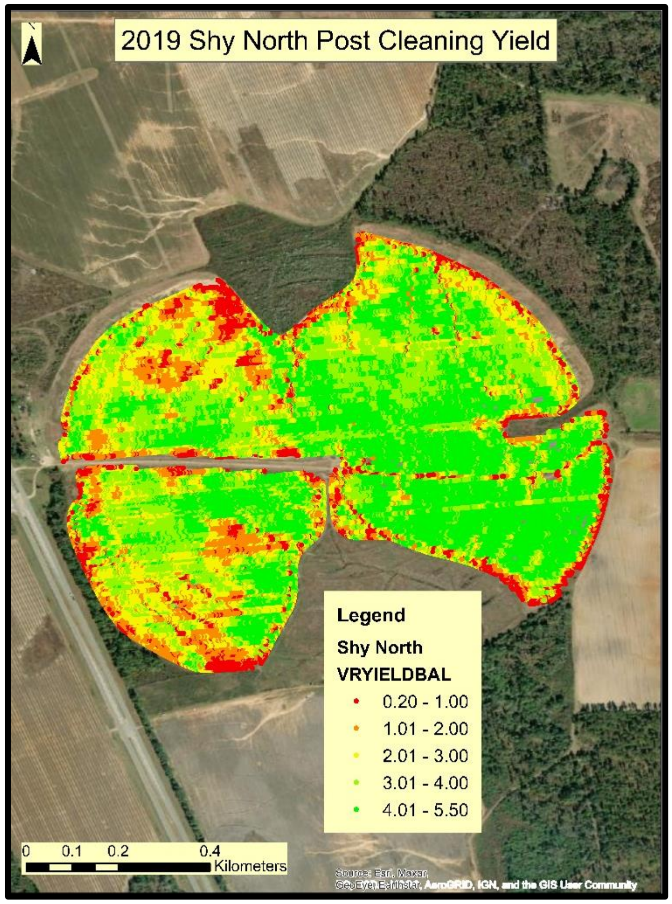


Figure 17: A cleaned yield map from the 2019 season containing only a third of original data, and showing a better clearer view of field performance.

Finding Module Point Ranges

To understand what points in ArcMap, represent each module, point ranges associated with timestamps had to be utilized. Each point in the harvest shapefile is not only georeferenced but given a timestamp as well. The HID file also has a creation timestamp for each of the modules. Using both of these files, the user is able to accurately notate each module's harvest area. In ArcMap, the cleaned shapefile was already completed from the previous steps. In the attribute table, there is an option to export data. The important step in exporting this data was to click the drop down of the browse window to save the file as a text file. Users are also able to specify the file name and location to save. The newly exported text file can be opened in Excel to allow for manipulation. Using the find and replace function, Ctrl F, a window to find each unique timestamp values can be used. Copying the timestamp of each module and allowing the computer to find said value on the harvest text file saved a great deal of time. When the timestamp was found on the harvest file, it was necessary to record the FID column value for the point at which the module was created. It is understood that the next module harvest area can be marked at starting at the next point past the timestamp. This process was repeated for each module.

Averaging Module Fiber Quality

As it is unclear where each bale came from within a module due to blending, an average module fiber quality is the current spatial resolution of the mapping. To achieve this, average fiber must be computed for each parameter for each module. Originally this was done using an Excel calculator and bale report print-out. The process would require the manual input of fiber quality values for the associated bales for each module, and copying the output average to another sheet. A python code was eventually written to help negate human error and significantly decrease the turnaround time of the process. With a gin bale report, each bale had a unique number identifier, but also has the load number or module code given to its associated module prior to ginning. The gin report contained fiber parameter values as well as various identifiers for the grower and field. It was an important step to delete columns such as "Farm ID, Field ID, Gin Date, Pk, and Rm" as these will not be needed in the averaging process. The python code was written and then executed in the free Spyder IDE. The code was written to identify the load numbers present and group the rows of data according to that value, as each module's bales will be given the same load number as stated above. The code then adds the specified fiber quality parameters by load number and divides the sum by the instances of that load number present. The final line of code must be amended for each field to specific a file name and save location as an excel file is created from the averaged values. This code can be seen in figure 18 below.

```
#Module_averaging tool
#Luke Fuhrer


import pandas as pd
from pandas import DataFrame
from tkinter import Tk
from tkinter.filedialog import askopenfilename


Tk().withdraw()
filename = askopenfilename() #generates window to select bale report
print(filename)

df = pd.read_csv(filename) #creates dataframe from excel file
df = DataFrame(df, columns=['Load','NetWt','Lf','Mic','Str','Rd','b','Tr','Unif','Len','Rate', 'Loan'])
df_avg = df.groupby('Load')['NetWt','Lf','Mic','Str','Rd','b','Tr','Unif','Len','Rate', 'Loan']
df_avg = df_avg.transform('mean').drop_duplicates(['NetWt','Lf','Mic','Str','Rd','b','Tr','Unif','Len','Rate', 'Loan'])
print (df_avg)

df_avg.to_excel(r'C:\git_repo\ File_name.xlsx', index=False) #creates new excel file from averaged values
```

Figure 18: Python code created to perform module averaging of fiber quality from the gin bale report.

Attachment of Fiber Quality Data to Point Ranges and Harvest Shapefile

Using the previously ArcMap exported harvest text file, all the columns other than the FID was deleted. As this file was joined with the original harvest shapefile, all duplicate data was deleted to reduce the data load of the project. Column headers for each of the fiber parameters were added to the Excel sheet. With the newly created module average fiber quality file, the values for each module were copied and pasted to their associated point ranges. The fiber quality would be copied and pasted to the first point of each module and drug down to the end of the range. Once done the file was saved notating this was the file to join. With the ArcMap project opened, the harvest layer was selected and the "join and relates" option was selected. This feature allows for the user to join related outside data to an existing layer of the project. In the join window the top drop down was selected to "Join attributes from a table" as the joining file was a table containing no geographic reference. The join will be based on the FID of the shapefile for commonality. The join file was then selected in the browser. The FID was also chosen as the commonality in the table to base the join on. To check the join was done properly a quick look at the attribute table of the harvest shapefile showed the newly added fiber quality. With the fiber quality now added, the various fiber parameters were able to be displayed visually and analyzed. An important step was checking the module's harvested area. To check if the harvested areas made sense or there were no errors, an ArcMap layout of a module number was displayed This showed each module in a different color and allowed for quick check of the ranges and join. This module harvest path map can be seen in figure 19 below.

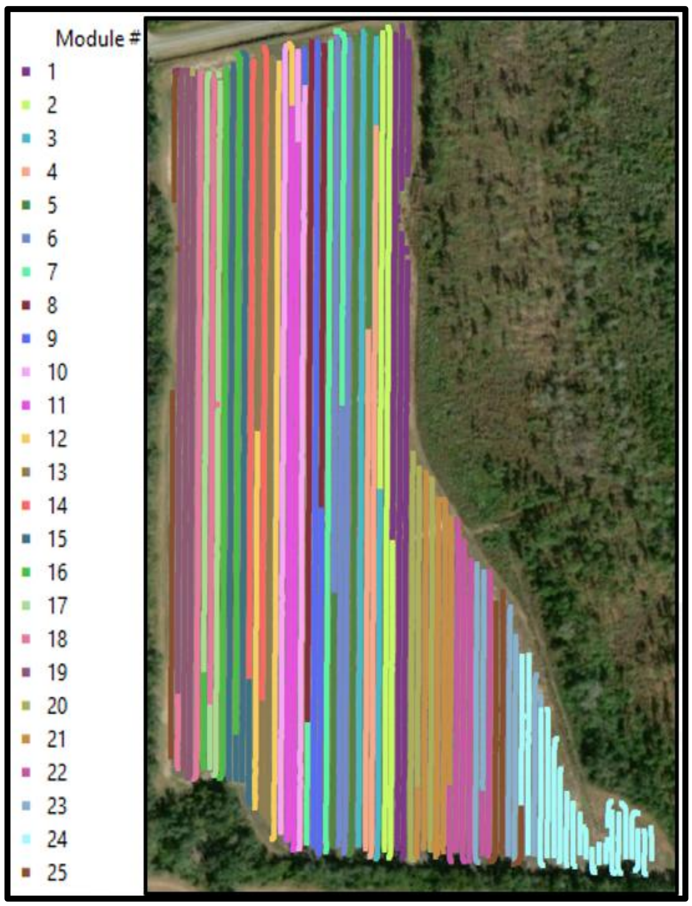


Figure 19: Fire Tower, 2020 season, field's module harvested area map utilizing the module number column.

In the computer data analysis portion of this project the materials used were as followed:

- Gin generated bale report
- Linked MyJohnDeere account with grower's

- Exported harvest file and HID file
- ArcGIS software
- Excel
- Python coding platform
- UGA Extension Enterprise Budget for Irrigated Cotton

Results and Discussion

Over the course of three cotton production seasons (2019-2021), 287 round modules were tracked from creation through the ginning process on seven fields near Colquitt, GA. This process allowed for the creation of cotton fiber quality map layers, providing a variety of fiber parameter maps. These maps represent the spatial variability of the cotton fiber quality at the round module resolution. Each of the average fiber quality parameters for each module was created due to the blending of a module when ginned. Growers can use these maps to make informed field decisions due to an additional layer of data that was not previously available to them. Visualization of these parameters allows for growers to identify areas in a field based on performance of both a yield and/or fiber quality perspective. The creation of these maps as seen in figure 20 below, fiber quality can be understood finally spatially, and creates an opportunity for more in-depth research potential as fiber quality can be tracked more easily on the commercial scale. These maps can allow growers to prioritize the harvest of areas with historically better fiber quality. Growers could also harvest according to their field trials, track their modules through the gin, and understand how different agronomic operation variations affect their yield and fiber quality.

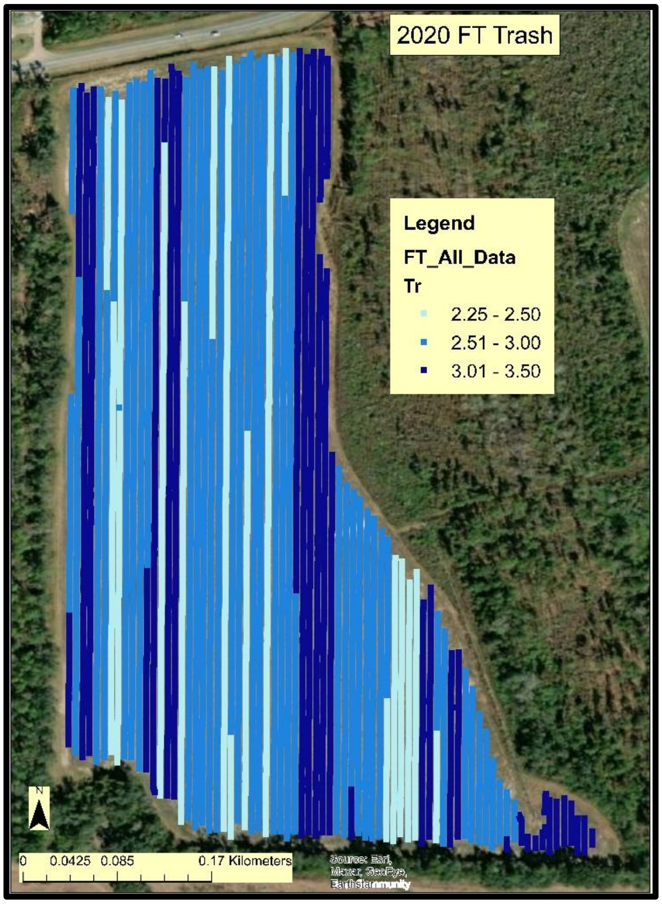


Figure 20: Fiber quality map of trash from 2020 season.

An important point of discussion though are the generated map legends of ArcMap. Most GIS software will automatically create a legend using the data range provided the scale and amount of data within the dataset, which can develop a false sense of variation. Figure 21 below could be seen as having a variation of micronaire across the field. From a cotton classing standpoint all of the values represented are in a single classification range. Cotton fiber quality ranges can be found in the AMS guidelines for cotton fiber quality, thus, the ranges for each fiber quality parameter should be set in the GIS software according to the AMS classed ranges, not automatic ranges. A depiction of strength variation utilizing the AMS classification in map creation can be seen in figure 22 below.

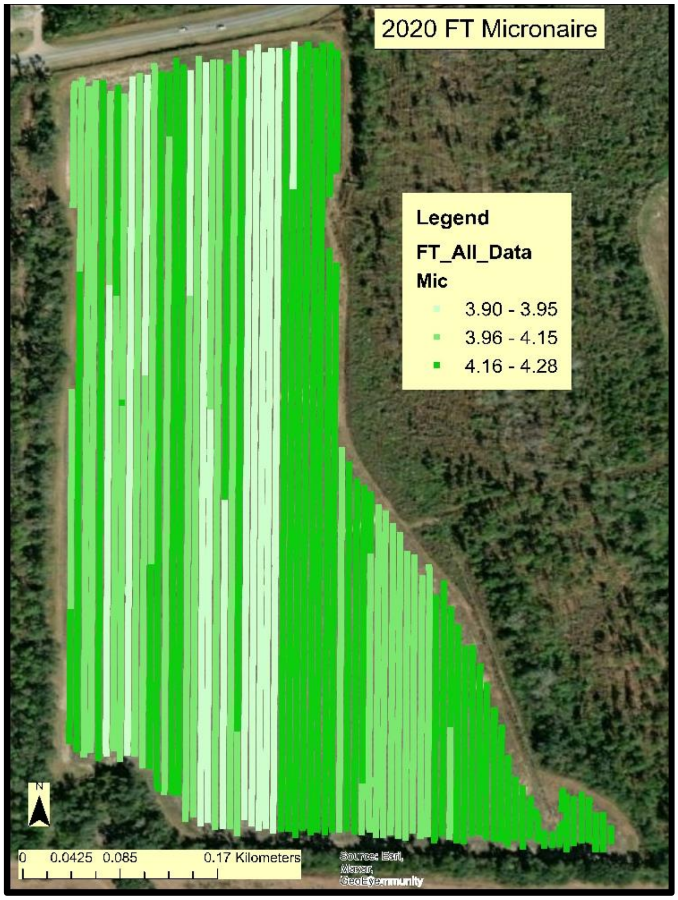


Figure 21: Micronaire mapped showing variability across the field, but all values fall within the G5 category and will receive no price difference.

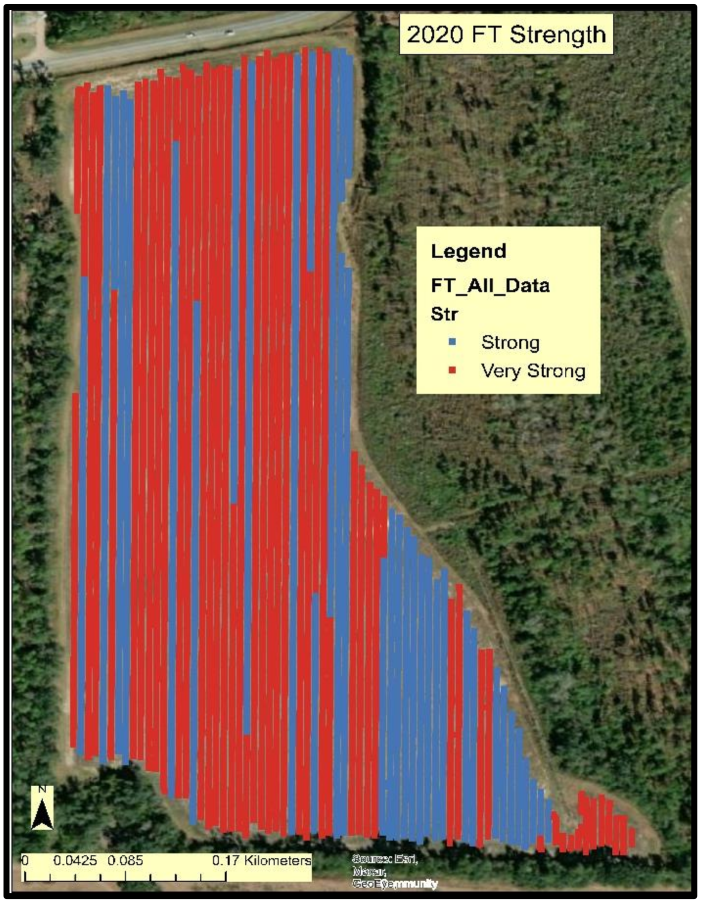


Figure 22: Strength map from the 2020 season following AMS classification for the legend ranges.

Depending on what agronomic practices were performed in each particular field, various other layers were explored, a few examples are seeding rate trials, variable rate fertilization, or variable rate irrigation. With growers now implementing on-farm trails, these data sets could provide an explanation for both yield and fiber quality variations. The loan value parameter in the gin bale report can also be averaged and show the spatial variability of average price received per bale by a module. Loan value being the price received per bale is calculated by the USDA AMS lab using the discounts and premiums given to the sampled fiber from each bale. This loan value, seen in figure 23, could be used in the making of decisions based on gross profit of the field.

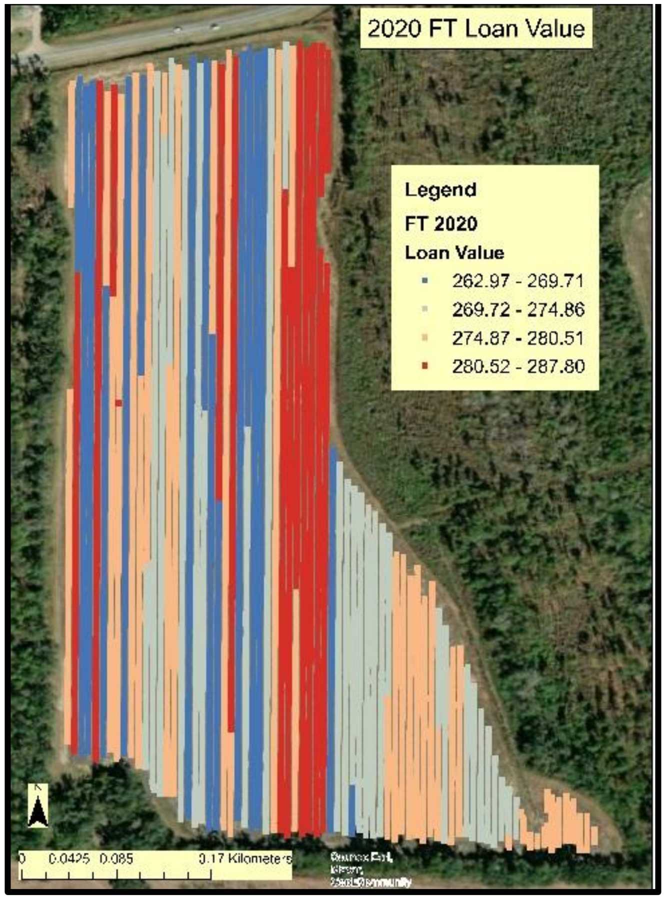


Figure 23: Loan value map from the Fire tower field showing the average $/ bale received by module from the 2020 season.

Each of the agronomic production data layers could also be spatially joined with the harvest file. The spatial join operation allowed for the software to join data based on the smallest distance between two adjacent points, and join each point's attributes. The spatial join operation was needed because even though the machine travelled the same rows using autosteer, it did not capture the sensor values at the same locations since each agronomic operation was different. Having both layers also provided a source of economic explanation as well. Understanding varied levels of operations and how they affect the final quantity or quality of the product allowed for the creation of net profit maps. The net profit calculation was achieved using the UGA Extension Enterprise Budgets (UGA, 2022). The UGA Enterprise budget is an excel document developed by UGA

Extension to provide estimated costs of production and calculations to growers. The calculator allows the user to input their data if desired to generate actual cost and profit breakdowns. The loan value per module, the production level for that area, and the cost of that specific treatment or average cost were all input into the calculator providing a net profit for that module area. Examining the net profit showed the effects of various treatments on the final profit margin, as some treatments may increase yield or boost fiber quality but will ultimately reduce net profit.

Conclusions

Cotton fiber quality, in opposition to yield data, was previously unable to be displayed spatially within a GIS program. Previous to the implementation of the HID system cotton fiber quality was a performance metric only available to be reviewed by a bale report provided to the grower by the gin. Limited research on the HID system has led to a need in understanding how to use the HID dataset and its potential. As shown in the methods of this study, a clear workflow to acquire, handle and utilize HID data in coordination with cotton fiber bale reports and harvest travel path allowed for the visual and spatial display of fiber quality data. The georeferenced harvest travel path was utilized to attach module level fiber quality data for spatial display in ArcMap. Due to multiple bales being produced from each module, a module average fiber quality was computed and utilized for each module. This computation was performed using a Python program. As fiber quality was able to be mapped, the displayed legends must be classified according to the USDA- AMS classification standards. This became important as the default GIS program generated legends could show varying levels of variability in contrast to the AMS grade classification which may not have any fiber variability. By following all of these procedures and properly classifying cotton fiber quality data, spatially accurate round module level fiber quality maps can be created.

CHAPTER V

Cotton Bale Fiber Variability

Introduction

Cotton fiber traits are determined by complex interactions among genetic, environmental, and processing conditions (Krifa, 2012). Cotton classing has historically had a vital impact not only on the economics of cotton production and marketing but also on the efficiency and profitability of the textile manufacturing operation. Without being able to thoroughly understand cotton bale fiber variability displaying the tracked seven major fiber and two economic parameters can be difficult and misrepresentative of field fiber quality values. An example of a source of fiber variability is fiber maturity. Fiber maturity is one of the most important fiber quality parameters as it has a potential impact on different fiber properties including fiber length, strength, the linear density of fiber or fineness, and other yield components such as cotton fiber density (Ayele et. al., 2017).

A 2,268 kg (5,000 lb) round module produces roughly four 217 kg (480 lb) ginned cotton bales. As modules are conveyed through the gin to the the gin stand they are first introduced to the gin through a module feeder. The feeder breaks apart the modules from their long rectangular or round shape. This feeding causes blending of the fiber present in modules. Due to the blending of modules upon entrance into the gin, a module average is the highest resolution available to spatially represent cotton fiber quality parameters. Cotton fiber quality is evaluated at the USDA AMS classing offices. Ten USDA AMS classing offices offer cotton fiber quality testing across the cotton belt. These locations are Visalia, Abilene, Corpus Christi, Lamesa, Lubbock, Rayville, Dumas, Memphis, Macon, and Florence. These offices use an instrument called a high-volume instrument (HVI) to quickly determine fiber quality from samples. HVI was developed in 1969, and uses automated sampling techniques and measures fiber properties from a bundle of fibers. This system remains popular today for both marketing and breeding because it is efficient in terms of time and cost (Negm et. al., 2015). Typical HVI measurements include fiber length, length uniformity, bundle tenacity, elongation, micronaire, color, and trash content. HVI is still the most popular system and is the system used by the USDA AMS classing facilities all along the cotton belt. While cotton fiber yield is easily quantified, fiber quality is a complex parameter (Bradow et. al., 1997). With three to five bales typically produced from a module an average of these values is a by-product of the previously mentioned blending. With such a great degree of variability possible in a field, determining if the bale fiber quality variation within a module can further help to understand the differences in quality present.

Research Question

Does a single module average fiber quality value accurately represent the variability seen in each fiber parameter within a module?

Chapter Objective

The main objective of this study was to evaluate the validity of module averaging, in its ability to accurately represent fiber quality parameter variability

Sub-Objectives

In order to satisfy the main objective of this study, the following sub objectives will be met.

- Creation of a Python program to perform standard deviation calculations, by fiber quality parameter, for each module.
- Perform an uncertainty analysis to explain the within module variability based on the variability of the input fiber parameter values.

Materials and Methods

Parameter Standard Deviation and Module Average Graphing

To efficiently calculate the standard deviation of each of the parameters for each module, an adapted averaging python code was utilized. The code similarly used the load number or module label to group bales from the gin report. Once grouped, instead of an averaging function, a standard deviation function was used. It also produced a new Excel file containing the computed values. The final line also was amended by the user to specify file name and save location. This new Excel output can be seen in Table 4 below. With the new excel file open, the first sheet can be named standard deviation, or a preferred naming convention. A sheet was then created for each of the fiber parameters, and named accordingly. A module number column was added to each sheet, as well as the calculated standard deviation values for each parameter. Finally, the module average fiber quality values from the previously computed Excel file can be copied to each associated sheet. With the average quality column highlighted, the 2-D column bar graph was selected. This bar graph style was selected to show the mean value for each module. In the design tab, the “add chart elements” option includes the addition of error bars. The error bars were added with the custom value option selected. A side window was used to specify specific values for both the positive and negative error bar. For these ranges the standard deviation column was highlighted. Figure 24 displays both the average value as well as the variability of the parameter by module.

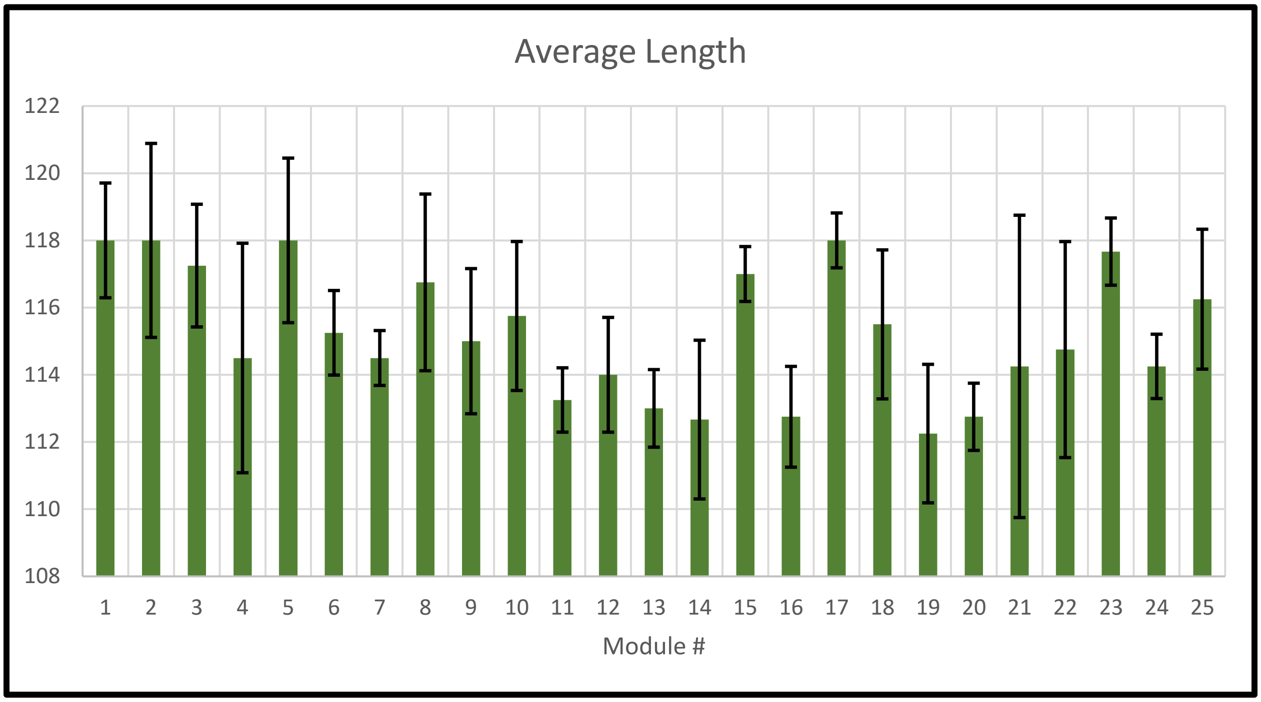


Figure 24: Average length of 25 modules from the Fire Tower field, illustrating the average value per module and the standard deviation error bars depicting the variability of the bales created for that parameter by module.

Bale Variability Uncertainty Analysis

An uncertainty analysis was performed by utilizing the standard deviation values computed by the python code referred to above. The equation below was used for the uncertainty analysis.

Equation 1 $$Uncertanity = \frac{Standard\ Deviation}{\sqrt{n}}$$

The variable n represents the number of bales per module. The number of bales produced from each module has to be notated to correctly input the value for n. To calculate the uncertainty analysis a sheet must be added to the standard deviation Excel file and named. A column for the number of bales per module was added to the sheet to be referenced by equation 1. Using the original bale report, how many bales corresponding to each module was determined and recorded in the new column. A header for each fiber parameter were also added. The equation entered into each cell can be seen in the equation below.

Equation 2 $Uncertantiy = \frac{Standard\ Deviation \text{ (a sheet and cell reference to the original computed standar deviation sheet)}}{\sqrt{n}\text{(number of bales cell reference for that module)}}$

Equation 2, with correct references, was written for the parameters for the first module and copied down to the following modules. To analyze the total average standard deviation and total uncertainty a table was made. For the average standard deviation by parameter, the Excel average function was used and a reference to all the values for that parameter entered. To calculate the total uncertainty by parameter, the average standard deviation just calculated was used and divided by the square root of the total number of modules. This table can be viewed in Table 4 below.

In the bale variability analysis portion of this project the materials used were as followed:

- Gin generated bale report
- Excel
- Python coding platform

Results and Discussion

By utilizing a bale report from the Fire Tower field from the 2020 season, 25 modules were tracked through the ginning process, and further statistical analysis was completed. Standard deviation and uncertainty analysis were performed to evaluate the distribution of data compared to the averaged module value. The uncertainty analysis was used to explain the variability of the output parameters due to variation of the input parameters. In this specific case the module averaged values were explained by the variability of the inputted fiber quality data. While standard deviation explains the single sample variation, the uncertainty analysis provides the deviation between the samples. The standard deviation of the bale variability from each module identified two parameters that should be considered for not averaging at the module level. A condition was applied to the cells to highlight each cell that was outside of the range of two standard deviations (-2.00 to 2.00). Assuming this dataset is normally distributed, it would account for 95% of data. Table 4 shows the highlighted cells present in both the length and loan value columns that were more than two standard deviations out of range. The standard deviations in Table 4 can be compared to the module averaged fiber quality values found in Appendix E.

The uncertainty analysis was used as a metric to further explain the variability between samples. With the uncertainty analysis using the standard deviation, and having such a small sample size, it followed a similar trend as the standard deviation. The highlighted cells from Table 4 were also quality parameters of interest in this analysis. The highlighted cells show the variation between the samples of both the length and loan value were too great to confidently be explained by the averaged value. Table 5 is a summarized form of these data, and the total average standard deviation and uncertainty analysis for all the 25 modules are displayed for each fiber quality parameter. Table 5 shows that the standard deviation for the length and loan value are still substantially higher than the other parameters. It also shows that with a larger sample size (n), the margin of difference for length and loan value are reduced in an uncertainty analysis.

Table 4: Standard deviations by parameter for each module, illustrating the variability of each parameter by module.

Standard Deviation of Fiber Quality Parameters by Module

Module #	**Lf**	**Mic**	**Str g/tex**	**Rd**	**b**	**Tr**	**Unif %**	**Len UHM**	**Loan Rate Cent/lb**	**Loan Value $/bale**
1	0.50	0.22	1.00	0.54	0.10	0.82	1.12	1.71	0.60	10.13
2	0.50	0.06	0.74	0.53	0.17	0.50	1.05	2.89	0.48	4.29
3	0.50	0.10	0.28	0.45	0.26	0.50	0.79	1.83	0.11	4.11
4	0.50	0.17	1.20	0.41	0.23	0.82	0.93	3.42	0.66	10.01
5	0.50	0.06	1.29	0.57	0.25	0.58	0.98	2.45	0.79	11.51
6	0.50	0.05	0.98	0.22	0.10	0.50	1.01	1.26	0.13	4.60
7	0.00	0.06	0.65	0.25	0.12	0.58	0.61	0.82	0.25	3.08
8	0.00	0.06	0.38	0.50	0.15	0.00	0.67	2.63	0.02	11.63
9	0.00	0.10	1.21	0.13	0.05	0.00	0.24	2.16	0.17	6.04
10	0.00	0.06	1.56	0.50	0.22	0.00	0.76	2.22	0.78	7.06
11	0.00	0.08	1.17	0.33	0.06	0.00	0.45	0.96	0.24	9.40
12	0.00	0.06	0.63	0.17	0.13	0.50	1.20	1.71	0.51	3.82
13	0.00	0.05	1.07	0.34	0.08	0.58	0.94	1.15	0.18	8.95
14	0.00	0.08	1.79	0.10	0.08	0.58	1.09	2.36	0.73	2.90
15	0.00	0.13	0.78	0.24	0.13	0.58	1.08	0.82	0.25	7.54
16	0.00	0.00	0.90	0.25	0.14	0.50	0.77	1.50	0.14	9.68
17	0.50	0.05	0.87	0.21	0.10	0.96	0.59	0.82	0.33	5.91
18	0.00	0.05	1.01	0.55	0.41	0.50	0.76	2.22	0.24	16.64
19	0.50	0.14	0.77	0.25	0.10	0.82	0.71	2.06	0.19	7.90
20	0.00	0.08	0.26	0.17	0.17	0.50	1.06	1.00	0.04	6.09
21	0.00	0.10	0.80	0.39	0.34	0.50	0.41	4.50	0.76	2.50
22	0.00	0.06	0.74	0.83	0.17	0.00	0.93	3.21	0.33	4.03
23	0.00	0.06	0.40	0.26	0.06	0.58	0.55	1.00	0.25	3.30
24	0.00	0.05	0.51	0.41	0.08	0.58	0.97	0.96	0.36	4.57
25	0.00	0.06	0.76	0.25	0.06	0.58	0.60	2.08	0.56	8.83

Table 5: Total averaged standard deviation and uncertainty analysis for all 25 modules by parameter.

Total SD & Uncertainty by Fiber Parameter		
Parameter	Average SD	Uncertainty
Lf	0.16	0.03
Mic	0.08	0.02
Str	0.87	0.17
Rd	0.35	0.07
b	0.15	0.03
Tr	0.48	0.10
Unif	0.81	0.16
Len	1.91	0.38
Loan Rat	0.36	0.07
Loan Value	6.98	1.40

Conclusion

Three to five cotton fiber bales are produced from each round module, introducing a large potential for variability in each fiber quality parameter. Due to the blending of fiber occurring at the feeder upon entrance into the gin an averaged fiber quality value was required. Without a clear understanding of where fibers within a cotton bale came from, the greatest resolution of certainty would be at the module level. It was important to determine if the fiber quality parameter variability was accurately represented by a single averaged value. An adapted Python code was written to compute the standard deviation of each of the fiber quality parameter developed from the cotton bales produced from each module. This code, similar to, the module averaging code mitigated human error and decreased the necessary computation time. Performing an uncertainty analysis on these data sets allowed for further explanation of the variability present in each fiber quality parameter. The standard deviation and uncertainty analysis showed that the parameters of length and loan value have a greater degree of variability present. This would lead to the conclusion that these two fiber quality parameters may not accurately represent the true variability compared to a single module averaged value. Since only length and loan value had unacceptable deviations in their fiber quality data the other fiber quality parameters are accurately represented by the single module average value and can be utilized in the georeferenced mapping of fiber quality.

CHAPTER VI

SUMMARY AND CONCLUSION

Understanding performance levels or metrics for any industry has become an integrated aspect to developing greater efficiency in all systems, understanding net profit, and improving overall performance. This continues to be the case in the agriculture industry as well. With the ability to track yield, growers can see spatially how the crop is performing, and display this metric in a variety of ways. The ability to understand where in a field a crop performed better or worse allows for another layer of knowledge. Yield monitoring has transformed how growers make decisions within a field and for future plans. For most of the major row crops this is sufficient in understanding the crop. Cotton, harvested for the fiber, is graded on several different aspects of fiber quality. Fiber quality adds another layer of performance that the crop can be judged upon. Depending on the fiber quality grades, the received price for the fiber can have a premium or discount applied. Currently, only small plot research has the ability to track fiber quality and relate it spatially to an area in the field. This practice can be seen in variety trials or research trials performed on various university farms. With the implementation of the HID system, the tracking of cotton fiber quality on a commercial scale has become possible. The first objective of this research was to develop a procedure to handle spatial fiber quality data and a methodology to create fiber quality maps. This objective was accomplished, but originally was a labor-intensive process. Utilizing several Python programs, the time required to process these data was decreased significantly. The method for creating these maps still requires trips to both the field and gin, and includes some manual computer work. The above procedure, allows for the display of module average fiber quality across the field, and provides a more in-depth look into crop production from the cotton fiber quality perspective. A secondary objective of the project determined if module averaging of fiber quality, for round modules, is effective at accurately capturing the variability of most of the fiber quality parameters. Through an evaluation of the standard deviation and an uncertainty analysis all parameters other than length and loan value are accurately represented by the module averaged value. Understanding how to effectively display fiber variations throughout a field is a major leap forward for cotton growers as they can better understand the metrics that lead to the final price they receive for their product. The hypothesis and objectives for this research were all accomplished and further associated works are being conducted.

REFERENCES

Addissu Ayele, Brendan Kelly, Eric Hequet. (2017). Evaluating Within-Plant Variability of Cotton Fiber Length and Maturity. *Agronomy Journal, 110*(1), 47-55.

AJ Sjolander , Alex Thomasson, R. Sui, Yufeng Ge. (2011). Wireless tracking of cotton modules. Part 2: Automatic machine identification and system testing. *Computers and Electronics in Agriculture, 75,* 34-43. doi:10.1016/j.compag.2010.09.015

Aleman, R., Lorenzo Aleman. (2011). Abiotic stress and cotton fiber development. In D. M. Oosterhuis (Ed.), *Stress Physiology in Cotton* (pp. 149-160). Cordova, TN: The Cotton Foundation.

American Society of Agricultural and Biological Engineers (2005). Cotton Module Builder and Transporter Standard. In.

USDA AMS (2018). Cotton Classification: Understanding the Data. In (pp. 1-32). Memphis, TN: USDA AMS.

Asghar Sabbaghi, Ganesh Vaidyanathan (2008). Effectiveness and Efficiency of RFID technology in Supply Chain Management: Strategic values and Challenges. *Journal of Theoretical and Applied Electronic Commerce Research, 3*(2).

Boyer, J. (1982). Plant Productivity and Environment. *Science, 218*(4571), 443-448. doi:10.1126/science.218.4571.443

Camp Hand, Stanley Culpepper, Glen Harris, Bob Kemerait, Yangxuan Liu, Calvin Perry, Wesley Porter, Phillip Roberts, Amanda Smith, Simerjeet Virk, Sudeep Bag. (2021). *Goergia Cotton Production Guide*.

Carlos Armijo, Derek Whitelock, Joe Thomas,, & Sidney Hughs, a. M. G. (2017). Roller Ginning. *The Journal of Cotton Science, 21*(3), 199-209.

Carol Kelly, Eric Hequet, and Jane Dever. (2012). Interpretation of AFIS and HVI Fiber Property Measurements in Breeding for Cotton Fiber Quality Improvement. *The Journal of Cotton Science, 15*(1), 1-16.

Cathey, G. (1987). *Cotton Physiology* (Vol. Chapter 14). Physiology of Defoliation in Cotton Production.

Center, A. M. R. (2017). Cotton. Retrieved from https://www.agmrc.org/commodities-products/fiber/cotton

Christenbury, G. (1996). *Cotton Picker Management and Harvesting Efficiency*.

Cotton Incorporated, (2017). *Cotton Irrigation Management for Humid Regions*. In E. B. Calvin Perry (Ed.), (pp. 70).

Cotton Incorporated, (2018). The Classification of Cotton. Retrieved from https://www.cottoninc.com/wp-content/uploads/2017/02/Classification-of-Cotton.pdf

Derek Whitelock, Mesilla Park, Vikki Martin, Ed Barnes. (2016). *EVALUATION OF RELATIONSHIP BETWEEN HVI ESTIMATED LEAF GRADE AND MDTA3 MEASURED PERCENT TRASH*. Paper presented at the Beltwide Cotton Conference, New Orleans, LA.

Dev Paudel, Eric Hequet, Noureddine Abidi (2013). Evaluation of cotton fiber maturity measurements. *Industrial Crops and Products*, *45*(February), 435-441. doi:https://doi.org/10.1016/j.indcrop.2012.12.041

Economics, U. o. G. D. o. A. a. A. (2022). UGA Extension Enterprise Budget. Retrieved from https://agecon.uga.edu/extension/budgets.html

Ed Hughs, Greg Holt, and Ross Rutherford. (2017). Saw Gin Stands. *The Journal of Cotton Science, 21*(1), 60-69.

Eric Hequet, Bobby Wyatt, Noureddine Abidi, Devron Thibodeaux. (2006). Creation of a Set of Reference Material for Cotton Fiber Maturity Measurements. *Textile Research Journal, 76*(7), 576-586. doi:10.1177/0040517506064710

Geoffrey Naylor, Christopher Delhom, Xiaoliang Cui ,Jean-Paul Gourlot and James Rodgers. (2014). Understanding the influence of fiber length on the High Volume InstrumentTM measurement of cotton fiber strength. *Textile Research Journal, 84*(9), 979-988. doi:10.1177/0040517513515318

George Vellidis, Calvin Perry, Glen Rains, Dan Thomas, Rodney Hill, Dewayne Dale. (2003). SIMULTANEOUS ASSESSMENT OF COTTON YIELD MONITORS. *American Society of Agricultural Engineers, 19*, 259-272.

Glen Rains, Calvin Perry, George Vellidis, Dan Thomas, N Wells, Craig Kvien, Dewayne Dales. (2002). *Cotton Yield Monitor Performance in Changing Varieties*. Paper presented at the ASAE, Chicago, IL.

Gregory Schwab, G. L. Mullins, C. H. Burmester (2000). Growth and nutrient uptake by cotton roots under field conditions. *Communications in Soil Science and Plant Analysis*.

Jared Whitaker, Stanley Culpepper, Mark Freeman, Glen Harris, Bob Kemerait, Calvin Perry, Wesley Porter, Phillip Roberts, Yangxuan Liu, Amanda Smith. (2019). *2019 Georgia Cotton Production Guide*. In J. Whitaker (Ed.), (pp. 150).

Joao Henrique Zonta, Ziany Neiva Brandao, Josiane I. S. Rodrigues. (2017). Influence of boll sampling method and water stress on fiber quality of irrigated cotton (gossypium hirsutum L.). *African Journal of Agricultural Research, 12*. doi:10.5897/AJAR2016.12007

John Wanjura, Kevin Baker, and Edward Barnes. (2017). Harvesting. *The Journal of Cotton Science, 21*(1), 70-80.

John Wanjura, M. S. Kelly, Randal Taylor, Wesley Porter, Edward Barnes, M.G. Pelletier, G.A. Holt (2014). *EVALUATION OF A COTTON STRIPPER YIELD MONITOR.* Paper presented at the Beltwide Cotton Conference, New Orleans, LA.

Judith Bradow, Gayle Davidonis (2000). Quantitation of Fiber Quality and the Cotton Production-Processing Interface: A Physiologist's Perspective. *The Journal of Cotton Science, 4*(1), 34-64.

Judith Bradow, Lynda Wartelle, Philip Bauer, and Gretchen Sassenrath-Cole. (1997). Small-Sample Cotton Fiber Quality Quantitation. *The Journal of Cotton Science, 1*(1), 48-60.

Knowlton, J. (2005). *INTERNATIONAL DEVELOPMENTS IN COTTON CLASSIFICATION*. Paper presented at the Beltwide Cotton Conference, New Orleans, LA.

Krifa, M. (2012). Fiber length distribution variability in cotton bale classification: Interactions among length, maturity and finess. *Textile Research Journal, 82*, 1244-1254. doi:10.11770/0040517512438124

Luis Ruiz-Garcia, Lorendana Lunadei (2011). The role of RFID in agriculture: Applications, limitations and challenges. *Computers and Electronics in Agriculture, 79*, 42-50. doi:10.1016/j.compag.2011.08.010

Michael Plumblee, Kendall Kirk, Michael Jones, Jay Crouch, Charles Davis. Jonathan Croft. (2020). *Precision Agriculture: Cotton Picker Yield Monitor Calibration*.

Mohamed Negm, Suzan Sanad, G. Kulger. (2015). A Comparison of HVI, AFIS and CCS Cotton Testing Method. 1-8.

Noureddine Abidi, Luis Cabrales, Eric Hequet. (2010). Fourier transform infared spectroscopic approach to the study of the secondary cell wall development in cotton fiber. *Cellulose, 17*(2), 309-320. doi:10.1007/s10570-009-9366-1

Randy Boman, John Wanjura, Mark Kelly, Chris Ashbrook, Eric Hequet. (2011). *PICKER VS. STRIPPER HARVESTING IN THE TEXAS HIGH PLAINS: AGRONOMIC IMPLICATIONS*. Paper presented at the Beltwide Cotton Conference, Atlanta, GA.

Simerjeet Virk, Wesley Porter, Kade Fue, John Snider, Jared Whitaker. (2018). *EVALUATING THE EFFECT OF PLANTER DOWNFORCE AND SEED VIGOR ON CROP*

EMERGENCE AND YIELD IN HILL-DROP VS SINGULATED COTTON. Paper presented at the Beltwide Cotton Conference, San Antonio, TX.

Troy Dumler, Stewart Duncan (2004). Cotton Marketing Basics. Retrieved from www.agmanager.info/marketing/publications/marketing/cotton_marketing_basics.pdf.

Wesley Porter, John Wanjura, Randal Taylor, Micheal Buser. (2012). *Evaluating Cotton Stripper Field Performance*. Paper presented at the ASBAE AIM, Dallas, TX.

Wilkins TA, Jernstedt JA (1999). Molecular genetics of developing cotton fibers. In A. S. Basra (Ed.), *Cotton fibers, developmental biology, quality improvement, and textile processing* (pp. 231-269). New York: Food Products Press.

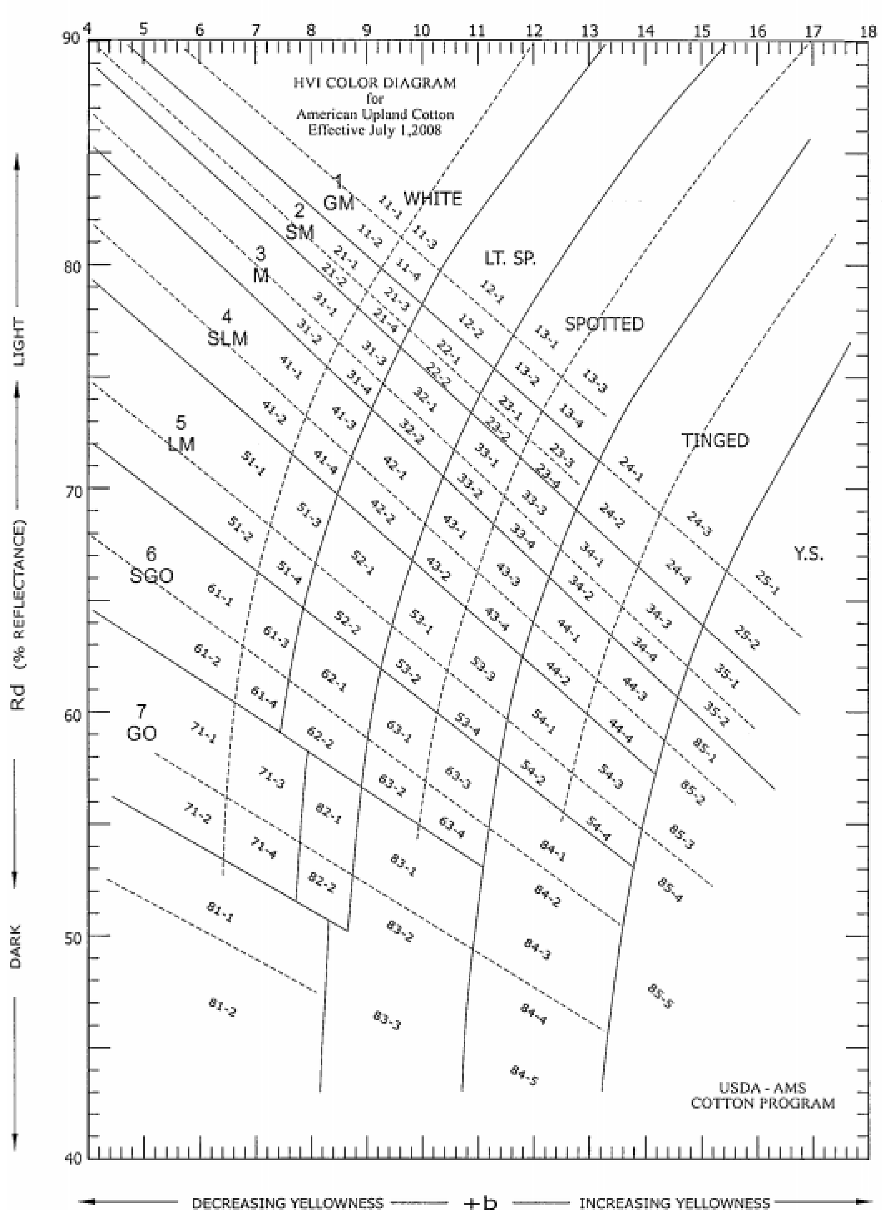
Williford, J. R. (1992). Influence of Harvest Factors on Cotton Yield and Quality. *ASAE, 35*.

Yongliang Liu, John Foulk (2013). Potential of visible and near infrared spectroscopy in the determination of instrumental leaf grade in lint cottons. *Textile Research Journal, 83*(9), 928-936. doi:10.1177/0040517513478481

APPENDIX

Appendix A: HVI color grade of Upland Cotton

HVI COLOR GRADES FOR AMERICAN UPLAND COTTON

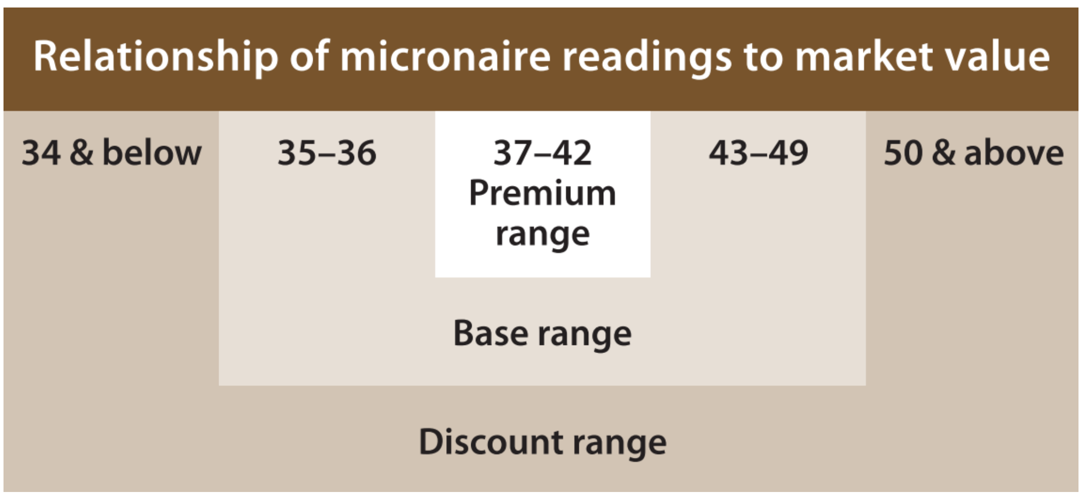


Appendix B: HVI length uniformity grades Upland Cotton

Interpreting length uniformity

Description of degree of uniformity	Length uniformity index (percent)
Very high	above 85
High	83–85
Intermediate	80–82
Low	77–79
Very Low	below 77

Appendix C: HVI micronaire grade ranges Upland Cotton



Appendix D: HVI strength grades for Upland Cotton

Interpreting fiber strength	
Description of degree of strength	**Strength (grams per tex)**
Very Strong	31 & above
Strong	29–30
Average	26–28
Intermediate	24–25
Weak	23 & below

Appendix E: Module averaged cotton fiber quality for 2020 Fire Tower Field

Module #	**Lf**	**Mic**	**Str** (g/tex)	**Rd**	**b**	**Tr**	**Unif** (UHM)	**Len**	**Loan Rat** (Cent/lb)	**Loan Value** ($/bale)
1	3.00	3.95	30.03	78.40	8.10	3.00	79.65	118.00	55.33	268.64
2	3.00	4.28	30.83	78.90	7.80	3.25	80.28	118.00	55.90	276.38
3	2.75	4.15	29.95	79.70	7.73	2.50	79.90	117.25	55.95	272.69
4	3.00	3.95	30.78	78.63	7.83	2.75	79.75	114.50	55.88	274.35
5	2.75	4.28	29.35	80.20	7.20	3.00	80.55	118.00	56.05	281.98
6	3.00	4.10	30.00	80.03	7.50	2.50	80.68	115.25	56.05	278.38
7	3.00	4.13	30.60	78.60	8.00	3.50	79.95	114.50	55.68	269.30
8	2.75	3.95	30.43	78.35	8.03	2.75	80.13	116.75	55.94	263.61
9	3.00	4.17	31.43	78.47	7.93	3.33	80.13	115.00	56.05	274.86
10	3.00	4.17	30.07	78.40	8.17	3.33	79.87	115.75	55.68	277.31
11	2.75	4.20	30.28	78.78	8.05	3.00	80.23	113.25	55.93	272.22
12	3.00	4.27	28.83	80.13	7.30	3.00	80.97	114.00	56.03	274.75
13	2.75	4.10	30.85	79.95	7.68	3.00	80.78	113.00	56.48	269.71
14	2.75	4.08	29.63	80.10	7.48	2.75	80.35	112.67	55.98	272.18
15	3.00	4.28	30.48	79.80	7.45	3.50	80.88	117.00	56.31	284.81
16	3.00	3.95	30.28	80.03	7.60	2.50	80.40	112.75	56.34	272.24
17	3.00	3.90	31.60	78.43	8.05	3.00	80.53	118.00	56.38	262.97
18	2.75	4.23	29.25	80.08	7.13	3.25	81.50	115.50	56.38	287.80
19	3.00	4.08	29.98	79.85	7.40	2.50	81.08	112.25	56.39	280.12
20	3.00	4.18	29.80	79.68	7.48	2.75	81.00	112.75	56.36	284.82
21	3.00	4.20	29.50	80.08	7.30	2.75	81.40	114.25	56.33	280.51
22	3.00	4.08	30.35	79.43	7.73	3.00	80.60	114.75	56.34	276.61
23	2.25	4.03	31.28	78.00	8.13	2.25	79.80	117.67	56.40	280.31
24	3.00	4.05	30.93	79.33	7.68	3.00	81.28	114.25	56.54	276.76
25	3.00	4.20	31.40	78.75	7.98	2.75	81.03	116.25	56.55	282.61