OPTIMIZING MANAGEMENT OF IRRIGATED COTTON IN A DEGREE DAY LIMITED ENVIRONMENT

By

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Abstract: The decline of the Ogallala Aquifer has jeopardized the future of agriculture in the states that it underlies. This has increased interest in growing crops with lower water requirements in the central Ogallala region, such as cotton. However, this region is challenged with low rainfall, limited growing degree days, and risk of early and late freezes. The objective of this study was to evaluate management systems to maximize profits and irrigate efficiency to maintain cotton quality. In the 2021 growing season, a trial was planted on the McCaull Research and Demonstration Farm near Eva, Oklahoma under a variable rate irrigation (VRI) equip pivot. The trial consisted of 19 treatments replicated 3 times. Treatments 2-7 were dictated by participants of the Testing Agriculture Performance Solutions (TAPS) program. Treatments 8-19 consisted of irrigation replacement based on evapotranspiration (ET) rates from the Oklahoma Mesonet, altered at various growth stages. This growing season was coupled with timely rainfalls and an extended growing season that reached yields of 2206 kg ha^{-1} in the full irrigation treatment with no detriment to fiber quality. Ceasing irrigation after squaring caused a significant decrease in lint yields and increasing irrigation in treatments of 40% of full during squaring to 70% of full or full irrigation allowed for recovery of lint yield compared to the constant 40% of full treatment in the short season variety, PHY205. In the TAPS studies, we observed a delay in maturity because of more irrigation. However, further data collection is necessary to draw definitive conclusions regarding the relationship between irrigation and delayed maturity in this environment. The results of this study demonstrate the importance of end-of-season irrigation and demonstrate how the management of various varieties can alter cotton growth and development.

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CHAPTER I

REVIEW OF LITERATURE

1.1 COTTON PRODUCTION

Cotton first arrived in Oklahoma with the Five Tribes and was first planted in the Choctaw nation in 1825 (Fite, 1949). Oklahoma was the third largest producer of cotton behind Texas and Mississippi. In the early 1900s, all but three counties in Oklahoma raised cotton on nearly one-fourth of the state's arable land. Much of the cotton was raised in the southern portion of the state and in the area northeast of Oklahoma City to the Arkansas River. Cotton hectares across the state exceeded 2 million hectares in 1925. This large-scale adoption helped to meet the high demands of exported cotton to Europe, but boll weevils began to damage crops, and the market price of cotton decreased. The 1933 Agricultural Adjustment Act called for farmers to plow nearly 500 thousand hectares of cotton (Nall, n.d.). This policy as well as the drought conditions, boll weevil damage, and poor market conditions caused a 70% reduction in cotton farmers and a 40% decrease in harvested hectares that continued through the end of the century (Green, 1990; Nall, n.d.). The southwestern region of the state began to supply their crops with supplemental irrigation via a canal system (Adams, n.d.). This source of irrigation caused water loss from absorption into the canal channels and the evaporation from open water transport. Center pivot irrigation with drop nozzles developed in the 1970s decreased water waste. Other innovations including the mechanization after World War II and the Freedom to Farm Act of 1995 allowed cotton to remain an important crop in Oklahoma agriculture (Nall, n.d.). The previous 5 agricultural survey years (1997, 2002, 2007, 2012, 2017) have shown the southwest district of Oklahoma to dominate in the total bales of cotton produced. This includes the counties of Caddo, Comanche, Cotton, Greer, Harmon, Jackson, Kiowa, and Tillman which contribute to most of the cotton production in Oklahoma (USDA NASS, 2017).

The 2017 NASS shows that the 350,500 hectares of cultivated land in the Oklahoma panhandle has been dominated by 51% winter wheat, 25% grain sorghum, 21% corn and less than 2% cotton and soybean combined (USDA NASS, 2017). In 2006 there were 1,300 hectares of cotton planted in the Oklahoma Panhandle. This was the first time since 1978 cotton was planted at a large enough scale to be reported in NASS. Before 2017, cotton production in the panhandle was limited. In 2012, about 7,400 bales of cotton were produced in the panhandle counties of Cimarron, Texas, Beaver, Ellis and Harper counties, increasing to 33,000 bales in 2017 (USDA NASS, 2017). Since 2017 there has been around 31,000 hectares of cotton planted in the Oklahoma Panhandle (USDA NASS, 2017). The central high plains are dominated by a semi-arid climate and a degree-day limited growing season (Esparza et al., 2007). Cotton hectares are extensive south of Amarillo due to the longer growing season and ideal environment. At its height, cotton hectarage planted in Oklahoma, Texas, New Mexico, Kansas, and Colorado reached 9.7 million planted hectares in 1925 combined. Planted area took a sharp decline in 1963 and never recovered back to these intense hectares. The most recent combined high was in 2018 when 3.6 million hectares were planted throughout these states (USDA NASS, 2016).

The following data was generated through the NASS system with the defined counties underlying the Ogallala Aquifer in the central sub-divided region denoted in Ajaz et al., (2020). The central high plains region with support from the Ogallala Aquifer includes the counties in the northern panhandle of Texas (Carson, Dallam, Gray, Hansford, Hartley, Hemphill, Hutchinson, Lipscomb, Moore, Ochiltree, Oldham, Potter, Roberts, Sherman, and Wheeler), northeast New Mexico (Harding, Quay and Union), southeast Colorado (Baca, Cheyenne, Kiowa, and Prowers), central and southwest Kansas (Clark, Comanche, Edwards, Finney, Ford, Grant, Gray, Greeley, Hamilton, Harvey, Haskell, Hodgeman, Kearny, Kingman, Kiowa, Lane, McPherson, Meade, Morton, Ness, Pawnee, Pratt, Reno, Rice, Scott, Sedgwick, Seward, Stafford, Stanton, Stevens, Wallace, and Wichita), and the counties in the panhandle and far west portion of Oklahoma (Beaver, Cimmaron, Ellis, Harper, Rodger Mills, and Texas). Corn hectarage planted was reported in NASS from 1933 and cotton from as early as 1909 in this region (USDA NASS, 2017). Aside from wheat and sorghum, corn is the highest planted crop in this region, and occupies the greatest irrigated hectares and the number of irrigated hectares in the central high plains has diminished significantly. Corn grown in the central region of the Ogallala Aquifer increased steadily over the years to a peak of 30% of the total crop cultivated in these states supported in the small area of the Ogallala Aquifer. Recently this number has declined to around 20% of the crop load (USDA NASS, 2017). Cotton hectares planted reached a high in 2018 with 330,000 hectares planted in the central high plains' counties dependent on the Ogallala Aquifer. On average the total area of cotton planted in the central region of the Ogallala Aquifer comprised less than 4% of total cotton hectarage planted entirely in the cotton producing states (TX, OK, NM, and KS) near the Ogallala Aquifer. Whereas over time that percentage has steadily climbed to around 9% in 2017 and 2018 and was about 8% in 2020 showing an increase of cotton hectares in regions affected by the decline in the aquifer (USDA NASS, 2017).

The decline in the aquifer and the higher irrigation demanded for corn is a factor that has influenced the switch to crops with a lower water requirement, such as cotton. This switch will become more important as the levels of the Ogallala Aquifer continue to decline (McGuire, 2014). Along with the declining water levels in the Central High Plains, producers also face challenges on limited growing degree day units, risk of freezing in season and a lower average rainfall compared to the cotton belt in Texas and the southeastern United States (Esparza et al., 2007). Texas County Oklahoma has experienced freezes as early as September 2nd that can halt boll opening (Lange and Hake, 1991; Mesonet 2002-2021 data retrieval). Planting can be delayed, or germination can be affected by freezes as late as May 10th. Growing days in the southernmost point of Oklahoma can extend to 230 days whereas Texas County's growing season is in the 185-day region (Mesonet Daily Data Retrieval).

1.2 HISTORY OF IRRIGATION IN THE REGION

The depletion of the Ogallala Aquifer began in the 1950s shortly after the rapid increase of irrigation activity in the High Plains (McGuire, 2017). Terrell (2002) reported a history of irrigation in the High Plains that began from adaptations of oil field technology. As farmers immigrated to the area, they knew the rich deep groundwater that awaited them. They saw this aquifer as an inexhaustible resource that began supplying irrigation water by the late nineteenth century (Fite, 1977). Early forms of irrigation equipment were designed for shallow water sources that could only produce water for a very limited number of hectares. The first deep wells were drilled on the Texas Plains in 1909 that yielded 6,050 liters of water per minute to the surface (Terrell et al., 2002). The drought of the 1930s and 40s, known as the Dust Bowl, caused a surge in development and interest in irrigation technologies (Musick et al., 1988). Farmers were hopeful of the impact irrigation could have on the semi-arid environment of the high plains. Now called a deep-well turbine pump was merged to an inexpensive automobile engine by a "gear-head" that increased hectarage from 30 to 57 hectares per wellhead. Water delivery continued to be plagued by water evaporation and the soakage of transporting water via canals (Terrell et al., 2002). Progression to underground pipes improved irrigation water transport and allowed for irrigation through an overhead sprinkler system. These systems were put on wheels for mobility and evolved into electric propulsion engines used to move pivots today. Through engine innovation and improvements to the water delivery system, the Ogallala Aquifer has quickly been depleted from the deep bountiful waters that first led farmers to this area (Terrell et al., 2002). From 1909 when irrigators drilled the first wells to the present day, technology has come a long way (Terrell et al., 2002). By creating advanced systems that conserve irrigation waters such as drip tape or Low Energy Precision Application (LEPA) systems, producers have less evaporation before water can contact the plant or soil.

1.3 OGALLALA AQUIFER DEPLETION

The Ogallala Aquifer stretches from South Dakota to Texas. The aquifer lies below 8 states and around 49.3 million hectares of land. These states rely on the aquifer to produce $35 billion worth of crops, hundreds of animal feeding operations, as well as general water use (Basso et al., 2013). Since 1950 there have been around 3000 irrigation wells drilled in Oklahoma pumping water out of the Ogallala Aquifer. Half of these wells have been drilled in Texas County followed by Cimarron and Beaver County in the Oklahoma Panhandle. Texas county has been deemed the largest consumer of water and has seen the largest decline of the Ogallala Aquifer in the state (Taghvaeian et al., 2017). Between 1950 and 1979 irrigated hectares in the panhandle increased from about 5,000 to nearly 164,000 (Guru & Horne, 2001). These hectares have contributed to the extensive decline in the aquifer water levels. Due to the declining levels of the Ogallala Aquifer, some states have had trouble supplying sufficient irrigation water to crops, and this issue will only continue as capacities decline (Basso et al., 2013). The innovation of more efficient irrigation systems has increased the number of irrigated hectares and this trend is expected to continue as systems become more efficient (Guru & Horne, 2001). In Texas, producers began to switch reliance of irrigation systems to those that could be more efficient. Furrow irrigation, which was the dominant source of irrigation at the time, declined by 39% (Musick et al., 1988; Bordovsky, 2019). This caused an upward trend in the adoption of sprinkler irrigation systems. By 1984 sprinkler irrigation averaged 37% of irrigated land in the Texas Panhandle (Musick et al., 1988). With the reliance on irrigation systems, Texas' 41 counties that overly the aquifer accounted for about 70% of the total depletion that sparked a transition to dryland farming due to the declining ground water resources (Musick et al., 1988). Since then, more efficient overhead irrigation systems have been created with little modification to existing systems. Examples of these modifications include mid-elevation spray application (MESA) or low energy precision application (LESA) which was created in 1978, and is shown to increase application efficiency while reducing evaporation (Bordovsky, 2019; Musick et al., 1988).

The region has developed efforts to conserve the nonrenewable resource through programs like the Ogallala Aquifer Initiative, switching to crops with a lower water demand, and practicing conservative irrigation. Research has shown improving water management by irrigating crops at critical growth stages, switching to crops with a lower crop water use, and irrigating to replace water loss due to ET can achieve profitable yields while minimizing withdrawal (Zonta et al., 2017; Baker & Acock, 1986; TAMU, 2007). Evaluation of water levels in the aquifer will continue to track the changes made by conservation practices to help secure the future of agriculture in the Oklahoma Panhandle.

1.4 IRRIGATION SYSTEMS COMPARISON

Irrigation methods vary from canal irrigation in Egypt, flood irrigation in Indonesia, and pivot irrigation in the United States, watering crops looks different around the world. Irrigation methods are limited to water availability, equipment, upkeep cost and access to technology (Evans, 2010).

Irrigation water loss due to evaporation is greater in semi-arid environments like the High Plaines region in comparison to the humid climates of Georgia (Whitaker et al., 2008). Furrow irrigation is the main source of irrigation throughout the United States (Howell, 2001). The major drawbacks of furrow irrigation include loss of water to deep percolation and tailwater runoff (Musick & Walker, 1987). Due to the decline in well capacities and the need to increase efficiency, various irrigation systems have been developed to increase the amount of water that permeates into the soil profile for crop use (Whitaker et al., 2008). These systems include Mid-Elevation Spray Application (MESA), Low Energy Precision Application (LEPA), Low Elevation Spray Application (LESA), and sub surface drip irrigation (SSD).

USGS (2021) defines furrow irrigation as water transported via trenches through crops. Irrigation water can be supplied to furrows through pipes from a well or canal, through a siphon tube directly out of the canal, or direct from the canal (Bjorneberg & Sojka, 2005). Furrow irrigation requires little technology to begin irrigation and lower investment costs (Bjorneberg &

Sojka, 2005). Water flow rates are limited with furrow irrigation depending on the delivery method and the field's slope. Polypipe, metal pipes, or siphon tubes can allow for variable water flow rates depending on the number of holes punched in polypipe, the hole diameter, if the metal pipes are gated, and the diameter of siphon tubes (Bjorneberg & Sojka, 2005). An important detail when designing furrow irrigated systems is soil permeability. In comparison to soils with a moderate permeable soil, soils with a low permeability would not benefit from a surge flow approach to surface irrigation system because of the low percolation expectation of the system that is designed to move water down the field instead of through the soil profile (Musick et al., 1988). Field leveling can also be adjusted to regulate flow rates down the field (Bjorneberg & Sojka, 2005). Water runoff can also be reduced in furrow irrigation and sprinkler irrigation using basin tillage, small mounds of soil placed perpendicular to crop rows to create small basins in the furrow, or in-furrow crop residue (Bordovsky, 2019; Lyle & Bordovsky 1983; Lyle & Dixon, 1977). These two field alteration methods can also ensure an increase in rainfall retention (Bordovsky, 2019). Disadvantages to furrow irrigation would be water loss to runoff at the bottom of the field, tailwater, and water loss to evaporation (Apalkov et al., 2020). Systems are available to reuse tailwater runoff to increase the efficiency of furrow irrigated systems (Musick et al., 1988). Furrow irrigation's ET can be comparable to the ET of other irrigation systems such as SSD because of the continuous wetting of the soil surface versus the 10-day frequency of furrow irrigation events. The daily ET values of drip exceeded those of furrow irrigation by almost 9% except for the three days following a furrow irrigation event (Pruitt et al., 1982). It is unclear if this source accounts for the total water delivery system and the ET incurred from the open water delivery. The total ET lost between these two irrigation methods was identical regardless of the irrigation event differences (Tarantino et al., 1982). Other forms of surface irrigation include high and low-frequency irrigation. High-frequency irrigation is supplying a small amount of water to the root zone frequently (Phene & Beale, 1976). Furrow-irrigated land is most likely to transition into a dryland system because of the inability to supply sufficient water to irrigate crops or because the economic loss is too great (Musick et al., 1988). The transition to a system with a higher water use efficiency (WUE) can prevent the irrigated hectarage from returning to dryland.

Mid-elevation Spray Application (MESA) dominates 80% of irrigated hectarage in the Southern High Plaines (Evett et al., 2019). An average of 17% of irrigation water applied via sprinkler fed systems is lost each year to evaporation or drifting in arid areas of the High Plains. This arid environment is challenged with variation in atmospheric water demand that can influence water lost from the soil (evaporation) and water lost from plants (transpiration) in combination these losses are ET (Musick et al., 1988). Low-pressure sprinkler heads placed closer to the ground (LEPA) can increase water application efficiency to 90-95% compared to the 83% efficiency of traditional sprinkler irrigation methods (Bordovsky, 2019; Musick et al., 1988). Conversion from a MESA to a LEPA system and a reduction in flow rates from 70.15 liters per minute ha^{-1} to 60.80 liter per minute ha^{-1} and a conversion of systems with a reduction of 3,218 liters per minute to 2,650 liters per minute saw no change in yield (Peters et al., 2019).

Low Energy Precision Application (LEPA) and Low Elevation Spray Application (LESA) are additions to a center pivot irrigation system that lower the sprinkler heads much closer to the ground, reduce spacing between sprinklers and/or reduce pressure at which water is emitted (Peters et al., 2019). LEPA systems were developed in 1978 to combat issues related to the depletion of the Ogallala Aquifer (Bordovsky, 2019). The main method of irrigation during this period was furrow irrigation in the High Plaines (Bordovsky, 2019). Conversion to the

LEPA system began to combat issues relating to runoff and evaporation. Researchers found that replacing bubblers with spray nozzles increases uniform irrigation application while increasing efficiency despite a greater potential for evaporation due to high winds (Bordovsky, 2019). In comparison to MESA, 18% more water reached the ground using LESA (Peters et al., 2019). Slope can influence the amount of water lost to runoff with LEPA irrigation systems installed, in fact, on a 3.8% slope, corn yields were reduced by 14-18% compared to systems with modifications to the soil surface (basin or reservoir tillage) (Bordovsky, 2019). Conversion to these systems takes little modification to preexisting MESA systems. These systems are not suitable for every crop and issues can arise in narrow-spaced crops like corn where LESA heads can be pulled off and damage the crop due to the free swinging of the hose (Peters et al., 2019). The increased cost of additional and different irrigation heads and more drop hoses is offset by the water savings from the conversion (Peters et al., 2019). Stationary grooved plate sprinkler heads priced around $2 are used in place of wobblers used in MESA systems that retail for $15-20 (Peters et al., 2019). In installation, the weight of water must be accounted for as the center of the main pipe supplying water will droop causing the heads to be closer to the ground, so adjustments might be necessary for the initial use of the system (Bordovsky, 2019). Other disadvantages for this system can include difficulty in chemigation due to applicators being below the canopy, overwatering can occur with the increase of the number of nozzles in the pivot span, and an increase in plugged nozzles because of the smaller nozzle size (Peters et al., 2019). Overall, the cost savings on energy to run a LEPA or LESA modification to a traditional pivot can pay for the conversion to these systems. LEPA systems in a favorably permeable soil with average wind speeds can decrease the evaporation lost from irrigation, but this is not always the case in arid climates with high wind speeds (Bordovsky, 2019). These systems, while trying to eliminate some environmental factors, cannot combat high winds like systems placed underground such as drip tape.

Subsurface drip (SSD) irrigation is irrigation water supplied via drip irrigation tape or emitters buried underground (Camp, 1998). This method of irrigation supplies irrigation water to the root zone (Ritchie et al., 2009). SSD can be buried deeper to avoid damage from tillage or used in alternative furrows to reduce instillation costs while also conserving loss of water from evaporation (Ritchie et al., 2009; Whitaker et al., 2008; Camp, 1998). SSD has been evaluated to be almost 100% efficient in replacing ET with water supplied (Pendergast et al., 2013). Other benefits include a less favorable environment for disease and pathogens due to a decreased humidity in the crop canopy, decrease in energy costs in comparison to irrigation methods requiring fuel to run an engine, and less interactions from the environment (Lamm, 2002). SSD can reduce runoff positively impacting water quality issues and the irrigation equipment being located underground, allowing for less wind or equipment damage (Lamm, 2002). There are also disadvantages such as not being able to see leaks as emitters are located underground, germination issues during dry conditions where water from emitters may not encounter the seed, and initial investment is high with little to no resale or salvage value (Lamm, 2002). SSD systems can provide a 14% increase in yield over LEPA irrigation systems which increase yield 16% compared to overhead sprinkler methods (Bordovsky, 2019). SSD irrigation is best suited in the semi-arid environment of the High Plains (Murley et al., 2018).

In relation to irrigation efficiency, different methods can be adapted to fit diverse environments regarding the technology and equipment available. Overhead irrigated sprinkler irrigation and SSD produced similar results in terms of yield, fruit size or mass of fruiting structures (Ritchie et al., 2009). Studies indicate comparable similarities between overhead sprinkler irrigated cotton and SSD irrigation with good quality (lack of saline) water in non-saline soils in Georgia on cotton and greenhouse studies on bell peppers. Although these crops are different the fruit size in peppers and boll mass and quantity in cotton can be affected by water stress and show no significant differences in irrigation application type (Bernstien and Francois, 1973; Ritchie et al., 2009). Overhead irrigation has been shown to be a potential issue for the integrity of complete pollination in cotton (Ritchie et al., 2009). Abscission of unpollinated flowers will occur 55 percent of the time in greenhouse tests with flowers having a small amount of water interference and this has been observed by Pennington and Pringle (1987) with a 65% decrease in flower retention under overhead sprinkler irrigation systems (Esparza et al., 2007). In 2013 and 2014 in Georgia, Porter et al. (2014) compared fiber quality effects due to overhead versus subsurface drip irrigation. Although not statistically significant there were negative effects on the prolonged exposure of irrigation water from an overhead system on color grade, but no effect on micronaire, uniformity, or length. Whitaker et al., (2008) reported potential negative effects on cotton flowering when irrigation water is applied to open flowers. Other irrigation systems such as SSD resulted in higher yields explained by the interference of pollination from sprinkler irrigation waters on open flowers as the difference of boll distribution (Ritchie et al., 2009). A study using sprinkler irrigation and drag sock irrigation saw a 21% yield loss in 2000 and an 11% yield loss in the overhead treatments potentially because of water's contact with open flowers (Esparza et al., 2007). Complete confidence in these conclusions has not been investigated to the full extent as other studies comparing furrow and SSD irrigation have seen comparable results in the number of unpollinated flowers without irrigation waters coming in contact with open flowers (Mateos et al., 1991). Other irrigation effects such as, extending irrigation past the recommended termination dates there is a risk of damaging fiber quality when using overhead irrigation systems (Porter et al., 2014). On the High Plaines in 2010 and 2011 research indicates a higher micronaire value when ending irrigation early but saw positive effects from yield with later irrigation termination under SSD irrigation (Reeves et al., 2012).

1.5 ADAPTATION OF COTTON

Cotton is traditionally a woody perennial plant now grown commercially as an annual field crop (Oosterhuis, 1993). Cotton one of 40 species of cotton throughout the world. Wild species are highly diverse and have adapted to their respective environments. These species have shown adaptation to extreme temperatures and varying rainfall amounts (Saranga et al., 1998; Bibi et al., 2008; Brown and Oosterhuis, 2010). Wild species have undergone phenotypic and genotypic changes to best adapt to each unique environment. The characteristics of wild species can be reintroduced into cultivated varieties by selective breeding (Fryxell, 1986). One challenge is still universal and deters wild and cultivated varieties from surviving throughout the year in their prospective habitats are freezes. A freeze kills the plants protoplast and stops further development (Fryxell, 1986). Cotton varieties are very adapted to temperature fluctuations, high temperatures, rainfall amounts, differing soil types, and frost dates (Fryxell, 1986).

1.6 COTTON PHYSIOLOGY

An understanding of cotton's growth habits is an essential part of successful cotton production (Ritchie et al., 2007). Once the cotton seed is planted it takes 4-14 days to emerge (Ritchie et al., 2007). The ideal soil temperature for cotton to begin germination is 18°C with minimum temperatures at 15.5°C though this will increase the time of germination. Temperatures below 10°C can decrease overall seedling vigor, stand establishment, and increase the seedlings risk for disease (Boman and Lemon, 2005). The seed imbibes water and begins to swell as the radicle is the first thing to emerge out of the seed (Ritchie et al., 2007). During vegetative growth, one of the plants' top priorities is developing a strong root system to explore the soil for necessary water and nutrients as plant demand increases for these resources. The depth the roots can reach is affected by the variety, soil type, soil texture, soil temperature, and soil moisture content (Albers, 1993). Cold soils, hard pans, low soil pH, water stress, or rotting can limit root growth and cause issues further into the maturity and growth of the cotton plant (Ritchie et al., 2007). The primary tap root has the potential to reach depths over 3 meters. From the tap root, lateral roots extend outward and can reach lengths of up to two meters. As the plant growth continues roots grow until the onset of bolls occurs (Albers, 1993). The older roots die as the plant focuses energy on producing fruiting structures (McMichael, 1986). This decline of roots as the plant gets older can be detrimental to the plant because it occurs during boll fill when nutrient demands are highest. Therefore, early season root growth is critical in providing sufficient nutrient and water uptake during boll formation (Albers, 1993). Cotton rooting depth is an important factor to establish access to water and nutrients at times of high temperatures where irrigation or rainfall has not occurred (McMichael, 1986). The radicle establishes this depth early in development which is necessary for the plant's survival throughout the growing season (Ritchie et al., 2007). At germination, the primary tap root will grow for several days without any secondary roots (McMichael, 1986). The tap root has the potential to grow 25.4 centimeters in depth before the cotyledons can unfold (Albers, 1993).

The next challenge is for the hypocotyl arch to emerge from the soil. From here cotyledons supply necessary nutrients to the growing seedling before unfolding to begin photosynthesis. The longer the emergence of the seedling takes the greater risk for yield loss or plant death (Ritchie et al., 2007).

Cotton has an indeterminate growth pattern that produces sympodial fruiting branches (Mauney, 1986). Although vegetative branches can produce bolls to contribute to yield, these sympodial fruiting branches attribute more than 80% of yield to be found on reproductive branches in the F_1 or F_2 position leaving the other 20% to other boll positions or vegetative branches (Mauney, 1986). Producers are concerned with maximum seed and lint production that goes against the typical perennial growth pattern of cotton (Ritchie et al., 2007). The meristem is the main growing point that allows for upward and outward growth of the plant (Ritchie et al., 2007). Sympodial branches stem from buds at the base of each leaf (Mauney, 1986). These two buds are the first and second axillary buds. Typically, nodes 1-5 are vegetative branches produced until the plant is induced to flower (Ritchie et al., 2009).

At floral induction the first axillary bud becomes a fruiting branch, and the secondary remains vegetative and dormant (Mauney, 1986). The continual vegetative growth of the plant uses resources that could be put into lint and seed production (Ritchie et al., 2007). It is rare for the plant to revert to vegetative branches after a fruiting branch has been produced but it seldom does happen (Mauney, 1986). The normally dormant secondary bud can produce floral branches if the plant is vigorous in reproductive development. This floral branch may only produce one flower but can be an important site for additional boll production. Vegetative branches will also produce small fruiting branches that will begin to flower later in the season (Albers, 1993). Cotton is unique in the fact that vegetative and reproductive growth happens simultaneously (Ritchie et al., 2009).

Cotton, once known to be a perennial short-day photoperiodic tree with an indeterminate crop growth habit, is now bred to behave as a day neutral crop with varying levels of indeterminate growth characteristics which require various management practices (Prewitt et al., 2018; Ritchie et al., 2007). Many studies recognize the transition from vegetative to reproductive growth of plant to an environmental factor such as a change in photoperiod or temperature (Andrés and Coupland, 2012; Khan et al., 2013). Others have expanded these reasonings to hormonal responses of the plant or genetic controlled timing of flowering termed as aging (Takeno, 2016; Khan et al., 2013). In cotton it has been ruled that most commercially available cotton is not photoperiod sensitive, and timing of flowering is unlikely in response to this change (Lewis and Richmond, 1957). Cotton grown in greenhouse-controlled environments have shown the ability for cotton transpiration to adapt to rapid changes in photoperiod length. This trial switched from an 8-hour light followed by 16-hour dark period to a 16-hour light and day period once the stomata adapted to this switch in about 3 days, the period was shifted back to the 8/16-hour period in which again cotton adapted to this change within a 24 hour period (Bugbee, 2011). Temperature closely relates to the GDU accumulation and can be used to gauge development of the cotton plant but cannot accurately predict the current growth stage, which explains the fact that heat units alone cannot explain the point at which cotton will flower (Hodges et al., 1993; Ritchie et al., 2007). Data has been pooled by variety due to the lack of response in time from square to flowering of cotton grown in various temperature regimes (Hodges et al., 1993). The last two hypothesis in relation to flower initiation, are those that fall in the realms of hormonal or genetic signals that signify flowering. Plant hormones such as 6-benzylaminopurine (6-BA), salicylic acid (SA), abscisic acid (ABA) have played a large role in sympodia development and individual floral bud differentiation (Li et al., 2016; Takeno, 2016). SA and ABA are hormones generated under plant stress and take part in the regulation of gene expression to overcome environmental stressors (Takeno, 2016). Stress is shown to break the barriers to induce fluorescence in coffee trees (Alvim, 1960). It is understood that elevated stressors in cotton will have a noticeable effect on productivity, but the intensity and timing of these events can dictate the level of detriment to growth, development, and final yield (Loka et al., 2011). However progressive and continuing research is being conducted to better understand the flowering habits of perennial plants and factors that can contribute to floral bud differentiation (Khan et al., 2013; Tan and Swain, 2006; Andrés and Coupland, 2012). Flowering timing is crucial in many perennial plants to restrict vegetive growth to allocate resources to reproduction and in turn optimize yield (Takeno, 2016; Andrés and Coupland, 2012). Drought induced flowering of the woody tree *Sapium sebiferum* provides a route to shorten vegetative growth due to water stress (Takeno, 2016). Stress induced flowering is restricted to those in the angiosperm clade and can be regulated by various growth hormones such as SA, but these factors do not under isolated conditions cause the induction of flowering (Takeno, 2016). Multiple reviews and studies have indicated that flowering is genetically controlled but is not the sole source of initiation (Khan et al., 2013; Tan and Swain, 2006; Southwick and Davenport, 1986; Fang et al., 2018; Prewitt et al., 2018; Takeno, 2016; Cheng et al., 2021). Cheng et al. (2021), has identified a gene deemed GhCAL, which when over expressed, promoted the switch from vegetative to reproductive growth in *Arabidopsis thaliana*. Cheng et al. (2021) went further to show the importance this gene can play in cottons transition to vegetive and reproductive growth and produced three transgenic lines were formed with the GhCAL gene being silenced, which resulted in a 21 to 14-day delay in flowering versus the wild type. Another study indicated that the miR169 family is prevalent in restricting a transcription factor to allow the FLOWERING LOCUS T (FT) gene, involved in stress-induced flowering, to initiate flowering (Takeno, 2016). This family is also involved in the drought tolerance of plants in tomato and A. *thaliana* (Lima, 2012). The mechanisms responsible for the initiation of flowering are unknown in cotton but has been traced to genes that control the transition from vegetative to reproductive growth, but there are no known environmental stressors or management factors that can independently hasten the transition in cotton (Simao et al., 2013).

Most of the yield is set on 8 to 10 fruiting branches that develop in as little as three weeks dependent on heat unit accumulation (Albers, 1993). Cotton plants set 2-3 times the true number of bolls that the plant can support which causes the stress response of dropping bolls, making this the most variable yield component (Baker & Acock, 1986). The growth of the cotton plant highly relies on the availability of water and the ability for the roots to explore the soil profile to find water. Water stress can also affect the retention of flowers early in the season and late-onset squares at the end of the season (Mauney, 1986). Squares form on fruiting branches as soon as they develop (Ritchie et al., 2007). Up to four squares can form on a fruiting branch as the internode expands outward from the first position square away from the main stem (Ritchie et al., 2007). As squares begin to form on sympodial branches new main stem node production decreases, this concept is called cutout and is a gauge of physiological maturity (Baker & Acock, 1986). The elongation of the sympodial branches passed 3 nodes would risk the retention of bolls in the first ($1F_1$) and second ($2F_1$) positions. As the season progresses, the number of flowers per day peaks and then drops to zero as the horizontal flowering interval (HFI) becomes greater (Mauney, 1986). With various water treatments, length of variety maturity, and other genetic factors can also alter the behavior of fruit set thus altering flowering positions (Guinn and Mauney, 1984; Pettigrew, 2004; Ritchie et al., 2009). The decrease of the onset of flowering can also be due to the decrease in daily temperature leading to the end of the growing season (Mauney, 1986). Various studies have been shown that 43-76% of yield comes from the $1F_1$ bolls followed by 16-32% of yield can come from $2F_1$ nodes. Although this is a repeatable outcome, Snowden et al, (2013a) gathered data on various varieties showing accumulation of bolls in the $1F_1$ position as well as the $2F_1$ position on fruiting branches. Only about 10 percent of bolls are located on vegetative branches and are exclusively in the F_1 position (Mauney, 1986). Sympodial branches having a limited length are beneficial for the energy efficiency of the plant (Mauney, 1986). This is limited by the competition between adjacent plants that determines the number of vegetative branches and the competition within each plant that determines the length of the fruiting branch (Mauney, 1986). Plant populations can affect the number of vegetative branches and the number of flower sites on each sympodia. Adequate resources can promote horizontal or vertical boll loads (Pettigrew, 2004). The higher plant populations are more likely to develop vegetative limbs than focus energy on the length of sympodial branches. Dense canopies can lead to self-shading that continues to promote vegetative growth from the increased need for photosynthesis to produce carbohydrates for square development and boll maturity (Mass, 1997). This can also explain the length of sympodia being reduced because of the reduced carbohydrate production (Mauney, 1986). A study in Lubbock TX concluded that adequate irrigation is more important to lint yield than below or above average planting populations (Feng et al., 2014).

There are about 21 days of square development before plants begin to bloom which continues for about 6 weeks (Ritchie et al., 2007). Temperature can cause the transition from square to flower to boll to speed up as temperature increases (Oosterhuis & Snider, 2011). A flower blooms white and remains this way for the first day, upon pollination the flower turns pink on day two and eventually matures into a deep pink/red color before drying and falling off (Ritchie et al., 2007). As the flowering branches move further up the plant and flowers extend to the furthest nodes the plant begins to cut-out (Mauney, 1986). In the field this cessation of flowering or cutout can be tracked by measuring the nodes above white flower (NAWF) (Ritchie et al., 2007). At the beginning of bloom NAWF measurements range between 8 to 10. As the season progresses this number decreases at a rate correlated to the earliness of maturity of the variety (Ritchie et al., 2007). Physiological cut out is said to be the stage at which the number of NAWF is less than or equal to 5 (Oosterhuis, 1993). Bourland (1992) concluded that fruiting sites above the 5 NAWF does not significantly contribute to yield. This is where assimilation switches energy production from flower production to fruit maturity (Ritchie et al., 2007). Cutout occurs when the NAWF reaches 4 to 5 and the plants energy will be diverted to maturing fruit already on the plant rather than creating new fruiting structures (Ritchie et al., 2007). This growth pattern occurs even with no environmental stress to the plant. Stressors do however impact the timing and severity of flower cessation (Mauney, 1986).

High temperature conditions can increase sterility and boll retention. Greenhouse studies have been conducted to eliminate other stressors and isolate the temperature effect. Results indicated daytime temperatures at 40°C with a decrease in nighttime temperatures to 32°C resulted in near complete abscission of immature squares when no bolls had begun development (Hodges et al., 1993). Other studies have also observed no production of fruiting branches or squares with the same environmental factors (Reddy et al. 1992). Stress relating to water deficit coincides with increasing temperatures, but adequate irrigation can help to alleviate this issue (Oosterhuis & Snider, 2011).

1.7 COTTON WATER DEMAND

Throughout cottons growth and development, the demand for water changes with the progression of each growth stage (Zonta et al., 2017; Reddy et al., 1991; DeTar, 2008; Baker & Acock, 1986). The most sensitive stage to water stress is during reproductive development behind the critical period of crop establishment (Loka et al., 2011; Saini, 1997). The sensitivity of fruiting structures to water stress decreases as the season progresses as the longer set bolls (10-14 days post flowering) are more likely to remain while young bolls and squares are easily shed during this time, but has a negligible impact on yield (TAMU, 2007).

1.8 IRRIGAITON EFFECT ON COTTON GROWTH PARAMETERS

Irrigation scheduling and timing are dependent on location, time, and weather. Other factors such as variety selection can play a vital role in dictating when irrigation events should occur (Collins and Hake, 2015). Insufficient watering in cotton will cause the cotton to begin to cut out early and can have negative impacts on yield and fiber quality (Booker et al., 2005). Proper irrigation can increase yields by more than 350 kg ha^{-1}, but over-irrigation can lead to excess growth and not have a significant impact on yield (DeTar, 2008; Bendarz et al., 2003). Overirrigating can cause cotton to grow excessively and become difficult to harvest (DeTar, 2008). Therefore, a balance must exist. In years with substantial amounts of rainfall, it is challenging to depict differences in irrigation treatments because the rain has supplied more than the ET replacement for all treatments (Booker et al., 2005). Proper irrigation can increase fiber length and fiber fineness. Insufficient irrigation can increase immature fibers produced and lower micronaire, however, excessive irrigation can lower fiber strength and increase micronaire that can affect lint value (Spooner et al., 1958; Ramey, 1986). These effects are observed under extreme cases and may not be detected in samples from large modules (Ramey, 1986).

When a cotton plant is introduced to stressors, energy is reallocated throughout the plant. The plant creates this energy from photosynthesis conducted in the leaves (source) and then transports the energy to other parts of the plants that cannot produce its own energy (sinks) (Krieg & Sung, 1986). The export depends on the location of the sink relative to the source and the growth stage of the plant (Krieg & Sung, 1986). When water stress occurs on the plant, the overall rate of photosynthesis decreases as leaf area reduces (Brown, 1968). As maturity progresses bolls become a major sink evident by the reduction in NAWF showing a reduction in vegetative growth and a focus on maturing bolls (Bhaskar & Oosterhuis, 2001). As the season progresses bracts become a major source for boll growth as that becomes the main sink in the late season (Brown, 1968). This can explain the shedding of squares, flowers, and bolls throughout the season because of the increased competition for water and nutrients as the plant develops (Guinn, 1982).

An inadequate supply of water is a major factor affecting the physiological development of cotton (Chaves et al., 2009). Drought stress in cotton significantly reduces potential yield throughout the world (Osakabe et al., 2014). Lack of water can inhibit complete plant growth in the early season and affect the retention of squares and young bolls that can potentially contribute to final yield (DeTar, 2008; Hsiao, 1976; Hearn, 1994). Drought stress becomes evident in plants when metabolic processes in the plant are interrupted, and overall turgor is decreased (Farooq et al., 2009). These processes can include photosynthesis, cell elongation, and nutrient transport (Loka et al., 2011). As stress continues to increase in the plant, no matter the source, assimilates continue to be directed to different sinks in the plant. Extended time without adequate water can exponentially increase the adverse effects of water deficit (Pilon, 2015). Drought tolerance has been bred into current commercial varieties from the indeterminate wild-type cotton which held characteristics of drought stress due to harsh climatic conditions of the native environments (Lee, 1984; Quisenberry et al., 1981). From emergence to boll fill, cotton is sensitive to water stress. Reproductive periods of the plant life cycle in many crops are sensitive to water deficits with the most sensitive stage being germination and seedling establishment

(Saini, 1997). Water stress during flowering and boll fill has negative effects in flower and boll retention and impacting lint yield (Loka et al., 2011).

Vertical and horizontal distribution is not only variety dependent but can be influenced based on irrigation differences (Pettigrew, 2004; Guinn and Mauney, 1984; Ritchie et al., 2009). Sufficient irrigation allows for vertical expansion of bolls on the plant in contrast, water stressed plants exhibit a lower onset of bolls (Pettigrew, 2004; Guinn and Mauney, 1984; Ritchie et al., 2009). Similarities can be seen with early or later maturity groups. Early season varieties are bred to produce fruiting sites early as they are limited by growing season length while later maturing varieties can put on more vertically distributed bolls with a greater tolerance to water stress due to the additional fruiting sites (Snowden et al., 2013b; Bednarz and Nichols, 2005). The onset of additional fruiting sites could show the lack of interplant competition or limit the continued horizonal development of flowering sites due to uneven plant density and its competition for resources such as water, sunlight, or nutrients (Maas, 1997).

Water is a crucial element for cell elongation throughout the plant. This will negatively affect root, stem, and leaf growth in times of water stress (Hsiao, 1976; Hearn 1994). Root growth takes precedence in times of water stress compared to shoot growth as roots explore the soil profile for additional resources (Pace et al., 1999). Older leaves were prone to dropping after water stress was alleviated and can decrease photosynthesis rates as the plant can find water (Loka et al., 2011). The restriction of stomatal activity as water stress occurs causes reduced photosynthesis as plants try to conserve water (Loka et al., 2011). Water is crucial for early flowering stages, peak flowering, and boll development although it is unclear if early flowering or peak flowering has the greatest effect on yield if water is limited (Constable and Hearn, 1981;

Cull et al., 1981; Turner et al., 1986; Pilon, 2015). Drought-stricken plants are met with decreased height, fewer nodes, and an increased taproot length (Pace et al., 1999).

Limited water supplied at early vegetative growth stages in cotton is less likely to negatively impact yield as cotton plants can compensate for stunted growth throughout the season (Zonta et al., 2017). Increased temperatures and lack of moisture have increased the number of aborted squares and young bolls in multiple studies (Reddy et al., 1991; DeTar, 2008). During squaring, water stress has a lower impact on yield as the plant has set more fruiting sites than it can support which allows for compensation as the season progresses (Baker & Acock, 1986). The least likely fruit to shed are bolls retained in the F_1 position followed by the F_2 and F_3 positions (Hake et al., 1992). A plant under limited stress is more likely to retain a boll after it has remained on the plant 10-14 days post-bloom (TAMU, 2007). The shedding of these reproductive structures is most detrimental to yield later in the season when the time for recovery is limited (Hake et al., 1992).

Pollination can be affected by elevated temperatures and dehydration of pollen spores because of inadequate water (Burke, 2004). A study from Gwathmey et al. (2011) found that inducing water stress at the beginning of anthesis led to an increase in the number of aborted flowers and that water deficits at the end of flowering reduced overall boll retention and continued reproductive growth. Whereas Guinn (1982) concluded these fruiting sites were less sensitive to shedding than young bolls, reducing potential yield.

Irrigation termination is a factor to be considered when trying to maintain fiber quality as bolls begin to fill (Porter et al., 2014). The application of irrigation after bolls crack can degrade lint quality because of the introduction of water directly into the open boll (Porter et al., 2014). Terminating irrigation too early can negatively affect yield to a maximization level while increasing irrigation cost and harming fiber quality with irrigation systems that subject water to open bolls (Silvertooth, 2006). Drought stress late into boll maturation will induce the early opening of bolls because of the increased rate of overall plant maturity (Spooner et al., 1958). It is also important to keep in mind that due to the short-seasoned environment there is no guarantee to develop late-bloomed flowers into bolls which require around 420-475 GDU(°C). This concept is essential to note when determining whether to continue irrigation and try to mature those fruiting sites or to protect previously set bolls and allow them to fully mature with sufficient resources (Raper & Gwathmey, 2015). Based on 20-year historical weather data the average last effective bloom date for the Oklahoma Panhandle is August 3rd. The Texas Panhandles' last effective date is August 15th (Bell et al., 2022). The last effective bloom dates for North Mississippi is August 18th and August 21st in south Mississippi (Dodds, 2018). These dates in mid-west Texas can be as late as August 28th (TAMU, 2007).

Once there are four or fewer mainstem nodes from the first position cracked boll (NUCB) to the uppermost harvestable boll (NUHB) consideration for insecticide and irrigation application should be terminated and this NUCB to NUHB measurement will determine the timing for defoliation to occur (Gwathmey et al., 2011). It is recommended for the crop to meet two of the maturity indicators which can include the NUCB method, NAWF method, or 60 percent open bolls across the entire field (Raper & Gwathmey, 2015).

Overall, there is extensively more research directed to the effects of water deficit in vegetative stages of cotton growth and more information needed in the reproductive stages of plant development as this is the main determinant of yield (Pilon, 2015). As the plant continues to mature bolls there is a smaller chance of water limitations harming the already set and developed bolls due to the small to null energy requirements demanded to retain that fully formed boll on the plant (Zonta et al., 2017).

Cotton management throughout the season can help maximize yield in terms of resources available and achieve ideal fiber quality as the plant develops (Reeves et al., 2012). Fiber quality parameters are combined to estimate a loan price of cotton based on the overall quality of the sample (Cotton Inc, 2017). Cotton Incorporated (Cary, NC) has set a group of standards for fiber quality based on their use in textiles and maintains highly accurate standards to calibrate high volume instruments (HVI) results. The parameters of importance are micronaire, fiber length, fiber strength, and uniformity of the sample and these values through HVI are the only official classification of cotton fiber (Cotton Inc, 2018). Fiber color grade is also of interest in terms of the dye-ability products produced from lint. Irrigation trials in Georgia saw negative effects of prolong contact with irrigation water from overhead systems on fiber color grade with no effect on any other quality parameters (Porter et al., 2014). Length is highly influenced by variety, drought stress, excess temperatures, insects, and nutrient deficit stress (Bauer et al., 2009; Ramey, 1986). It is calculated by the upper half mean of sample length. Greater numbers are ideal in fiber length as this impacts the strength, evenness and efficiency of the yarn spinning process (Cotton Inc, 2018). Uniformity relates to how uniform the length of the entire sample is and the variation between sample lengths. Uniformity is presented in a percentage and the higher the number the higher the degree of uniformity (Cotton Inc, 2018). Fiber strength is genetically dependent, can be impacted by the environment, and management can impact strength (Saleem et al., 2010).

The greater strength contributes to the yarn quality and how it holds up with usage as a textile. Micronaire is a measurement of how fine and mature the fibers are. The fibers can be too coarse or too fine, negatively affecting micronaire. Micronaire is the product of fiber fineness and fiber maturity but cannot be used to gauge these characteristics alone (Heap, 2000). Reeves et al., (2012) conducted SSD irrigation trials on the High Plains and found higher micronaire values with early irrigation termination. Multiple studies have concluded that increasing irrigation rates can harm micronaire values (Feng et al., 2014; Booker et al., 2006; Silvertooth et al., 2006; Pettigrew, 2004). While others have seen no significant differences in irrigation amount and micronaire values (Dağdelen et al., 2009; Silvertooth et al., 2006; Pettigrew, 2004). Discounts are given to cotton with a micronaire <3.4 or >5.0. The Base range is from 3.5-3.6 and 4.3 to 4.9 with premiums given at 3.7-4.2. Micronaire is highly dependent on environmental factors and are essential when it comes to textile processing (Cotton Inc, 2018).

1.9 SHORT SEASONED ENVIRONENT

Cotton production in the High Plains region has gained renewed interest in recent years as producers look to it as a crop with a lower water need as compared to corn. However, the short-season, high evaporation rates and low seasonal rainfall makes cotton a difficult crop to grow in the High Plains (Howell et al., 2004). With the development of short-seasoned varieties the feasibility of growing cotton in outside the southeastern United States or the "Cotton Belt," where cotton was the main cash crop from the 18th to the 20th century, has increased (Esparza et al., 2007). Cotton requires about 1444(°C) heat units, but recent studies have indicated a potential to decrease the heat units by one third and still produce cost effective cotton growth in short-seasoned environments like the Oklahoma and Texas Panhandle (Waddle, 1984; Howell et al., 2004). Wrona et al., (1996) found a fully mature cotton boll and four bolls with 85% maturity needed 1000(°C) heat units for formation. With this knowledge, Esparza summarized 40 years of historical climate data to gauge the relative heat units accumulated in the High Plains region. Of the 131 counties in the study 110 met the minimum 1000(°C) total heat unit to reach 1000 kg ha^{-1} of cotton production (Esparza et al., 2007; Gwathmey et al., 2011). This area does fall below the typical range for heat unit accumulation, but development of short-seasoned varieties has allowed producers in the Oklahoma and Texas Panhandle to grow cotton.

The growth of cotton in this region is possible, with a potential impact on yields and fiber quality due to below optimal heat unit accumulation (Morrow & Krieg, 1990). It is important to prevent water and nutrient stress in this short-seasoned environment to prevent delays in maturity (Morrow & Krieg, 1990). Early planting has been suggested for this region, however, it increases the risk of a late spring frost but when successful allows fibers to fully mature. In contrast planting late allows for a higher stand establishment but increases the risk of termination by an early fall frost without proper fiber maturity (Johnson et al., 2002; Howell et al., 2004). The development of short seasoned varieties has shown promising results of increased yield and fiber quality in this short season environment (Johnson et al., 2002). Early maturing varieties can help to reduce the risk of pests in this area by avoiding the first generation of boll weevils (*Anthonomus grandis*) and avoiding the typical life cycle of other pests that can have an impact on cotton yield (Heilman et al., 1979). A key factor when growing cotton in a degree day limited environment is to consider the relative maturity of the variety selected.

Growing long-term, fully irrigated cotton in this area is not feasible. The introduction of short-seasoned varieties will allow for sufficient heat unit accumulation 3 of 4 years in the counties in the Oklahoma Panhandle with a confidence level of 75% (Esparza et al., 2007). Although these changes to a unique crop will take adjustment as it is important to understand the basics of cotton physiology and its response to irrigation in order to produce a successful crop (Ritchie et al., 2007). Information collected in 2018 surveyed the reason behind irrigation events.

These options included crop condition, soil feel, a personally created schedule, a government or water supplier dictated schedule, soil or plant moisture sensors, when neighbors do, ET reports, or using computer-based models. Out of 1,835 farms reporting, and producers being able to select more than one method of initiating irrigation the results were as follows. The largest majority indicated irrigation based on crop condition (84%), followed by soil feel (36%), personally created schedule (10%), government or water supplier dictated (9%), soil or plant moisture sensors (6%), when neighbors do (4%), ET reports (3%), computer-based models (<1%) (USDA NASS, 2017). Many of these decisions are not factually or reasonably based and showing the economic as well as conservation benefit from irrigating to replace ET will begin to create an information driven direction of effective and efficient irrigation. Research tied to effective management strategies for irrigation scheduling, timely growth regulator application, and sufficient maturity of the early-season varieties will allow producers to be successful in growing this crop.

Cotton, while having the potential to save water in the Ogallala Aquifer region can cause issues without proper management. Withholding water during early growth stages can decrease the initial cell elongation which can limit the growth of roots and leaves that are necessary to set the crop up for a successful season (Loka et al., 2011). Water deficits around flowering and the establishment of young bolls can lead to unsuccessful pollination and abscission of young bolls that have the potential to alter yield (Gwathmey et al., 2011; Mateos et al., 1991). There is a fine balance between over irrigation leading to excess growth and under irrigation that can cause a detriment to yield (DeTar, 2008; Bendarz et al., 2003).

1.10 RESEARCH OUTLOOK

Producers in the Oklahoma Panhandle will continue to face an arid, short season environment, and issues tied to the decline of the Ogallala Aquifer. There is a chance of reducing aquifer withdrawals by creating a more efficient irrigation schedule for cotton and a transition to crops with a higher water use efficiency and a lower crop water demand (Colaizzi et al., 2009; Basso et al., 2013). The main objective of this project is to investigate various management strategies in relation to irrigation use, variety selection, plant population and plant growth regulator rates in degree day limited cotton. In hopes of developing management strategies that maximizing profits with efficient irrigation that produces the highest quality cotton. These factors work together to define the best practice as a single growing unit. Throughout the growing season, the response to irrigation will be noted between different growth stages. This will help to understand the response of cotton to different irrigation scheduling methods in the semi-arid environment of the Oklahoma Panhandle.

CHAPTER II

OPTIMIZING MANAGEMENT OF IRRIGATED COTTON IN A DEGREE DAY LIMITED ENVIRONEMNT

2.1 INTRODUCTION

The Ogallala Aquifer provides water for nearly one-fifth of the nation's corn, cotton, and wheat (Guru & Horne, 2001). Water levels from 1950 to 2013 decreased by an average of 4.82 meters a year (McGuire, 2017). This decline is of concern because the Ogallala Aquifer has a slow recharge rate. The widespread adaptation of more efficient use of the dwindling resources of the Ogallala Aquifer will secure the future of crop production in the high plains region.

Corn has dominated the region for years, but the crop's water requirements have made it difficult to grow. Compared to corn, cotton requires half the water needed to grow cotton at maximum yields (Colaizzi et al., 2009). This has influenced the renewed interest of cotton (Goss*ypium hirsutum L.*) into the area due to the decreasing water levels of the Ogallala Aquifer (Guru & Horne, 2001). Before 2012 cotton had not been reported to the USDA (United States Department of Agriculture) National Agricultural Statistics Service (NASS) in the Oklahoma Panhandle, to an extend that could be shared without singling out individual farms. In 2012, 7,378 bales were produced which came shortly after McGuires (2017) report on the decline in the Ogallala Aquifer (USDA NASS, 2017).

The High Plains is divided into three regions, the northern, central, and southern sub-regions. Together it is defined by the 8 states that overly the Ogallala Aquifer (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming) (USGS, 2021). The central high plains region occupies the Texas and Oklahoma panhandles, western Kansas, and eastern Colorado. This division of the high plains' region is also characterized by the limited number of growing degree units that are accumulated throughout the growing season which limits the crops that have been grown in this area. With respect to the limited growing degree units (GDU), research in the central high plains has been conducted to verify the ability to produce cotton in this region despite the GDU limitations (Esparza et al, 2007). Efficient irrigation of cotton in the central high plains has not been fully studied.

2.2 OBJECTIVE

The objective of this project is to investigate various management strategies in relation to irrigation use, crop variety selection, plant population, and plant growth regulator rates on degree-day limited cotton by maximizing profits with efficient irrigation that produces the highest quality cotton.

2.3 MATERIALS AND METHODS

In 2021, the study was conducted at the McCaull Research and Demonstration Farm near Eva, Oklahoma on a Gruver clay loam (Fine, mixed, superactive, mesic Aridic Paleustolls). Cotton was planted 6 May 2021 into wheat stubble for seedling protection (Table 3). The field was rotated with corn, wheat, and cotton. Anhydrous ammonia fertilizer was applied at 135 kg ha^{-1} across the study area before planting with a strip tillage implement. Pesticides were applied in accordance with Oklahoma State extension recommendations. Daily heat unit (HU) accumulation is calculated with the following equation:

$$\frac{Daily\ Maximum\ Air\ Temperature\ (℃) + Daily\ Minimum\ Air\ Temperature(℃)}{2} - Crop\ Base\ Value(℃)$$

These values are added together to determine the total HU accumulation for the season.

This experiment consisted of two separate experiments at the same location simultaneously, with minor differences in the experimental procedures. The experiments will be termed the fixed irrigation treatments and the TAPS management systems and will be discussed separately in this document. Both experiments used the same general plot design with consistent data collection collected across both experiments. While their design was to investigate the effects of irrigation on cotton production, the fixed irrigation treatments looked at the effects of irrigation as a percent replacement of water lost through evapotranspiration (ET) while the TAPS experiment evaluated cotton growth and development from a whole systems approach with farmer input on their management system including variety selection, planting population, growth regulator selection, and the amount of irrigation applied approximately every 5 days. The data collected from both experiments were analyzed using the Glimmix procedure in SAS 9.4 with denominator degrees of freedom detailed by Kenward Roger (1997) at an alpha level of 0.05 (SAS, 2013). Means were separated using Fisher's Protected LSD. Fixed irrigation treatments were analyzed independently based on variety. TAPS management was compared against the non-irrigated check and full irrigation treatments to segregate the management decision differences as a cohesive unit. In all analyses rep was the random variable. Overall, the two experiments were very similar in design, but the differences in irrigation or management allowed us to explore the independent effect of irrigation on cotton in the fixed irrigation treatments as well as the complete management decisions impacts on the TAPS treatments.

Fixed Treatments. The treatment structure consisted of a block design with blocks completely randomized and split based on irrigation treatment. The length of each plot varied between 39 to 58 m due to curvature of the pivot system. The variety was the whole plot factor with a sub plot factor of irrigation rate. The blocks were 24 rows wide with 8 rows planted to Phytogen 350 (PHY350) and 8 rows planted to Phytogen 205 (PHY205) at a planting population found in Table 1. In each plot, 4 guard rows were on either side to account for irrigation overspray. Irrigation was delivered with a variable rate irrigation (VRI) capable overhead sprinkler irrigation system and remotely programed irrigation rates based on irrigation treatments displayed in Table 2. Irrigation treatments for the fixed treatments were based on replacement of water lost from ET and adjusted for rainfall received, calculated by the Mesonet station located near the experimental sites. Full irrigation treatment is meant to supply 90% of the estimated ET while accounting for rainfall calculated and measured at the Eva Mesonet location. This treatment is referred to as the full irrigation treatment. The remaining treatments were set to supply 70, 40, or 0 percent of full irrigation during squaring and bloom stages as described in Table 2. Limitations included the amount of irrigation supplied due to limited pumping capacities as well as timing of irrigation application due to other experiments in the same field as well as equipment complications. The maximum amount of water that could be applied was 25 mm in a 5-day period. Table 2 breaks down the percentage of total irrigation supplied at each respective growth stage for each treatment. Irrigation events began with pre-water applications to promote even germination, to fill the soil profile for the times in the season when irrigation could not fully replace ET due to the pumping capacity limitations, and for herbicide incorporation. On 26 May and 29 May 2021, 19 and 16 mm of irrigation was applied to all plots for herbicide incorporation. The total pre-water applied to all plots was 35 mm (Table 3). The first irrigation treatment based on ET was initiated on June 1st. Treatment 1 served as the control with no irrigation applied except for that necessary to ensure seedling emergence and herbicide activation (35 mm). Growth regulator applications in the form of mepiquat chloride at 1,420 g ai ha^{-1}, 2,839 g ai ha^{-1}, 2,366 g ai ha^{-1}, or 3,312 g ai ha^{-1} (PIX, BASF, Florham Park, New Jersey) were applied 62, 82, 90, and 95 DAP at rates are displayed in Table 1. The treatments consisted of a constant 90% replacement of ET treatment (full irrigation treatment), a constant 70% of full irrigation and a constant 40% of Full irrigation. At the onset of bloom irrigation rates were changed such that treatments receiving Full irrigation prior to bloom were set to receive Full, 70, 40 or 0% of Full irrigation, constant 70% treatments then received Full, 70, 40 or 0% of Full irrigation and so forth. The last treatments were given the same irrigation at the beginning of the season as the check and then treated with a 70% of Full irrigation through squaring and maintained or decreased to 40% thereafter (Table 2). The shift to a bloom application of irrigation was based on field observations of the crop. This change in irrigation rate at bloom was initiated 85 DAP on July 30th. Irrigation was terminated on September 6th (Table 3).

TAPS Management. The experimental design was consistent with the fixed irrigation treatments. The 24 rows blocks were planted with 8 rows being the standard variety PHY350 planted at 111,200 seeds ha^{-1} and 8 rows planted to participant chosen variety and population found in Table 1. 4 guard rows were on either side of each variety as in the fixed treatments. PHY350 was chosen as a standard variety as it was a longer maturing variety that can be grown in this environment only under irrigation. Irrigation was applied by VRI overhead sprinkler irrigation based on TAPS participant suggestions which were remotely programed. The total irrigation rates are displayed in Table 2. The same limitations existed in terms of pumping capacity and other experiments in the field. Soil moisture sensors were installed in one replication of each participant plot which was accessible by each grower to evaluate the soil moisture before making an irrigation application. The percentage of total irrigation can be found in Table 2 for each respective growth stage. Pre-water applications were consistent with the fixed irrigation treatments with a total application of 35 mm to all plots (Table 3). The first opportunity for irrigation was on June 1st with subsequent opportunities approximately every 5 days. Growth regulator applications in the form of Pix applied 62, 82, 90, and 95 DAP at rates displayed in Table 1. Irrigation was terminated on September 6th (Table 3).

In both experiments data collection proceeded as follows. Stand counts collected on June 3rd (28 DAP), targeted 10-14 days after emergence. In-season plant height and nodes above white flower (NAWF) were collected in two-week intervals once 50-60% of the field had reached white flower. The initial measurement was taken 81 DAP and continued in a two-week interval up to physiological cutout <5 NAWF, two weeks after first bloom (98 DAP), four weeks after first bloom (112 DAP) and 6 weeks after first bloom (126 DAP) (Table 4 & 5). These measurements are meant to aid in tracking plant development and understanding what fruiting sites will be able to successfully contribute to yield. End of season measurements were taken 145 DAP and included final plant height, total nodes, node of first fruiting branch (NFFB), node of uppermost cracked boll (NUCB), node of uppermost harvestable boll (NUHB), open bolls, and total bolls in a 3-meter row. Boll counts were conducted on harvestable bolls in which bolls were considered harvestable at about 25 mm in diameter and open if fiber from one lock was accessible to the harvester (Table 6 & 7). These measurements were taken before the application of harvest aids and show the natural maturity of these varieties in terms of supplemental irrigation applied. This measurement was set to be taken when the field had reached 50-60% open bolls, but due to the threat of season terminating weather conditions these measurements were taken at about 30% open bolls in 2021. Two rows were harvested with a modified John Deere 484 cotton stripper (Deere & Company, Moline, IL) equipped with a bagging attachment for plot harvest in the 8-row plot and total plot weight was calculated into seed cotton (kg ha^{-1}) (Table 8). A subsample was pulled out of harvested cotton for lint turnout calculations and for further processing for lint quality (Table 9). Lint turnout was calculated by the amount of cleaned, ginned lint per unit of seed cotton yielded after the cotton harvested from the field was field cleaned (Table 8). Samples were then run through a stationary field cleaner, and a 20 saw Eagle gin (Continental Gin Company, Birmingham, Alabama) ginned on the campus of Oklahoma State University. Ginned sampled were sent to the Fiber and Biopolymer Research Institute on the campus of Texas Tech University to be tested using High Volume Instrument (HVI) testing which included the analysis for fiber strength, fiber length, uniformity percentage, and micronaire. Other factors included leaf and color grade these parameters will not be mentioned as the basis of equipment is not ideal for them. Leaf and color grades were set to a standard level of 4 and 41 respectively and all loan values were based off a base value of $1.15 per kilogram from the USDA Commodity Credit Corporation (2021). Some of these quality factors are genotypically controlled and are displayed in varietal information including fiber length and strength (Table 9).

2.4 FIXED TREATMENT RESULTS

Climate and Irrigation. Heat unit accumulation in 2021 trended similarly to the past 5-year heat unit accumulation retrieved from the Oklahoma Mesonet (Appendix 1.1). The beginning of the season had less HU accumulation about 25 DAP until 50 DAP where accumulation briefly matched the 5-year average from 2016-2020. After that point, it remained below the average HU accumulation until 130 DAP where the 2021 season accumulated about the same number of HU as previous years. The total accumulated heat units (HU) in the 2021 growing season, from planting to harvest, were 1131 $GDD_{15.6}$ (Table 3). Rainfall accumulation for 2021 was about 20mm higher than the 5-year average for the Eva Mesonet Station. 24% of the rainfall from planting to harvest fell 25 DAP which provided water to add to pre-water applications. Rainfall was heavily weighted towards the beginning of the season whereas the 5-year average has a relatively even distribution throughout the season (Appendix 1.2). The Full irrigation treatment received 313 mm of irrigation and 337 mm of in season rainfall which was equivalent to 102% of seasonal ET, from planting to irrigation termination, as estimated by the Mesonet Irrigation planner. The check received a total of 35 mm of supplemental irrigation and 337 mm of in season rainfall which comprised approximately 58% of seasonal ET replacement (Table 2). After irrigation was terminated there was an additional 214 mm of estimated ET removed from the system which was 33% of ET from planting to irrigation termination.

Plant Growth and Development. Stand counts showed no significant difference across treatments within PHY205 or PHY350 respectively averaging 86,281 plants ha^{-1} and 79,605 plants ha^{-1} (Table 4). The average germination percentage was 80% in PHY205 and 72% in PHY 350. The earlier variety, PHY205, had differences in plant heights at first bloom but showed no difference after 6 weeks of flowering (Table 4). Within this variety plant height at first bloom showed a significant difference between the Fully irrigated treatment and the check treatment. In fact, all treatments that applied Full irrigation during square were not significantly different than the Fully irrigated treatment at first bloom. The treatments receiving 40% of Full irrigation during squaring did not significantly differ than the check. Those receiving 70% of Full irrigation during square were not significantly different than the Full irrigation treatment at first bloom excluding the treatment with 70% at squaring followed by 40% post flowering which was more similar to the check treatment. The differences in plant height declined throughout the remainder of the season with no significant differences between the check and Fully irrigated treatments observed at 2, 4 and 6 weeks after first bloom. However, at end of season, significant differences were observed with those treatments receiving Full irrigation during squaring not being significantly different than the Full irrigation throughout the season. None of the treatments receiving 40% of Full irrigation during square were significantly taller than the non-irrigated check. The treatment receiving 40%

of Full irrigation during square followed by Full irrigation during bloom remained significantly shorter than the Full irrigation treatment. This suggests that the vegetative growth as indicated by plant height is controlled by early season irrigation and increasing late season irrigation will not compensate for this effect. Four weeks after first bloom the treatment receiving 40% during square and Full irrigation during bloom was significantly shorter than the check as well as the other treatments with a 40% replacement during squaring.

PHY350, the later maturing variety did not present significant difference in plant height until 2 weeks after first bloom measurements (Table 4). Significant plant height differences were observed throughout the remainder of the growing season. Between 2 weeks after first bloom and final plant height measurements the check treatment remained significantly shorter than the Full irrigation treatment. During these same observations, the treatments supplying 70% of Full irrigation did not significantly differ from the Fully irrigated treatment. Any treatment that supplied 40% of Full irrigation at squaring remained significantly shorter than the Fully irrigated treatment between 2 weeks after first bloom and harvest. Any treatment receiving 40% at squaring was not significantly taller than the check. Similarly, any treatment receiving 70% of Full irrigation during square was not significantly different than the Fully irrigated treatment. Generally, there were no differences between the treatments receiving 40% and 70% of Full irrigation during squaring except at harvest when the constant 40% treatment and the treatment receiving 40% during square followed by 70% during bloom became significantly shorter than the treatment receiving 70% of Full irrigation throughout the season. In fact, those that received 40% during square followed by Full irrigation during bloom never recovered to a height similar to the Full. At final plant height measurements, the 40% of Full irrigation during squaring treatments as well as the low pre-water with 70% at squaring and bloom treatment were not different than the check with all other treatments being not different than the Full replacement treatment. As in PHY205, the vegetative growth seemed to be controlled by early season irrigation and that increasing late season irrigation did not compensate for reduced growth sufficiently to increase plant heights close to the Fully irrigated treatments.

NAWF decreased as the plant approached physiological cutout when NAWF is <5. Both varieties met this cutout threshold around 3 weeks after first bloom (Table 5). Neither variety presented any differences at initial, 2-, or 4-weeks after first bloom. The 6-week after bloom measurement of NAWF was not collected due to the lack of flowers at this point in the plant's life cycle. In PHY205, the initial NAWF measurement averaged 7 NAWF. This value continued to decrease over time where averages were 4 and 2 at two- and four-weeks after first bloom, respectively. The trend continued in PHY350 with no differences between all treatments at any time point. Averages for this variety were 8, 5, and 3 NAWF at initial, two-, and four-weeks post bloom.

End of Season Maturity Measurements. NFFB in PHY205 showed no differences between irrigation treatments with an average value of 5.6 (Table 6). In PHY350 there were no differences detected between the Fully irrigated and check treatments, however, the treatment receiving 40% of Full irrigation during square followed by 70% during bloom had the lowest NFFB which was significantly lower than all treatments except for the treatment receiving 70% of Full throughout the season and the treatment receiving 70% during square and 40% during bloom.

NUCB showed a significant difference between the check and Fully irrigated treatments in PHY205 with the Fully irrigated treatment having lower NUCB (Table 6). Furthermore, the treatment receiving Full irrigation during square and 70% of Full during bloom, which received the second highest amount of total irrigation had NUCB that was not significantly different than the Fully irrigated treatment. All other treatments had NUCB that was significantly higher than the Fully irrigated treatment. The check in PHY350 had a significantly higher cracked boll position (NUCB) than the Full irrigation treatment. All other treatments except that receiving 70% of Full irrigation throughout the season were intermediate between the Full irrigation and check treatments. The treatment receiving 70% of Full irrigation throughout the season had an NUCB that was lower than the Fully irrigated treatment but not significantly different.

PHY205 had no differences among treatments in the position of upper most harvestable boll and total nodes on the plant with NUHB being 13.3 and total nodes being 17.1 (Table 6). PHY350 presented significant differences in the NUHB with the treatments receiving Full irrigation, Full irrigation during squaring followed by 40% of Full during flower or 70% during flower, and the treatment receiving low pre water with 70% of Full during square followed by 40% during bloom having a significantly higher harvestable boll than the check treatment (Table 6).

The total nodes on PHY350 showed no significant differences between the Full irrigation and check treatment despite the check having the third lowest number of nodes (Table 6). However, significant differences in other treatments were detected. The treatments with significantly more nodes than the check were the treatments receiving Full irrigation during square followed by either 40 or 70% of Full irrigation during bloom and the treatment receiving low pre water followed by 70% of Full during square and 40% during bloom, however these treatments were not different that the Full irrigation treatment. These treatments that appear to maximize total nodes also had significantly more nodes than the treatments receiving Full irrigation during bloom and no irrigation during bloom, the treatment receiving 40% of Full during square and 70% during bloom, and the treatment receiving low pre water followed by 70% of Full for the remainder of the year.

The number of open bolls and the percentage of open bolls in PHY205 displayed no significant differences with an average of 44 bolls open across treatments equating to about 35% open bolls (Table 7). The Fully irrigated treatment had a greater number of total bolls in a 3-meter section than the check treatment. Stopping irrigation after squaring decreased the number of bolls to be no different than the check while having less bolls than the Full irrigation treatment. PHY350 presented differences in open bolls with the check having more open bolls than the Full irrigation treatment. The reduction of irrigation to 0% of Full after squaring resulted in more open bolls than the Full irrigation treatment. However, there were no significant differences in total bolls across treatments with about 121 bolls per 3-meter section. The % open bolls in the PHY350 showed similar trends to the open boll values with % open bolls generally increasing with decreasing irrigation. Interestingly, shifting to zero irrigation during bloom increased percent open bolls to values equivalent to the check, suggesting that maturity could be hastened with late season removal of irrigation.

Yield. Cotton harvested was measured and calculated on a basis of seed cotton (kg ha^{-1}), lint yield (kg ha^{-1}), and seed yield (kg ha^{-1}), they are related due to the fact that percent turnout of lint showed no differences among treatments (Table 8). This is true for PHY205 and PHY350 where lint turnout averaged 39% within each variety respectively. For PHY205, the treatments with the highest seed cotton, lint yield and seed yield were the two treatments with the highest amount of irrigation, Full irrigation and Full irrigation at square followed by 70% of Full at bloom which were not statistically different. The 40% at squaring followed by full or 70% at bloom treatments as well as the constant 70% treatment also yielded more seed cotton, lint, and seed than the check. All treatments with 40% or 0% irrigation during bloom had values significantly lower than the Fully irrigated treatment and not being different than the check except the low pre-water, 70% at squaring and 40% at bloom treatment which remained intermediate. The low pre-water, 70% at squaring and 70% at bloom treatment was different than the check and Full irrigation treatment in terms of lint yield and not being different than the check in seed cotton or seed yield.

In PHY350 the seed cotton, lint and seed yield all exhibited similar trends among treatments, again because there were no treatment effects on lint turnout (Table 8). The constant 40% treatment and the treatments with no irrigation after squaring resulted in values lower than the Fully irrigated treatment while not different than the check. Except for the constant 40% treatment, all treatments receiving irrigation during bloom produced yields that were statistically similar to the Fully irrigated treatment.

Fiber Quality. No differences were shown in fiber strength between irrigation treatments within each variety (Table 9). Fiber strength for PHY205 averaged 30.5 g tex^{-1} and 28.9 g tex^{-1} for PHY350. The same was true with fiber length with average values being 27.0 mm and 28.3 mm for PHY205 and PHY350 respectively. There were also no significant differences in micronaire values resulting from irrigation treatments within each variety. PHY205 had an average micronaire value of 4.16 and PHY350's average value is 3.93.

The fiber quality parameter that showed significant differences was the percent uniformity of fiber length (Table 9). Treatments receiving 70% of Full irrigation during bloom did not show significant differences between the Fully irrigated treatment in PHY205. In PHY205 all treatments with a reduction of irrigation during bloom resulted in uniformity values no different than the check treatment except the Full irrigation during squaring followed by 70% of Full during bloom treatment. The treatment in PHY 205 with 70% of Full irrigation at squaring and 40% after resulted in a value that was no different than the check or Full irrigation treatments. In PHY350 the check and Full replacement treatments uniformity was not different. In fact, no treatments were statistically different than the Full replacement treatment within this parameter. Treatments in PHY350 with Full irrigation at squaring followed by 40 or 70% of Full during bloom had a higher percent uniformity than the check. This is also true for the two treatments receiving low pre water followed by 70% during square and 40% or 70% of Full irrigation during bloom.

Loan value, as estimated by Cotton Incorporated's Upland Loan Calculator for 2021, shows no significant differences within individual varieties (Table 9). The average loan values were \$1.14 kg^{-1} and \$1.15 kg^{-1} for PHY205 and PHY350, respectively. Lint value, the product of lint yield and loan value, highly correlates to lint yield with an ^{2} value of 0.9889 for PHY205 and 0.9645 for PHY350 (linear regression not shown). Therefore, lint value will be discussed in further detail.

The lint value response to irrigation treatments were similar for both varieties (Table 9). The lint value increased with increasing irrigation rate for the constant irrigation treatments. In PHY205 the treatments receiving Full or 70% of Full during square followed by a decrease in irrigation to 40% or 0% of Full irrigation during bloom resulted in no difference as compared to the check. However, the treatment receiving low pre-water followed by 70% of Full irrigation during square and 40% of Full irrigation during bloom produced a lint value that was significantly greater than the check while still being lower than the Full irrigation treatment. Both low pre-water treatments were more similar to the constant 70% of Full irrigation treatment, despite having supplied less total irrigation. The treatments with 40% of Full irrigation at squaring and an increase to 70% of Full irrigation at bloom compensated to be no different than the Full irrigation treatment while the treatment receiving 40% of Full irrigation during squaring followed by Full irrigation during bloom produced intermediate lint value that was significantly lower than the Fully irrigated treatment but higher that the constant 40% of Full irrigation treatment.

In PHY350, treatments without irrigation after squaring resulted in no difference in lint value from the check treatment regardless of early season irrigation amounts (Table 9). The treatments receiving 40% of Full irrigation during square followed by 70% of Full or Full irrigation produced lint values equivalent to the Fully irrigated treatment, while the constant 40% of Full irrigation treatment separated itself from the Fully irrigated treatment and was no different than the check. The Fully irrigated treatments at squaring with a decrease to 40 or 70% of Full irrigation at bloom also resulted in no differences from the Full irrigation treatment. All treatments except the check and the treatment receiving Full irrigation during square followed by 0% of Full irrigation during bloom showed no differences in lint value compared to the Fully irrigated treatment. The value of lint seemed to be dictated by total irrigation in PHY205 as it was generally more responsive to irrigation differences ($r^2 = 0.4067$) whereas PHY350 had less of a response to irrigation differences ($r^2 = 0.2355$) (Appendix 3).

PHY205 was more responsive to irrigation and therefore showed significant differences in irrigation water use efficiency (Table 10). Within the constant irrigation treatments, water use efficiency (WUE) increased with increase irrigation rate, suggesting that the Full irrigation rate still limiting yield in this production year. Irrigation WUE was maximized in the treatment receiving 40% of Full irrigation prior to bloom followed by 70% of irrigation during bloom and the treatment receiving low pre water followed by 70% of Full during square and 40% during bloom due to optimum yields achieved by these treatments. In contrast, terminating irrigation during bloom had a catastrophic impact on irrigation WUE by reducing yields to below those achieved by the check while consuming irrigation water. Those where Full irrigation or 70% of Full irrigation was applied prior to bloom and were followed by 40% of Full irrigation during bloom resulted in intermediate irrigation WUE values.

2.5 TAPS MANAGMENT RESULTS

Participant's management characteristics can be found in Table 1. In this discussion of results, as was done in prior discussion of the fixed treatments, will be split by the split block design of the treatment structure. Specifically, the "participant management systems" that include TAPS 2-7 will be compared to the check and Fully irrigated data from that half of the treatment structure (Table 1). The "standard management systems" will have received the same irrigation treatments but were planted to PHY350 and received the standard pix rate. Characteristics will be outlined as needed. Pix rates used by participants ranged from 1,420 – 3,312 g ai ha^{-1} (Table 1). Stand counts showed no significant differences in percent emergence, regardless of planting decisions, where all TAPS participant plots averaged 91,500 seeds ha^{-1} with an average germination of 77% (Table 11).

Among the participant management systems there were significant differences in plant height at first bloom, 2, and 4 weeks after first bloom as well as final plant height (Table 11). The check treatment had shorter plants than all treatments at first bloom. The check was significantly shorter than the remaining treatments at first bloom, but these differences declined over time, such that the Fully irrigated was the same height at the check at 2 and 4 weeks after first bloom. Differences among varieties can be observed at 4 weeks after first bloom where TAPS 3 and 4 are significantly taller than the check, suggesting that PHY332 generates taller plants than the PHY205 used in the Fully irrigated treatments.

Within the standard treatments, there were only differences in plant height at 6 weeks after first bloom (Table 11). Here, the check was significantly shorter than all management treatments except for TAPS 2 which received the lowest irrigation rate among remaining treatments.

No differences were detected in nodes above white flower (NAWF) at the FB, 2, and 4 weeks after first bloom with the average across the treatments being 7, 5, and 3 NAWF, respectively, with no white flowers at the 6-week interval (Table 12).

The average node of first fruiting branch (NFFB) for the TAPS participants was 6 with no significant treatment effects (Table 13). Node of upper cracked boll (NUBC) showed significant differences between the check and Full irrigation treatment with the check, TAPS 2 and TAPS 5 having a higher NUCB than the Fully irrigated treatment. TAPS 3 and 4 had the lowest NUCB which was less than the check treatment but not different than the Full irrigation treatment. The average node of upper harvestable boll (NUHB) for participant treatments was node 13.0 with no differences detected. Plants averaged about 17 total nodes within these treatments as well.

The standard treatments showed significant treatment effects for NFFB and NUCB (Table 13), where TAPS 2 showed the highest NFFB, which was significantly higher than the check as well as the Fully irrigated but not different than TAPS 4 and 5. All remaining treatments were statistically similar to the check treatment. These effects on PHY350 planted to all standard treatments are the result of differences in irrigation as all other management factors were the same for these treatments in contrast to the participant treatments which varied based on irrigation, variety, population, and pix application rates. The NUCB was suppressed by irrigation applied to the TAPS 6 and irrigation treatment when compared to the check treatment with all other treatments being similar to the check.

Prior to harvest, differences in boll counts were observed for the participant management treatments but no differences were observed for the standard treatments (Table 14). Among the participant treatments, the check and Full irrigation treatments as well as TAPS 2, 5, and 6 had statistically the same amount of open bolls in a 3-meter row with TAPS 3, 4 and 7 having significantly fewer open bolls.

The check had the least total bolls present but was only significantly lower than the fully irrigated treatment and TAPS 6 (Table 14). The Full treatment did not differ in total bolls from TAPS 2, 3, or 6 but all other treatments had a total boll number more similar to the check irrigation treatment. The percentage of open bolls has no differences between the Full and check with TAPS 3, 4 and 7, which were planted to PHY332 or PHY400 (Table 1), being statistically lower than the check treatment. The TAPS 2 and 5 treatments maximized the percent open bolls but did not result in a statistical difference between the Fully irrigated or check treatments, both of which were also planted to PHY205. No significant differences in open bolls, total bolls or percent open bolls were observed in the standard management subplots (Table 14).

The participant treatments also showed significant differences in seed cotton, lint, lint turnout, and seed yield (Table 15). Consistently, the Full irrigation treatment had a significantly higher yield than remaining management treatments within all three yield components, except lint turnout, which was intermediate for the Full irrigation treatment. The TAPS 7 treatment produced the lowest seed lint, lint yield and seed yield among the irrigated treatments and was not statistically different than the non-irrigated check, however it had the highest lint turnout percentage, which was statistically higher than both the check and Fully irrigated treatment. TAPS 6 had the lowest lint turnout but only significantly lower than TAPS 2, 5 and 7. Among the TAPS treatments 2-7, TAPS 6 generated a yield significantly higher than remaining TAPS treatments, with TAPS 5 providing an intermediate yield. The remaining TAPS treatments generated yields no different than the check treatment, disputing being irrigated.

The standard management treatments showed no significant differences in seed lint yield, lint yield, or seed yield. However, as was observed in the participant management treatments TAPS 6 had the lowest lint turnout despite generating the second highest yield among treatments. TAPS 3 and 7 maximized lint turnout at 40.4 and 40.9 % but these values were not significantly higher than the check treatment.

There were no statistical differences detected in lint quality values among the 8 participant management treatments (Table 16). The average fiber length was 27 mm with an 81% average length uniformity. Fiber strength averaged 30 g tex^{-1}. Micronaire values 4.05 with a maximum value of 4.38 and a minimum value of 3.59. These values were not enough to affect loan value estimated from Cotton Incorporated Upland Cotton Loan Calculator which averaged 1.14 \$ kg^{-1}. The differences detected in lint value for both varieties independently can therefore be explained by the lint yield with the participant management treatments having an R value of 0.983 and the standard management having a R value of 0.943 (Appendix 1.4). The Full irrigation treatment had a significantly higher lint value than any other treatment. The lint value of the check was not different than TAPS 2, 3, 4, and 7.

No significant differences in quality parameters, loan value, or lint value were observed among the standard management treatments in this analysis (Table 16).

Significant differences in water use efficiency were only detected in participant management treatments (Table 17). All treatments have a significantly lower WUE than the Full irrigation treatment except TAPS 6, this data suggests that cotton yield was limited by water availability in this study.

2.6 DISCUSSION

Fixed Treatments. PHY205 showed differences in plant height at first bloom, and at 2 and 4 weeks after first bloom as well as at the end of the season (Table 4). Those treatments receiving zero irrigation or 40% of Full irrigation during square were generally shorter than those receiving Full irrigation during square, and they did not regain height as a result of increasing irrigation rates during bloom. PHY350 showed a similar trend that irrigation at 40% or less prior to bloom stunted plant height and that increasing irrigation during bloom did not allow plant to rebound from this effect. This shows that suppressed plant growth as a result of limited irrigation prior to bloom cannot be compensated for with late season increases in irrigation. This is similar to prior research where limiting irrigation early caused the plant to pull resources from stored reserves in the soil in order to properly finish development (DeTar, 2008; Hsiao, 1976; Hearn, 1994). DeTar (2008) showed final plant heights relating to lint yield at an $r^2 > 0.80$ although this relationship was stronger with final plant height relating more to the time at which cutout occurred. The current study showed that final plant height was not related to lint yield (Table 8).

NAWF is indicative of the relative maturity of the variety more so than dictated by irrigation decisions. NAWF values in the current study were found to range between 8 to 10 nodes at the beginning and decrease at a rate based on the varieties maturity (Ritchie et al., 2007). PHY205 reached physiological cutout, NAWF > 5 nodes, prior to the second week of flowering whereas PHY350 reached this point around the second week of flowering (Table 5). There are no treatment differences to show NAWF or cutout timing being altered by irrigation amounts as this value should be similar within variety to ensure consistent maturity when looking at this on field scale basis. In contrast, other studies have shown insufficient irrigation to cause premature cutout that can decrease the number of fruiting sites able to contribute to yield (Booker et al., 2005).

Commonly vegetative branches are produced at nodes 1-5 on the plant with the first fruiting branch being induced from the axillary bud at node 6 with rare reversions back to vegetative branch growth while the plant does continue to grow vegetatively simultaneous with reproductive growth (Mauney, 1986; Ritchie et al., 2009). This was found in the PHY205, however, in the PHY350, the application of a constant 40% of Full irrigation treatment maximized the NFFB but if the 40% of Full at square was followed by an increase of irrigation to 70% of Full at bloom the NFFB was reduced significantly to 4.8 (Table 6). Therefore, this increase of irrigation at the beginning of bloom was enough to promote reproductive growth lower on the plant due to the increased resources received at that point. More investigation is needed to isolate this effect of irrigation on NFFB at the initiation of flowering. Sharma et al. (2015) collected periodic boll distribution data in order to determine irrigation effects on where various cultivars set bolls respective of different stress timings. Boll mapping or collecting data similar to these measurements could be beneficial in understanding fruit shedding patterns. Irrespective of irrigation, the NFFB developed on node 7.5 in Mississippi when multiple years and varieties were pooled (Pettigrew, 2004). Gaining a deeper understanding of cotton reproductive initiation can aid in promoting the activation of the first auxiliary bud, which can establish a fruiting branch at a lower position on the plant. This, in turn, can increase the potential for yield as more fruiting sites would be available in the critical F_1 position. As with plant height and NAWF parameters (Table 4 & 5), within each variety independently NUCB and NUHB values (Table 6) were dominated by the different maturity groups the two varieties were classified within. Lack of sufficient irrigation at the beginning of the season could have contributed to the differences detected in both varieties' NUHB separately. The lower water treatments early in the season could have resulted in the abscission of young flowers or bolls as resources were inadequate to carry a boll load higher on the plant. Bolls retained for 10 to 14 days are at lower nodes on the plant and are less likely to be shed as the energy required to keep them is minimal in comparison to other sources (Gwathmey et al., 2011; Mauney, 1986; TAMU, 2007). This agrees with prior research delineating water stressed plants having a heavier boll load lower on the plant and those with adequate irrigation expand the vertical extent of bolls on the plant (Pettigrew, 2004; Guinn and Mauney, 1984; Ritchie et al., 2009). Variety is also an influence on boll distribution with early seasoned varieties having a skewed accumulation of bolls at the bottom of the plant and later maturing having a better vertical distribution (Snowden et al., 2013b; Bednarz and Nichols, 2005). NUCB was able to detect the effect of irrigation on the variety's relative maturity with the deficit irrigated treatments undergoing natural maturity and dry down thus cracking bolls on the plant at a higher position as maturity occurs from the bottom first position boll up the plant and across sympodial branches (Spooner et al., 1958). Similarly, percentage of open bolls can also help to better understand the irrigation treatments that promoted faster maturity within PHY350 as no differences were detected in PHY205 (Table 7). The lack of differences detected in PHY205 can relate to the earliness in the variety overshadowing any further maturity delays from deficit irrigation (Morrow & Kreig, 1990). More irrigation led to less naturally open bolls in PHY350 and ceasing irrigation at bloom hastened maturity as stored resources were quickly exhausted and unable to be replenished at a rate to preserve further development of lint (Spooner et al., 1958). In Jackson, TN, an environment with limited heat units, a delay in maturity of 0.56 days per every additional centimeter of irrigation applied was observed (Gwathmey et al., 2011). This carries over into this experiment where increasing irrigation can delay plant maturity, as seen across percent open bolls as well as NUCB (Table 6 & 7). There is no way to definitively say that the more mature bolls were retained at this point of increased plant stress as resources dwindled, but they were more likely to be retained than later set fruiting sites (Mauney, 1986; Raper & Gwathmey, 2015; Zonta et al., 2017).

While differences were noted in boll count data collected, these have been shown to be problematic in estimating yield (Table 7). While this data gives an estimate of lint yield it must be meticulously collected and is best used to look at areas of the field or fields that could yield more than others and, in this study, plots that yield higher than others (Raper, 2019). Issues with these counts include not enough data collection sites and incomplete data such as not obtaining the weight of the bolls or inaccurate estimates of lint turnout percentages (MSU, n.d.; Raper 2019). The boll count data in this study allowed us to get an estimate of treatments that would outperform others but could not provide direct correlation between boll count and yield (Table 7).

Between seed cotton harvested and lint yield in this study the same conclusions can be drawn; the treatment receiving the greatest amount of irrigation yielded the most cotton in which there was no level of irrigation that led to a diminishing lint yield nor did yields plateau (Table 8). Studies conducted in Xinjiang, China show the highest irrigation rates did not lead to maximum lint yield where 93 - 79% of the Full irrigation treatment produced the highest lint yield (Zhang et al., 2016). Contrasting results were found in the Texas High Plaines where Snowden et al. (2013a) observed the Fully irrigated treatment out yielded all deficit treatments with the Fully irrigated treatment producing 944 kg ha^{-1} more lint than the check treatment which received no water after the initiation of irrigation treatments. Other observations include an overhead irrigation study in Georgia which had a dryland treatment as well as a 70% and 100% ET replacement that showed a linear increases in yield (Bednarz et al., 2003). This study in Georgia, also included treatments where ET replacement was adjusted according to growth stage. These treatments revealed that when irrigation was withheld until later stages of flowering (3-6 weeks after first flower) lint yields were increased beyond those achieved by treatments receiving Full irrigation treatment throughout the season in the second year of the study (Bednarz et al., 2003). The data collected in the current study at the McCaull Research and Demonstration Farm was similar in treatments where less than Full irrigation were applied during square generated yields similar to those achieved by the treatment receiving Full irrigation throughout the season despite having applied less total irrigation (Table 8).

Looking deeper into the differences it can also be concluded that irrigation termination after bloom caused a decrease in yield due to the sudden lack of resources to support development of the fruiting cites established with square irrigation (Table 8). Characteristically cotton sets 2-3 times the amount of bolls that it can generally support which is dictated by resources available to the crop early in the season (Baker & Acock, 1986; Mauney, 1986). The treatments with Full irrigation at squaring with a reduction to 40 or 0% of Full irrigation during flowering showed a 36 – 56% decrease in lint yield from the decrease in irrigation supplied during flowering. This is likely caused by the shedding of developing bolls late in the season with no time for recovery whereas increasing irrigation after the squaring period allowed for the recovery of yield as the developed and set bolls have a lower chance of shedding (Hake et al., 1992; Loka et al., 2011; Zonta et al., 2017). This study saw an increase in yield with more irrigation after squaring, with the 40% of Full at squaring increased yield by about 32% in the 40% of Full at squaring followed by either 70% of Full or Full irrigation during anthesis. Similar results were found by Gwathmey et al. (2011) showing that water stress early in the season caused flower abortion whereas the water stress later in the season caused less bolls to be retained as well as the absence of continued reproductive growth. Another study outlined the small chance of these developed bolls to be shed over young bolls which is in agreement with other studies previously mentioned in terms of boll retention after a period of time due to the small amount of energy needed to retain these bolls (Baker & Acock, 1986; Guinn, 1982; Mauney, 1986; TAMU, 2007; Zonta et al., 2017).

As mentioned, results from other studies cannot always conclude that the maximum yields will come from the highest irrigated treatments (Feng et al., 2014; Snowden et al., 2013a). The results of this study could be from a variety of factors including the insufficient estimation of ET from the Oklahoma Mesonet, errors in the maximum allowable deficit the Mesonet allows, as well as the favorable environmental factors at the end of the season that allowed for continued lint development within both varieties after termination of irrigation. More evidence of insufficient irrigation is seen when looking into the lack of differences seen between fiber quality parameters, more specifically those that are more likely to respond to overirrigation in previous studies.

Figure 1 shows the seasonal deficit of each respective treatment where the Full irrigation treatment saw a net deficit of 208 mm between planting and harvest of the crop. The Full irrigation treatment supply irrigation sufficient to replace 102% of the water deficient during the irrigated portion of the season, however, continued favorable growing conditions combined with lack of rainfall after termination of irrigation allowed for this 208 mm deficit to occur as indicated in Figure 1.

Fiber quality characteristics such as micronaire and fiber strength are parameters that can be affected by overirrigation with studies seeing an increase in micronaire values and lower fiber strength under limited irrigation (Booker et al., 2006; Feng et al., 2014; Pettigrew, 2004; Ramey, 1986; Silvertooth et al., 2006; Spooner et al., 1958). Other studies (Dağdelen et al., 2009; Silvertooth et al., 2006; Pettigrew, 2004) have seen no effect of various irrigation treatments on micronaire values, which is similar to the current study. Data collected in this study shows that late season indicators of maturity such as NUHB in the PHY205 was unaffected by irrigation. This parameter was affected by irrigation in PHY350. However, it is apparent that between assessment of this parameter and harvest even the PHY350 was capable of maturing those later bolls available for harvest. In general, differences in fiber quality tend to arise from when later set bolls have inadequate heat units to Fully develop fiber prior to cracking after applications of harvest aids. (Morrow & Krieg, 1990).

A heat unit (HU) accumulation chart to gauge cotton development was proposed by Oosterhuis (1990), has a basis of 1444 HU (°C) for traditional cotton growing regions in the Cotton Belt. In 2021, Eva Oklahoma accumulated 1131 $GDD_{15.6}$ calculated from data retrieved from past data for the Eva Mesonet station and lower than the 1444 HU threshold (Oklahoma Mesonet, 2021). Despite accumulating less than average heat units, cotton of premium quality was generated with maximum yields of 2206 kg ha^{-1} (Table 8). Reducing what is commonly believed to be total heat units needed to mature cotton to 1000 GDU (°C) in this environment introduces a greater likelihood of successful cotton production with short season varieties (Esparza et al., 2007). More specialized research is needed focusing on the HU accumulation necessary to reach a certain growth stage to have a definite conclusion of this concept in this short-seasoned environment. This idea can further expand research relating to irrigation termination and potential adjustments to the last effective bloom date for cotton in this region.

WUE shows greater efficiency in the short-seasoned PHY205 when supplementing irrigation at the end of the season (Table 10). This shows that irrigation at the end of the season is more important to lint development than water at the beginning of the season as there is no guarantee for continued resources to support the fruit set early in the season. The constant 40% of Full treatment can show the lower irrigation at the beginning of the season can give the plant enough water to set a realistic boll load that it can continue to support with limited resources.

TAPS Management. The data analysis suggests that in the TAPS participant management study, plant height did not show a strong correlation to yield (Table 11 & 15). However, within the standard variety (PHY350), plant height at first bloom as well as 6 weeks after had a stronger correlation to irrigation during the square period (Table 11). Whereas, the only significant differences detected in TAPS treatments 1-8 for the standard variety PHY350 was at 6 weeks after first bloom. First bloom plant height for participant varieties could not have been from Pix amounts as all treatments received 296 g ai ha^{-1} up to that point. Plant heights were taken 81, 98, 112, 126 and 145 DAP. Growth regulator applications (Pix) were applied 62, 82, 90, and 95 DAP. The last application was the only application applied at a variable rate based on participant recommendations where height measurements were taken the day after (Table 1).

NAWF remained insignificantly different among the various management treatments for participant management as well as the standard variety PHY350 (Table 12).

No significant difference in NFFB in TAPS participants was detected which is unexpected as this characteristic is variety dependent (Table 13). NFFB for TAPS 2 and 6 were significantly different in PHY350 under participant management while having many similar characteristics, including the majority of irrigation applied during bloom and similar percentages earlier in the season. Conversely, other treatments with higher percentages of water late in the season showed no significant differences in NFFB. This indicates that the maturity pattern in the fixed irrigation treatments for PHY350 was not upheld within all parameters. The NUCB in TAPS 3, 4, 7, and the Full irrigation treatments were not significantly different from each other, with TAPS 3, 4, and 7 being later maturing varieties. This highlights the possibility of controlling the maturity of a short-season cotton variety through irrigation management, as demonstrated by the Full irrigation treatment. This can be a significant factor for cotton producers in short-season environments, as it can reduce the risk of failing to meet maturity requirements while allowing them to grow a variety that can act as a later maturing variety to potential capitalize on extended growing seasons.

Boll counts conducted can also give us an insight to maturity, but do not show the differences between the Full irrigation treatment and the later maturing varieties in the TAPS participants (Table 14). However, the TAPS treatments 3, 4, and 7 are still not different, showing similarity of development under the same classification of maturity. The highest number of percent open bolls from natural maturity and dry down were the treatments planted to PHY205. The results show that irrigation management can potentially influence the maturity of short-season varieties to resemble later maturity varieties and vice versa.

In the TAPS standard management treatments, the only significant harvest parameter was percent lint turnout, which response cannot be explained at this time (Table 15). Seed cotton and lint yield were highest with the greatest amount of irrigation, regardless of other management factors. Lint value was influenced by lint removal from the field, while fiber quality parameters did not significantly affect loan value (Table 16) in either TAPS experiment.

Water use efficiency was not significantly different between TAPS 6 and the Full irrigation treatment (Table 17). Both of these treatments had the highest percentage of water applied at bloom, but was significantly different from TAPS 2 with the same irrigation allocation pattern, and all were planted to PHY205. Figure 2 shows the similarities in total water deficit between the Full and TAPS 6 treatments. This presentation shows that the Full irrigation provided from a smaller deficit during weeks 4-6 of bloom. The increased yield in the Full irrigation as compared to TAPS is thus not surprising when these results are compared to the results from the fixed irrigation treatments showing the reduction in yield resulting from reductions in irrigation during bloom.

2.7 SUMMARY

Cotton production in the short-seasoned environments overlying the water limited region of the Ogallala Aquifer is possible with careful management and consideration of environmental limitations. A better understanding of heat unit accumulation's role in progressing cotton development is needed for this region. In this year, with an extended growing season, higher irrigation rates led to higher cotton lint yields with no significant impact on fiber quality. While many parameters collected were found to have no direct correlation to lint yield, they did provide valuable insights into the maturity of the crop. Future research should focus on quantifying boll retention to gain a deeper understanding of the stress response of various maturing cultivars in this region. This year's data also suggests strategic irrigation of short season cotton varieties may help to mimic the maturity and performance of later maturing varieties, thus enabling producers to minimize the risk of season terminating freezes. This could be achieved through careful planning based on weather conditions towards the end of the growing season. Overall, this study provides important insights into the factors influencing cotton production and highlights the need for continued research to improve crop yield and quality.

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Table 1. Treatment characteristics including the variety, maturity, planting population, and growth regulator (Pix) application. Other information pertains to variety classifications from Corteva Agriscience™.

Irrigation Treatments	Variety	Maturity	Planting Population (seeds ha^{-1})	Pix Rate (g ai ha^{-1})	Height[x]	NFFB[x]	Strength[x] (g tex^{-1})	Length[x] (mm)	Micronaire[x]
Check	PHY205	Early	79,000	1420	Short	7.5	30.1	27.9	4.4
TAPS 2	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
TAPS 3	PHY332	Early/Mid	123,500	2839.0	Med/Tall	6.3	32.8	30.5	4.1
TAPS 4	PHY332	Early/Mid	155,000	2366.0	Med/Tall	6.3	32.8	30.5	4.1
TAPS 5	PHY205	Early	111,200	2839.0	Short	7.5	30.1	27.9	4.4
TAPS 6	PHY205	Early	136,000	1420	Short	7.5	30.1	27.9	4.4
TAPS 7	PHY400	Early/Mid	136,000	3312.0	Med	6.4	31.0	28.7	3.9
CNST 40	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
CNST 70	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Full	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Sq. Full/Bl. 0	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Sq. Full/Bl. 40	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Sq. Full/Bl. 70	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Sq. 70/Bl. 0	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Sq. 70/Bl. 40	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Sq. 40/Bl. 70	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Sq. 40/Bl. Full	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Low Pre/Sq. 70/Bl. 40	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Low Pre/Sq. 70/Bl. 70	PHY205	Early	111,200	1420	Short	7.5	30.1	27.9	4.4
Standard[z]	PHY350	Early/Mid	111,200	1420	Med/Tall	6.4	30.0	29.2	4.2

[x] Variety characteristics retrieved from Phytogen variety information sheets.

[z] Standard plots were planted in the neighboring 8-row plots in all treatments.

Table 2. Irrigation allocations for the 2021 growing season on the McCaull Research Station near Eva, Oklahoma.

Irrigation Treatments	Irrigation Received (mm)	Pre-Square Irrigation[z]	Square Irrigation[z]	Bloom Irrigation[z]
Check	35	100%	0%	0%
TAPS 2	146	27%	30%	43%
TAPS 3	154	36%	45%	20%
TAPS 4	201	52%	35%	13%
TAPS 5	210	48%	18%	34%
TAPS 6	256	33%	27%	40%
TAPS 7	186	35%	31%	34%
40% of Full	149	43%	20%	37%
70% of Full	231	35%	22%	42%
Full Irrigation	313	32%	24%	45%
Square= Full + Bloom=0% of Full	174	58%	42%	0%
Square= Full + Bloom=40% of Full	230	44%	32%	24%
Square= Full + Bloom=70% of Full	272	37%	27%	36%
Square=70% + Bloom=0% of Full	134	61%	39%	0%
Square=70% + Bloom=40% of Full	190	43%	27%	29%
Square=40% + Bloom=70%	191	33%	15%	51%
Square=40% + Bloom= Full	233	27%	13%	60%
Low Pre-water + Square=70% + Bloom=40%	160	33%	32%	35%
Low Pre-water + Square=70% + Bloom=70%	202	26%	26%	48%

[z] Pre square irrigation was from 5/26/2021 to 7/10/2021 (20 to 65 DAP). Square irrigation was from 7/11/2021 to 7/29/2021 (66 to 84 DAP). Bloom irrigation was from 7/30/2021 to 9/6/2021 when irrigation was terminated (85 to 123 DAP). Cotton was planted on 6 May 2021.

Table 3. Field management information for the Eva, Oklahoma site.

Year	Pre-Plant Irrigation[v] (mm)	Planting Date	Soil Temp[w] (Celsius)	Irrigation Treatment Start	Irrigation Treatment End	Harvest Date	Cumulative Heat Units[x] ($GDD_{15.6}$)	Seasonal Rainfall (mm)[z]
2021	34.5	6 May 2021	17.5	26 May 2021	6 Sept. 2021	19 Nov. 2021	1133	353

[v] Pre-Emergence Irrigation was accounted for from planting date to the start of the irrigation treatments.

[w] Soil temperatures taken at planting at a depth of 5 cm.

[x] Heat units were calculated from the Oklahoma Mesonet heat unit calculator and were collected from 1 DAP to 197 DAP.

[z] Seasonal rainfall was calculated from planting date to harvest date.

Table 4. Planted population and plant height (cm) at first bloom (FB), 2, 4, and 6 weeks after first bloom and final plant heights for Eva, Oklahoma in 2021.

	Planting Population (seeds ha^{-1})	Stand Counts[y] (plants ha^{-1})	FB Plant Height	FB+2wk Plant Height	FB+4wk Plant Height	FB+6wk Plant Height	Final Plant Height
			---(cm)---				
Phytogen 205							
Pr > F[z]	*<.0001*	*0.1144*	*0.0066*	*0.0039*	*0.0001*	*0.0916*	*0.0029*
Check	79,072 b	70,282	46 de	54 cde	56 e	60	55 de
CNST 40	111,195 a	85,343	50 bcd	61 bc	63 a-d	63	59 b-e
CNST 70	111,195 a	85,343	54 ab	64 ab	64 abc	65	66 ab
Full	111,195 a	95,383	53 abc	63 abc	62 b-e	63	63 abc
Sq. Full/Bl. 0	111,195 a	91,797	51 a-d	58 bcd	63 abc	60	62 a-d
Sq. Full/Bl. 40	111,195 a	81,040	56 a	70 a	66 ab	65	69 a
Sq. Full/Bl. 70	111,195 a	102,555	54 abc	66 ab	68 a	68	68 a
Sq. 70/Bl. 0	111,195 a	74,585	51 a-d	62 abc	61 b-e	63	59 b-e
Sq. 70/Bl. 40	111,195 a	83,191	49 de	60 bc	63 abc	63	66 ab
Sq. 40/Bl. 70	111,195 a	92,514	48 cde	51 de	57 de	54	55 cde
Sq. 40/Bl. Full	111,195 a	96,100	44 e	49 e	49 f	53	52 e
Low Pre/Sq. 70/Bl. 40	111,195 a	84,626	51 a-d	59 bcd	59 cde	60	58 b-e
Low Pre/Sq. 70/Bl. 70	111,195 a	78,888	50 bcd	60 bcd	60 cde	60	60 b-e
Phytogen 350							
Pr > F[z]	*n/s*	*0.4560*	*0.1017*	*0.0401*	*0.0041*	*0.0062*	*0.0006*
Check	111,195	70,999	53	60 c	61 d	62 d	62 f
CNST 40	111,195	91,080	57	65 bc	69 bcd	67 bcd	67 def
CNST 70	111,195	78,888	65	73 ab	73 bc	77 ab	76 abc
Full	111,195	88,211	62	77 a	78 ab	79 a	78 ab
Sq. Full/Bl. 0	111,195	82,474	59	68 abc	75 abc	71 a-d	75 a-d
Sq. Full/Bl. 40	111,195	74,585	62	73 ab	78 ab	80 a	80 ab
Sq. Full/Bl. 70	111,195	76,737	61	77 a	83 a	81 a	83 a
Sq. 70/Bl. 0	111,195	68,131	60	70 abc	75 abc	74 abc	74 a-d
Sq. 70/Bl. 40	111,195	80,323	58	69 abc	71 bcd	74 abc	75 a-d
Sq. 40/Bl. 70	111,195	76,020	58	61 bc	66 cd	64 cd	64 ef
Sq. 40/Bl. Full	111,195	85,343	58	68 abc	68 cd	69 bcd	68 c-f
Low Pre/Sq. 70/Bl. 40	111,195	86,777	55	73 ab	73 bc	71 a-d	71 b-e
Low Pre/Sq. 70/Bl. 70	111,195	75,302	56	61 c	67 cd	64 cd	64 ef

[y] Stand counts were taken at 28 DAP. First bloom heights were taken at 81 DAP and every two weeks thereafter. Final plant heights were taken 145 DAP. Cotton was planted on 6 May 2021.
[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$

Table 5. Nodes above white flower (NAWF) counts at first bloom (FB), 2, and 4 weeks after first bloom for Eva, Oklahoma in 2021.

	FB NAWF[y]	FB+2wk NAWF	FB+4wk NAWF
Phytogen 205			
Pr > F[z]	*0.4672*	*0.3609*	*0.9858*
Check	6	4	2
CNST 40	7	5	3
CNST 70	7	5	3
Full	7	5	2
Sq. Full/Bl. 0	8	5	2
Sq. Full/Bl. 40	7	5	3
Sq. Full/Bl. 70	8	5	3
Sq. 70/Bl. 0	8	4	2
Sq. 70/Bl. 40	7	4	3
Sq. 40/Bl. 70	7	4	2
Sq. 40/Bl. Full	7	4	2
Low Pre/Sq. 70/Bl. 40	7	5	2
Low Pre/Sq. 70/Bl. 70	7	5	2
Phytogen 350			
Pr > F[z]	*0.1694*	*0.0651*	*0.0858*
Check	7	4	3
CNST 40	8	5	3
CNST 70	8	5	3
Full	8	5	3
Sq. Full/Bl. 0	8	5	3
Sq. Full/Bl. 40	8	5	3
Sq. Full/Bl. 70	9	6	3
Sq. 70/Bl. 0	8	5	3
Sq. 70/Bl. 40	9	5	3
Sq. 40/Bl. 70	7	5	3
Sq. 40/Bl. Full	8	6	3
Low Pre/Sq. 70/Bl. 40	8	5	3
Low Pre/Sq. 70/Bl. 70	8	5	3

[y] First bloom NAWF were taken at 81 DAP and every two weeks thereafter.

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 6. End of season maturity measurements including final plant height (cm), node of first fruiting branch (NFFB), node of uppermost cracked boll (NUCB), node of uppermost harvestable boll (NUHB), total nodes on the plant for Eva, Oklahoma.

	NFFB[y]	NUCB[y]	NUHB[y]	Total Nodes[y]
Phytogen 205				
Pr > F[z]	*0.4124*	*0.0361*	*0.1659*	*0.2625*
Check	5.6	11.1 a	13.3	16.7
CNST 40	5.6	9.7 abc	12.1	16.5
CNST 70	5.2	10.0 ab	13.0	17.3
Full	5.8	8.2 c	13.6	16.8
Sq. Full/Bl. 0	6.0	10.4 a	12.7	16.9
Sq. Full/Bl. 40	5.8	10.2 ab	14.7	18.5
Sq. Full/Bl. 70	5.8	8.7 bc	14.5	18.0
Sq. 70/Bl. 0	5.5	11.0 a	12.4	16.6
Sq. 70/Bl. 40	5.5	10.5 a	13.6	17.7
Sq. 40/Bl. 70	5.4	10.9 a	13.5	16.7
Sq. 40/Bl. Full	5.8	10.0 ab	13.0	16.4
Low Pre/Sq. 70/Bl. 40	5.6	10.3 a	13.4	17.2
Low Pre/Sq. 70/Bl. 70	5.9	10.0 ab	13.1	17.2
Phytogen 350				
Pr > F[z]	*0.0178*	*0.0083*	*0.0299*	*0.0178*
Check	5.5 abc	9.3 a	11.8 c	16.1 d
CNST 40	6.0 a	8.5 ab	11.8 c	16.7 cd
CNST 70	5.1 cd	6.3 d	13.2 abc	16.6 d
Full	5.4 abc	7.3 bcd	14.3 ab	17.0 a-d
Sq. Full/Bl. 0	5.5 abc	8.2 abc	13.1 abc	16.5 d
Sq. Full/Bl. 40	5.9 ab	8.6 ab	14.0 ab	18.2 a
Sq. Full/Bl. 70	5.6 abc	7.0 cd	14.9 a	18.0 abc
Sq. 70/Bl. 0	5.7 ab	8.7 ab	12.4 bc	16.9 bcd
Sq. 70/Bl. 40	5.3 bcd	8.4 abc	12.7 bc	17.3 a-d
Sq. 40/Bl. 70	4.8 d	7.9 abc	11.6 c	16.0 d
Sq. 40/Bl. Full	5.5 abc	7.5 bcd	13.7 abc	17.0 a-d
Low Pre/Sq. 70/Bl. 40	5.9 ab	9.0 a	14.2 ab	18.1 ab
Low Pre/Sq. 70/Bl. 70	5.4 abc	8.4 abc	11.8 c	16.0 d

[y] Node at first fruiting branch (NFFB), node of uppermost first position cracked boll (NUCB), node of uppermost first position harvestable boll (NUHB), and total nodes taken 145 DAP.

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 7. Boll counts in a 3-meter row for Eva, Oklahoma in 2021. These counts were taken before the application of harvest aid.

	Open Bolls[y]	Total Bolls[y]	Open Bolls (%)
Phytogen 205			
Pr > F[z]	*0.3698*	*0.0098*	*0.0515*
Check	36	94 d	38
CNST 40	52	136 abc	40
CNST 70	41	141 abc	30
Full	38	166 a	23
Sq. Full/Bl. 0	58	118 cd	50
Sq. Full/Bl. 40	38	119 cd	32
Sq. Full/Bl. 70	26	132 bc	19
Sq. 70/Bl. 0	50	116 cd	44
Sq. 70/Bl. 40	48	110 cd	43
Sq. 40/Bl. 70	55	132 bc	42
Sq. 40/Bl. Full	50	155 ab	31
Low Pre/Sq. 70/Bl. 40	39	119 cd	32
Low Pre/Sq. 70/Bl. 70	38	124 bcd	31
Phytogen 350			
Pr > F[z]	*0.0227*	*0.0676*	*0.0009*
Check	45 a	99	46 a
CNST 40	30 abc	125	24 bcd
CNST 70	9 c	124	8 de
Full	12 c	162	8 de
Sq. Full/Bl. 0	38 ab	113	33 ab
Sq. Full/Bl. 40	10 c	89	11 cde
Sq. Full/Bl. 70	9 c	130	7 e
Sq. 70/Bl. 0	35 ab	106	32 ab
Sq. 70/Bl. 40	26 abc	102	26 bc
Sq. 40/Bl. 70	34 ab	123	28 ab
Sq. 40/Bl. Full	18 abc	154	11 cde
Low Pre/Sq. 70/Bl. 40	24 abc	128	18 b-e
Low Pre/Sq. 70/Bl. 70	28 abc	119	23 b-e

[y] Boll counts were taken 145 DAP. These measurements were to be taken at projected 50-60% open bolls across the field and accounted for only harvestable bolls (~25mm in diameter).

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$

Table 8. Effect of irrigation on harvest parameters including seed cotton, lint turnout, lint, and seed yield. Each variety is to be considered separately due to the difference in maturity.

	Seed Cotton ($kg\ ha^{-1}$)	Lint Turnout[y] (%)	Lint Yield ($kg\ ha^{-1}$)	Seed Yield ($kg\ ha^{-1}$)
Phytogen 205				
Pr > F[z]	*0.0001*	*0.4578*	*<.0001*	*0.0002*
Check	2,925 def	40	1,150 efg	1,690 def
CNST 40	3,602 cde	38	1,366 def	2,011 c-f
CNST 70	4,321 bc	39	1,695 bcd	2,511 bc
Full	5,898 a	37	2,206 a	3,506 a
Sq. Full/Bl. 0	2,592 ef	38	994 fg	1,525 ef
Sq. Full/Bl. 40	3,736 cd	38	1,414 cde	2,187 cde
Sq. Full/Bl. 70	5,329 ab	39	2,067 ab	3,132 ab
Sq. 70/Bl. 0	2,453 f	39	942 g	1,423 f
Sq. 70/Bl. 40	3,296 cdef	40	1,328 c-f	1,863 c-f
Sq. 40/Bl. 70	4,482 bc	40	1,815 bc	2,542 bc
Sq. 40/Bl. Full	4,577 bc	39	1,793 bc	2,634 bc
Low Pre/Sq. 70/Bl. 40	4,582 bc	39	1,763 bcd	2,671 bc
Low Pre/Sq. 70/Bl. 70	4,045 cd	40	1,622 cd	2,303 cd
Phytogen 350				
Pr > F[z]	*0.0048*	*0.1328*	*0.0028*	*0.0055*
Check	2,474 c	39	967 c	1,425 d
CNST 40	2,755 bc	40	1,103 bc	1,578 cd
CNST 70	3,930 ab	38	1,486 ab	2,306 abc
Full	4,277 a	38	1,599 a	2,569 a
Sq. Full/Bl. 0	2,501 c	40	1,000 c	1,422 d
Sq. Full/Bl. 40	3,724 ab	39	1,463 ab	2,148 abc
Sq. Full/Bl. 70	4,387 a	39	1,687 a	2,584 a
Sq. 70/Bl. 0	2,894 bc	40	1,167 bc	1,643 bcd
Sq. 70/Bl. 40	3,744 ab	39	1,460 ab	2,161 abc
Sq. 40/Bl. 70	4,222 a	41	1,717 a	2,390 ab
Sq. 40/Bl. Full	3,991 ab	38	1,516 ab	2,374 abc
Low Pre/Sq. 70/Bl. 40	3,706 ab	39	1,450 ab	2,146 abc
Low Pre/Sq. 70/Bl. 70	4,814 a	39	1,863 a	2,820 a

[y] Lint turnout calculated as cleaned, ginned lint obtained per unit of seed cotton after cotton was field cleaned.

[z] For each parameter, means followed by the same letter within the same column for each year are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 9. Fiber quality values evaluated at FBRI at TTU where HVI analysis was conducted to measure micronaire, staple length, uniformity, and strength for each irrigation treatment within each variety.

	Micronaire	Length (mm)	Uniformity (%)	Strength (g tex^{-1})	Loan Value[x] (\$ kg^{-1})	Lint Value[y] (\$ ha^{-1})
Phytogen 205						
Pr > F[z]	*0.1013*	*0.9546*	*0.0363*	*0.1021*	*0.2287*	*<.0001*
Check	3.99	26.7	81.0 bc	29.2	1.13	1,309 de
CNST 40	4.17	27.1	81.8 abc	31.1	1.16	1,584 cd
CNST 70	4.44	27.1	81.3 abc	30.0	1.16	1,959 bc
Full	4.21	27.6	83.5 a	31.4	1.17	2,591 a
Sq. Full/Bl. 0	3.53	26.9	80.6 c	29.4	1.09	1,088 e
Sq. Full/Bl. 40	4.16	27.1	81.3 bc	31.1	1.13	1,588 cd
Sq. Full/Bl. 70	4.25	27.2	83.5 a	31.1	1.12	2,331 ab
Sq. 70/Bl. 0	3.87	26.9	80.5 c	28.7	1.15	1,082 e
Sq. 70/Bl. 40	4.25	26.7	81.7 abc	30.2	1.12	1,487 cde
Sq. 40/Bl. 70	4.59	27.4	82.6 ab	31.1	1.17	2,117 ab
Sq. 40/Bl. Full	4.26	27.3	82.5 ab	32.1	1.17	2,093 b
Low Pre/Sq. 70/Bl. 40	3.92	26.8	82.3 abc	30.6	1.12	1,984 bc
Low Pre/Sq. 70/Bl. 70	4.40	26.7	82.6 ab	30.2	1.15	1,863 bc
Phytogen 350						
Pr > F[z]	*0.1013*	*0.0569*	*0.0342*	*0.1135*	*0.3482*	*0.0011*
Check	3.88	28.0	80.6 bc	27.4	1.14	1,101 e
CNST 40	4.28	27.9	81.7 abc	28.1	1.17	1,287 de
CNST 70	3.88	28.6	82.5 ab	30.7	1.15	1,698 bcd
Full	3.34	29.1	82.1 abc	29.8	1.08	1,724 abc
Sq. Full/Bl. 0	4.04	27.3	80.0 c	25.8	1.07	1,088 e
Sq. Full/Bl. 40	3.93	28.1	82.6 a	28.2	1.17	1,720 a-d
Sq. Full/Bl. 70	3.66	28.9	83.2 a	30.5	1.15	1,951 ab
Sq. 70/Bl. 0	4.05	26.8	80.4 c	27.0	1.12	1,313 cde
Sq. 70/Bl. 40	4.19	28.0	81.7 abc	28.9	1.17	1,709 a-d
Sq. 40/Bl. 70	4.27	28.2	82.1 abc	30.0	1.18	2,034 ab
Sq. 40/Bl. Full	3.51	29.2	82.4 abc	28.9	1.13	1,723 a-d
Low Pre/Sq. 70/Bl. 40	4.02	28.3	83.1 a	30.4	1.18	1,715 a-d
Low Pre/Sq. 70/Bl. 70	4.00	29.0	83.8 a	30.0	1.19	2,215 a

[x] The loan value is calculated from Cotton Incorporated's loan value calculator.

[y] Lint value is calculated by multiplying the loan value by cotton lint yield.

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 10. Water use efficiency calculated by correcting from the check treatment for each variety respectively.

	Water Use Efficiency	
Treatment	PHY205	PHY350
Pr > F[z]	*0.0001*	*0.0698*
Check		
CNST 40	1.89 bc	-0.41
CNST 70	2.77 abc	1.71
Full	3.78 ab	1.61
Sq. Full/Bl. 0	-1.12 de	-1.08
Sq. Full/Bl. 40	1.35 cd	1.61
Sq. Full/Bl. 70	3.87 ab	2.27
Sq. 70/Bl. 0	-2.09 e	0.17
Sq. 70/Bl. 40	1.15 bcd	2.00
Sq. 40/Bl. 70	4.25 a	3.62
Sq. 40/Bl. Full	3.24 abc	1.84
Low Pre/Sq. 70/Bl. 40	4.90 a	2.39
Low Pre/Sq. 70/Bl. 70	2.82 abc	4.27

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 11. Plant population and plant height (cm) at first bloom (FB), 2, 4, and 6 weeks after first bloomas well as final plant height of TAPS treatments for Eva, Oklahoma in 2021.

	Planting Population[y] (seeds ha^{-1})	Stand Counts (plants ha^{-1})	FB Plant Height (cm)	FB+2wk Plant Height	FB+4wk Plant Height	FB+6wk Plant Height	Final Plant Height
			------(cm)------				
Participant							
Pr > F[z]	*n/s*	*0.5312*	*0.0017*	*0.0199*	*0.0035*	*0.1600*	*0.0050*
Check	79,072	70,282	46 d	54 b	56 d	60	55 d
TAPS 2	111,195	84,626	52 c	62 ab	62 cd	60	62 cd
TAPS 3	123,550	114,029	58 ab	71 a	71 a	71	71 ab
TAPS 4	154,438	99,328	59 ab	69 a	70 ab	72	74 ab
TAPS 5	111,195	85,343	51 c	54 b	60 cd	59	59 cd
TAPS 6	135,905	111,878	52 c	65 a	64 bc	64	65 bc
TAPS 7	135,905	70,999	54 abc	67 a	66 abc	67	66 abc
Full	111,195	95,383	53 bc	63 ab	62 cd	63	63 bcd
Standard							
Pr > F[z]	*n/s*	*0.4053*	*0.0660*	*0.1615*	*0.350*	*0.0324*	*0.0590*
Check	111,195	70,999	53	60	61	62 b	62
TAPS 2	111,195	91,797	57	67	73	70 ab	75
TAPS 3	111,195	69,565	60	73	74	75 a	71
TAPS 4	111,195	77,813	63	73	70	74 a	76
TAPS 5	111,195	73,868	57	71	71	74 a	72
TAPS 6	111,195	72,434	59	68	76	75 a	70
TAPS 7	111,195	79,247	58	72	72	71 a	73
Full	111,195	88,211	62	77	78	79 a	78

[y] Plant populations were taken at 28 DAP. First bloom heights were taken at 81 DAP and every two weeks thereafter. Final plant heights were taken 145 DAP. Cotton was planted on 6 May 2021.

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at p≤0.05.

Table 12. Nodes above white flower (NAWF) counts at first bloom (FB), 2,4, and 6 weeks after first bloom of the TAPS treatments in Eva, Oklahoma in 2021.

	FB NAWF[z]	FB+2wk NAWF	FB+4wk NAWF
Participant			
Pr > F[z]	*0.5604*	*0.0860*	*0.5859*
Check	6	4	2
TAPS 2	7	4	2
TAPS 3	8	5	3
TAPS 4	8	5	3
TAPS 5	7	4	2
TAPS 6	8	5	2
TAPS 7	8	5	3
Full	7	5	2
Standard			
Pr > F[z]	*0.1749*	*0.0597*	*0.4349*
Check	7	4	3
TAPS 2	8	5	3
TAPS 3	8	5	3
TAPS 4	9	5	3
TAPS 5	8	5	3
TAPS 6	8	5	3
TAPS 7	7	6	3
Full	8	5	3

[y] First bloom NAWF were taken at 81 DAP and every two weeks thereafter.

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 13. End of season maturity measurements of TAPS treatments including final plant height (cm), node of first fruiting branch (NFFB), node of uppermost cracked boll (NUCB), node of uppermost harvestable boll (NUHB), total nodes on the plant at 145 DAP for Eva, Oklahoma.

	NFFB[y]	NUCB[y]	NUHB[y]	Total Nodes[y]
Participant				
Pr > F[z]	*0.5055*	*0.0014*	*0.6384*	*0.6912*
Check	5.6	11.1 a	13.3	16.7
TAPS 2	6.1	10.7 a	13.7	17.7
TAPS 3	5.7	7.7 c	12.2	17.0
TAPS 4	5.8	7.9 c	13.0	17.0
TAPS 5	5.7	10.3 a	12.7	16.5
TAPS 6	5.1	9.7 ab	12.7	16.6
TAPS 7	5.5	8.1 bc	13.1	17.4
Full	5.8	8.2 bc	13.6	16.8
Standard				
Pr > F[z]	*0.0184*	*0.0046*	*0.2792*	*0.5444*
Check	5.5 bcd	9.3 a	11.8	16.1
TAPS 2	6.0 a	9.0 ab	13.6	17.7
TAPS 3	5.4 cd	8.5 ab	13.1	17.1
TAPS 4	5.6 abc	8.7 ab	12.5	17.2
TAPS 5	5.6 abc	8.1 ab	13.6	17.3
TAPS 6	5.0 d	7.3 c	12.9	16.5
TAPS 7	5.9 ab	9.2 a	13.8	17.7
Full	5.4 bcd	7.3 c	14.3	17.0

[y] Node at first fruiting branch (NFFB), node of uppermost first position cracked boll (NUCB), node of uppermost first position harvestable boll (NUHB), and total nodes taken 145 DAP.

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at p≤0.05.

Table 14. Boll counts in a 3-meter row of TAPS treatments in Eva, Oklahoma in 2021. These counts were taken before the application of harvest aid.

	Open Bolls	Total Bolls	Open Bolls (%)
Participant			
Pr > F[z]	*0.0013*	*0.0198*	*0.0013*
Check	36 a	94 c	37.9 ab
TAPS 2	54 a	131 abc	42.3 ab
TAPS 3	17 b	129 abc	14.2 cd
TAPS 4	12 b	105 bc	11.8 d
TAPS 5	46 a	106 bc	43.7 ab
TAPS 6	42 a	144 ab	29.9 abc
TAPS 7	11 b	95 c	10.9 d
Full	38 a	166 a	22.7 bcd
Standard			
Pr > F[z]	*0.2116*	*0.0986*	*0.1594*
Check	45	99	45.5
TAPS 2	28	116	27.3
TAPS 3	21	97	21.0
TAPS 4	25	117	22.2
TAPS 5	16	110	15.8
TAPS 6	28	121	22.6
TAPS 7	17	90	19.1
Full	12	162	8.2

[y] Boll counts were taken 145 DAP. These measurements were to be taken at projected 50-60% open bolls across the field and accounted for only harvestable bolls (~25mm in diameter).

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 15. TAPS treatments harvest parameters including seed cotton, lint turnout, lint, and seed yield. Each variety is to be considered separately due to the difference in maturity.

	Seed Cotton (kg ha^{-1})	Lint Turnout[y] (%)	Lint Yield (kg ha^{-1})	Seed Yield (kg ha^{-1})
Participant				
Pr > F[z]	*<.0001*	*0.0132*	*<.0001*	*0.0001*
Check	2,925 cd	39.6 bc	1,150 d	1,690 cd
TAPS 2	3,090 cd	39.9 ab	1,230 cd	1,773 cd
TAPS 3	3,226 cd	39.0 bc	1,257 cd	1,873 cd
TAPS 4	3,340 cd	38.3 bc	1,279 cd	1,964 cd
TAPS 5	3,755 cd	40.2 ab	1,501 c	2,155 c
TAPS 6	4,936 bd	37.0 c	1,827 b	2,917 b
TAPS 7	2,800 d	42.4 a	1,181 d	1,528 d
Full	5,898 a	37.4 bc	2,206 a	3,506 a
Standard				
Pr > F[z]	*0.1679*	*0.0422*	*0.1238*	*0.1117*
Check	2,474	39.2 abc	967	1,425
TAPS 2	2,839	39.9 ab	1,128	1,631
TAPS 3	3,486	40.4 a	1,394	2,002
TAPS 4	3,578	39.1 abc	1,396	2,051
TAPS 5	3,221	39.9 abc	1,279	1,856
TAPS 6	2,977	36.7 c	1,404	2,311
TAPS 7	3,056	40.9 a	1,250	1,714
Full	4,277	37.5 bc	1,599	2,569

[y] Lint turnout calculated as cleaned, ginned lint obtained per unit of seed cotton after cotton was field cleaned.

[z] For each parameter, means followed by the same letter within the same column for each year are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 16. Fiber quality parameters response to TAPS irrigation treatments. This data was gathered from samples sent to FBRI at TTU where HVI analysis was conducted and produced micronaire, staple length, uniformity, and strength for each irrigation treatment within each variety. The economic analysis of cotton under the estimated basis of loan value from Cotton Incorporated loan value calculator based on fiber quality results.

	Micronaire	Length (mm)	Uniformity (%)	Strength (g tex^{-1})	Loan Value[x] (\$ kg^{-1})	Lint Value[y] (\$ ha^{-1})
Participants						
Pr > F[z]	*0.5457*	*0.2248*	*0.2962*	*0.1490*	*0.3216*	*0.0002*
Check	3.99	26.7	81.0	29.2	1.13	1,309 d
TAPS 2	4.17	26.7	81.1	29.6	1.11	1,363 cd
TAPS 3	3.96	27.9	80.8	28.0	1.14	1,449 cd
TAPS 4	3.59	28.5	81.4	29.8	1.19	1,520 cd
TAPS 5	4.38	27.3	81.7	30.0	1.15	1,733 bc
TAPS 6	3.84	27.2	82.0	31.3	1.09	1,994 bc
TAPS 7	4.24	27.6	80.3	27.7	1.16	1,378 cd
Full	4.21	27.6	83.5	31.4	1.17	2,591 a
Standard						
Pr > F[z]	*0.0782*	*0.0622*	*0.1335*	*0.3189*	*0.4328*	*0.4428*
Check	3.88	28.0	80.6	27.4	1.14	1,101
TAPS 2	3.81	28.2	81.5	28.2	1.17	1,322
TAPS 3	4.32	28.2	82.8	28.3	1.14	1,579
TAPS 4	3.71	28.3	81.8	39.8	1.16	1,613
TAPS 5	4.34	28.3	83.2	29.4	1.18	1,515
TAPS 6	3.51	28.4	81.2	29.4	1.07	1,518
TAPS 7	4.23	26.8	79.2	26.6	1.07	1,342
Full	3.34	29.1	82.1	29.8	1.08	1,724

[x] The loan value is calculated from Cotton Incorporated's loan value calculator.

[y] Lint value is calculated by multiplying the loan value by cotton lint yield.

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at $p \leq 0.05$.

Table 17. Water use efficiency calculated by correcting from the check treatment for each TAPS treatments respectively.

	Water Use Efficiency	
Treatment	Grower	Standard
Pr > F[z]	*0.0059*	*0.7772*
Check		
TAPS 2	0.55 c	-0.15
TAPS 3	0.69 c	1.58
TAPS 4	0.64 c	1.22
TAPS 5	1.67 bc	0.61
TAPS 6	2.65 ab	1.00
TAPS 7	0.17 c	0.54
Full	3.37 a	1.41

[z] For each parameter, means followed by the same letter within the same column are not significantly different based on Fisher's Protected LSD at p≤0.05.

Figure 1. Water deficit for fixed treatments separated by time periods correlating to growth stage specific irrigation treatments. This includes irrigation and rainfall added to the soil as well as evapotranspiration (ET) lost from the soil as well as the plant. This does not account for any preexisting moisture in the soil prior to initiating irrigation treatments. The red bar represents total water deficit from planting to harvest.

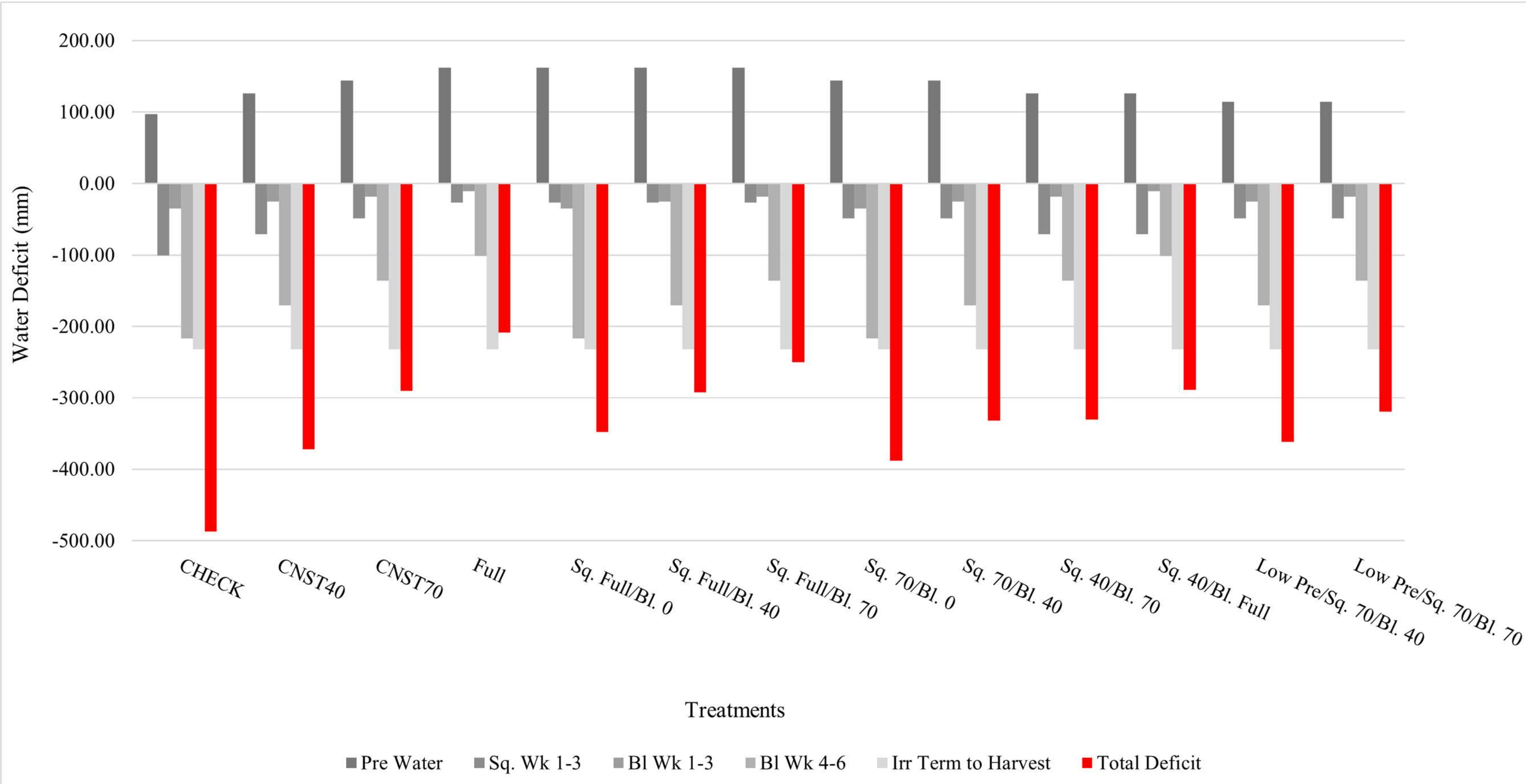
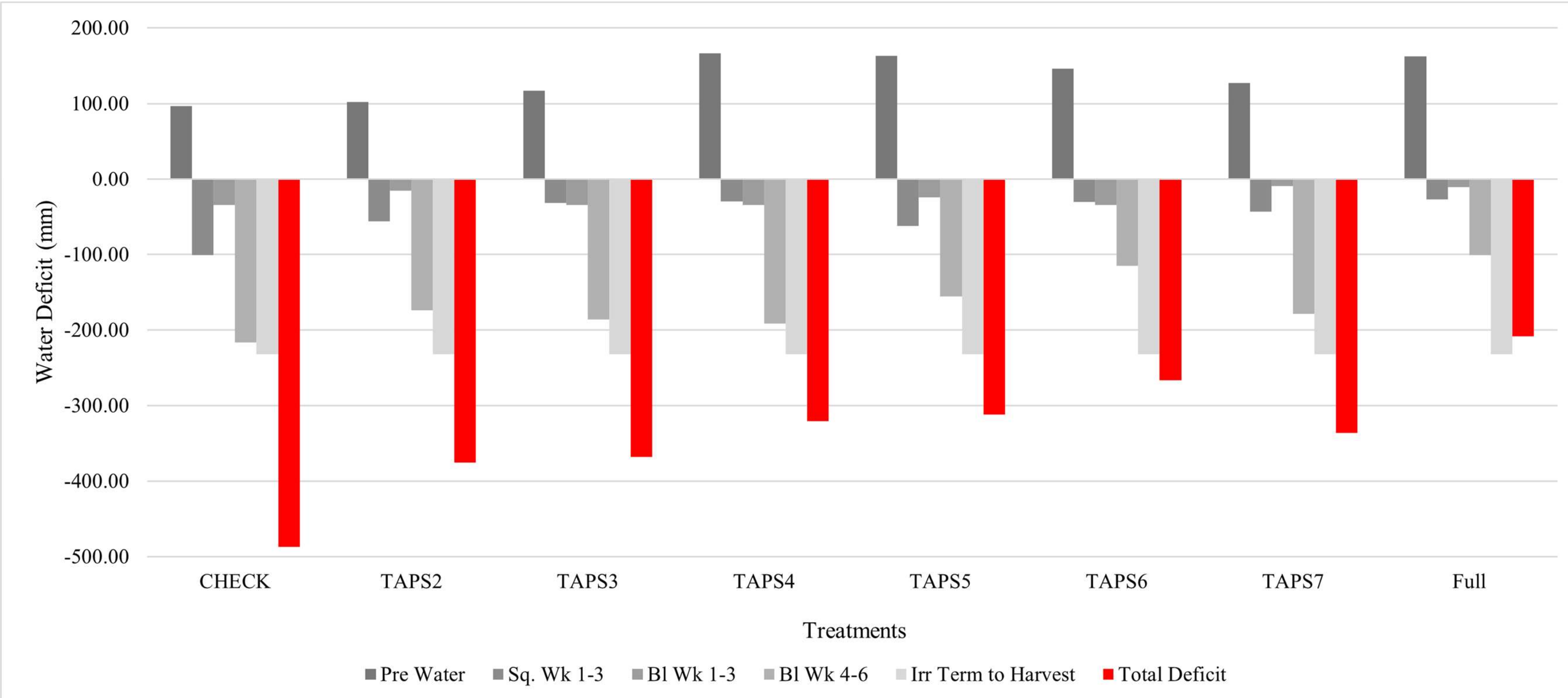
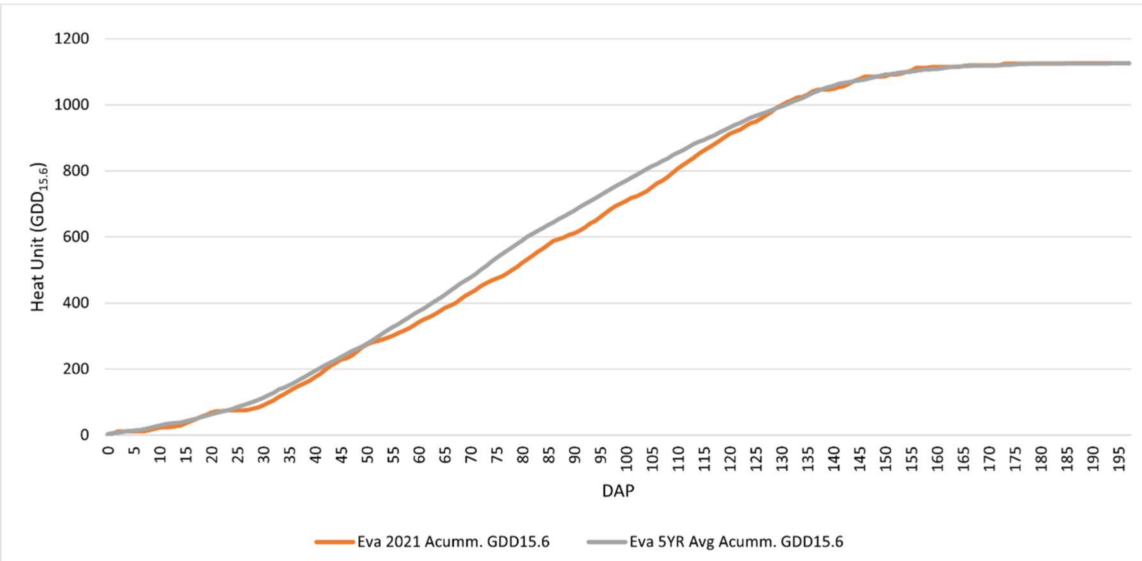


Figure 2. Water deficit for TAPS managed treatments separated by time periods correlating to growth stage specific irrigation treatments. This includes irrigation and rainfall added to the soil as well as evapotranspiration (ET) lost from the soil as well as the plant. This does not account for any preexisting moisture in the soil prior to initiating irrigation treatments. The red bar represents total water deficit from planting to harvest.

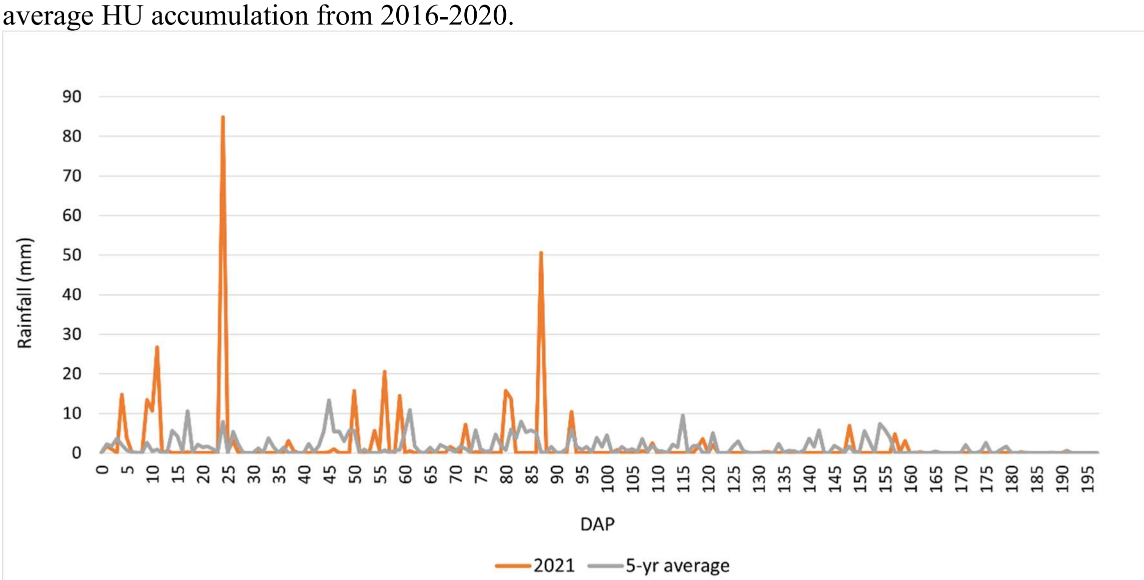


APPENDICES

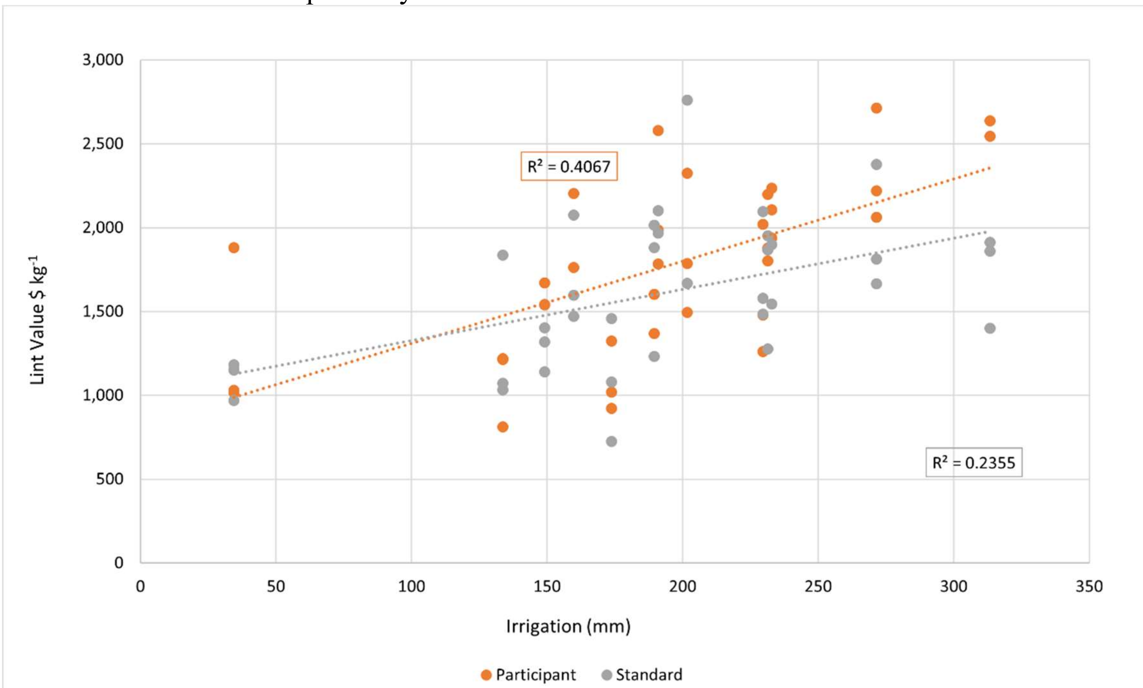
Appendix 1. Daily rainfall for the 2021 growing season and the daily average calculated from past Mesonet data from 2016-2020.



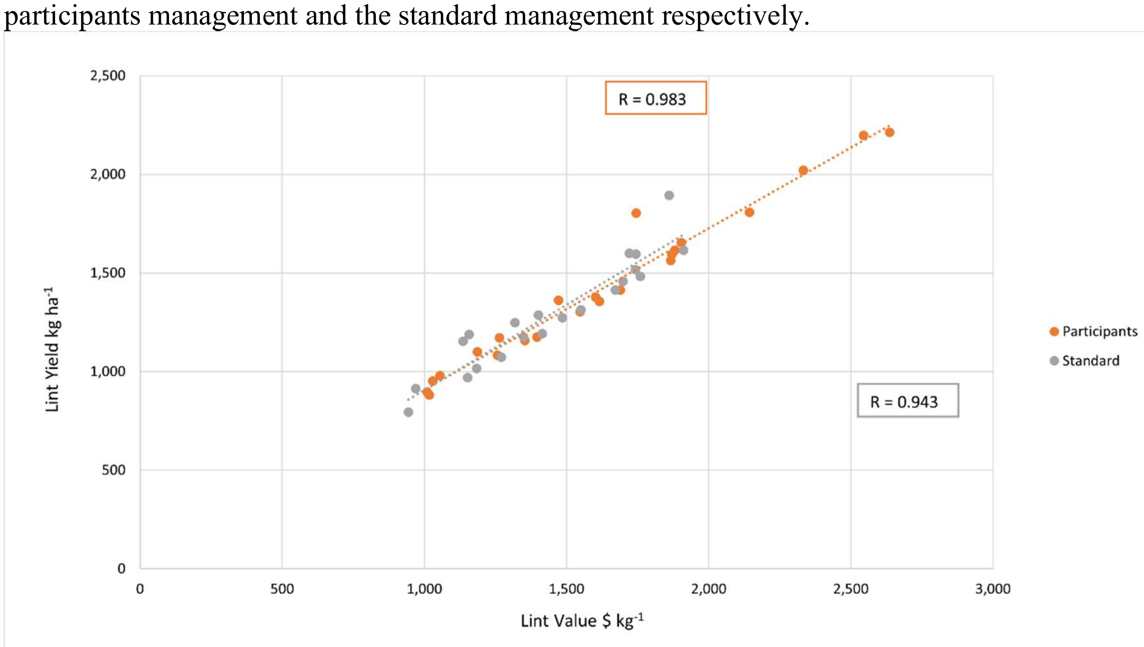
Appendix 2. Heat unit (HU) accumulation for the 2021 growing season in Eva Oklahoma and the 5-year average HU accumulation from 2016-2020.



Appendix 3. The impact of irrigation on cotton lint yield for fixed irrigation treatments within PHY205 and PHY350 respectively.



Appendix 4. The correlation between lint yield and lint value for TAPS management within the participants management and the standard management respectively.



VITA

BRENNA ASHTN CANNON

Candidate for the Degree of

Master of Science in Agriculture

Thesis: OPTIMIZING MANAGEMENT OF IRRIGATED COTTON IN A DEGREE DAY LIMITED ENVIRONMENT

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