A FIELD-SCALE ASSESSMENT OF SOIL-SPECIFIC SEEDING RATES TO OPTIMIZE YIELD FACTORS AND WATER USE IN COTTON

A Thesis

by

SCOTT MICHAEL STANISLAV

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Soil Science

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Approved by:

Chair of Committee,	Cristine Morgan
Committee Members,	John Thomasson
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ABSTRACT

A Field-Scale Assessment of Soil-Specific Seeding Rates to Optimize Yield Factors and Water Use in Cotton.

(August 2010)

Scott Michael Stanislav, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Cristine Morgan

Precision management of cotton production can increase profitability by decreasing inputs. The overall objective of this project is to improve cotton production by minimizing seeding rates while still maximizing yields and lint quality in water-limited soils. The research for this study was conducted at the Texas AgriLife Research IMPACT Center located in the Brazos River floodplain. In 2008 and 2009, 27 measurement locations were selected in production-sized center-pivot irrigated fields and planted in cotton variety Deltapine 164 roundup ready flex / bollgard II. Sites were selected based on soil apparent electrical conductivity (EC_a) values, in a low, medium, and high EC_a zones. Three seeding rates (74,100; 98,800; and 123,500 seeds ha^{-1}) were established in each of the three EC_a zones with three replications. In 2009, an additional seeding rate was added at 49,400 seeds ha^{-1}. At each measurement location, soil texture, soil moisture (weekly), lint quantity and quality (High Volume Instrument) were measured. An additional replication for each EC_a zone and seeding rate was selected for lint quantity and quality (HVI) measurements.

Results indicated that cotton lint yield increased as EC_a values, clay content, and water holding capacity of the soil increased. The seeding rates did not consistently affect cotton lint yield or quality. Seeding rates of 74,100 and 49,400 seeds ha^{-1} in a low and medium EC_a zone for IMPACT-08 and -09 yielded more lint (300 kg ha^{-1}), respectively. HVI lint quality parameters, such as, micronaire, fiber length, strength, uniformity, and elongation were significantly better in EC_a zone 3.

While the seeding rates did not affect the amount of soil water used throughout the season, lint yield variations between EC_a zones can be explained by the rate at which soil water was used. Lower rates at which soil water was used within EC_a zone 3 resulted in higher lint yields when compared to EC_a zones 1 and 2, which used soil water faster and at greater depths.

The findings suggest that irrigation applied to the low EC_a zone was not sufficient to meet the plants demand, while in a high EC_a zone, irrigation could have been reduced, resulting in cost savings through reduced inputs.

DEDICATION

I dedicate this thesis to my mom, Karen and my brother, Kyle. I thank them for their love and support throughout my tenure at Texas A&M University so I could achieve my dreams and goals.

ACKNOWLEDGEMENTS

I must acknowledge the aid and support of Dr. Morgan throughout my time at Texas A&M University. From my undergraduate degree to my graduate degree she has played a pivotal role in my success and education. As a mentor and teacher, her guidance and involvement have inspired and challenged me. My committee members, Dr. Alex Thomasson, Dr. Ruixiu Sui, and Dr. Tom Cothren, also deserve recognition for helping me complete my research and obtain my degree.

Praise should also be given to Dr. Amir Ibrahim and Dr. Kevin McInnes for their assistance in the statistical analyses and laboratory analysis. Mr. Alfred Nelson, Mr. Vince Saladino, and the entire Texas AgriLife Farm Services staff, should also be commended for their help with the everyday upkeep of the experimental site.

I would also like to express my gratitude to the entire hydropedology research group. From my fellow graduate students, to the many undergraduate student workers, they all deserve recognition.

Lastly, I would like to thank Mr. Andy Scamardo for allowing me to conduct a portion of my research on his farm.

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CHAPTER I

INTRODUCTION

Precision agriculture is the implementation of management practices on a site specific basis based on various soil or crop parameters, thus maximizing outputs while also minimizing inputs and environmental impacts (Pierce and Nowak, 1999; Taylor, 2007). Adoption of precision agriculture technologies in cotton at the production scale has been minimal. Limited adoption by cotton producers is likely because reliable, commercially available yield monitors (Wilkerson et al., 2001; Thomasson and Sui 2003; Vellidis et al., 2003) are still in the developmental stages. This is especially true when compared to grain yield monitors, which have been used consistently in the Midwestern United States since the mid 1990s (Bermudez and Mallarino, 2002; Kravchenko et al., 2000; Kravchenko et al., 2005). Even though grain yield maps are often created, grain yield variation from year to year due to biotic and abiotic factors makes yield alone an unstable proxy for developing a site-specific management plan (Morgan et al., 2003). Additionally, cotton lint prices are also a function of lint quality. Though lint quality has been shown to spatially vary in the field, sensors have yet to be commercialized (Stanislav et al., 2006; Ge et al., 2008).

Other precision agriculture technologies in cotton, such as variable rate seeding, fertilizer, pest management, and irrigation may have a positive impact on cotton production under a site-specific management plan, but implementation at the field-

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This thesis follows the style of the Soil Science Society of America Journal.

production scale is uncommon. Recent efforts have shown that variable rate technologies, e.g. irrigation and fertilization, have the potential to reduce inputs, but equipment costs make these technologies undesirable to producers that have working systems in place (Bronson et al., 2006; Seo et al., 2008). Implementation of these precision agriculture technologies in cotton, especially variable rate seeding, carry the likelihood of reducing inputs in poorly producing areas of a field, while still achieving the same yield and quality as if these areas were managed conventionally.

In general, cotton lint yield and quality are determined by a complex combination of factors, including cultivar, water availability, soil properties, and climatic factors such as rainfall, temperature, carbon dioxide, and solar radiation. Revenues for a cotton crop are driven mainly by cotton lint yield, but high quality fibers are desired by the textile mills and worth more money compared to low quality fibers. Cotton lint yield and quality can vary within a field because of variations in soil properties and topography alone, regardless of seasonal variations in weather. Variable rate seeding of a field according to soil variability may reduce inputs, maintain yield potential, and maximize fiber quality on less productive soils.

In 2006 and 2007, cotton yield and quality were measured in two fields, 20 and 36 ha. The fields were representative in size and soil types of other production agricultural fields in the Brazos River floodplain and other floodplain agricultural fields in Central Texas. Interestingly, 2006 was a typical, hot and dry growing season, while 2007 was cooler and wetter. Observations from 2006 indicated that cotton lint yield and quality increased as clay content and water holding capacities of the soils increased;

however, under the cooler and wetter growing conditions of 2007, cotton lint yield and lint quality (length, strength, and uniformity) showed no differences to the in-field soil variability. Based on these observations of cotton lint yield and quality responses to soil type in a dry versus a wet year, the hypothesis of this research is that reducing seeding rates in traditionally drought-stressed soils will still achieve maximum cotton lint yields and premium qualities because the lower plant populations will be less water-stressed. This hypothesis was tested on the same production-sized fields using prior knowledge of soil variability and conventional cotton production practices of the area. To address the potential benefits of variable rate seeding according to soil types at the production-sized field scale, the following objectives were addressed: 1) Quantification of lint yield and quality of different seeding rates on 3 soil types, 2) Determination of differences in plant use of soil water among seeding rates and soil types, and 3) Evaluation of how differences in soil water availability throughout the season may impact cotton lint yield and quality.

CHAPTER II

LITERATURE REVIEW

Soil apparent electrical conductivity (EC_a)

Site specific management in cotton production has progressed over the past decade through the introduction of GPS (global positioning system) guidance coupled with variable-rate equipment (e.g. planters, fertilizer implements, and sprayers) (Fridgen et al., 2004; Perry et al., 2004). To effectively incorporate precision management technologies and equipment, a template of fine resolution (meter-scale) geo-referenced information on spatially variable abiotic factors is needed. Arguably, this template should represent soil variability because soil is one of the primary abiotic factors that should be considered in a production-scale precision management program (Jaynes et al., 1995; Pierce and Nowak, 1999; Fraisse et al., 2001; Ping et al., 2005; Taylor et al., 2007). Apparent soil electrical conductivity (EC_a) can be used to map soil variability in situ, at a high spatial resolution, and non-invasively, making it a useful tool for creating meter-scale maps of soil variability which can be used to develop site-specific management zones (McNeill, 1980; Fraisse et al., 2001; Corwin et al., 2003). Soil EC_a is related to a wide range of well recognized yield-limiting soil attributes such as texture, water content, and salinity (Rhoades et al., 1976; Sheets and Hendrickx, 1995; Jaynes et al., 1995). In precision agriculture studies, soil EC_a commonly indicates the amount of soil water; however, the soil property that soil EC_a is responding to should be verified through classified sampling schemes and laboratory analysis (Corwin et al., 2003). In a

Colorado study, McCutcheon et al., (2006) concluded that clay content, clay mineralogy, temperature, cation exchange capacity, and organic matter were among the dominant soil properties affecting soil EC_a variability. Despite the multiple correlations between these soil properties and EC_a, soil water content was concluded to be the main factor driving soil EC_a response. Soil texture also influences soil properties such as temperature, cation exchange capacity, and organic matter content, thus making soil EC_a measurements a valuable method of measuring within-field soil spatial variability and aiding producers in creating site-specific management zones (McCutcheon et al., 2006).

Not only are soil EC_a measurements easily collected, but the data are usually more reliable and easier to interpret for site-specific management than yield monitor data. Yield maps integrate seasonal environmental factors, while EC_a measurements are, more simply, responding to soil variability. Additionally, soil EC_a measurements might be more appealing to the producer through ease in use, fixed costs, and the need for a single survey that remains descriptive of a field for many years. For example, Ping et al. (2005) reported that site-specific management zones should be based on stable features such as soil texture, organic matter, profile depth, cation exchange capacity, slope, and topography, while placing less interest on yield data because of variations caused by annual climatic factors. While site-specific management zones at the production scale can be produced quickly and efficiently using in situ soil EC_a measurements, applications of EC_a maps for precision management in cotton are needed. The use of soil EC_a maps to test variable seeding rates in cotton has not been reported. Moreover, little has been published on cotton yield and quality variations that may occur on a production-scale field containing variable soil types (Ge et al., 2008).

Cotton yield varies because of spatially variable soil attributes and seasonal weather patterns. Field-scale variability of soil and terrain, including slope, soil organic carbon, and clay content, have been cited as a major cause of spatial variability in cotton yield (Terra et al., 2006). In this study as well as others, soil EC_a was shown to represent the soil properties correlated with cotton and corn yields (Jaynes et al., 1995; Sudduth et al., 1995). In a dryland cotton production system in Mississippi, cotton yields were lower in areas with higher sand content and lower volumetric water content (Iqbal et al., 2005). In this situation, soil EC_a would have likely been highly correlated with soil water content, and hence cotton yield as well (Jaynes et al., 1995; McNeil, 1980; Sudduth et al., 1995).

Variable rate seeding and cotton lint yield and quality

The effect of seeding rates on cotton yield and lint quality has been well documented on plot-sized research with assumed uniform soils. In Louisiana, on a silt loam soil, Siebert et al. (2006) found that no differences in yield occurred when cotton is planted in densities ranging from 33,975 to 152,833 seeds ha^{-1}. In a similar study on a sandy loam soil in North Carolina, Jones and Wells (1998), found no yield differences in cotton planted at rates of 19,992 and 119,952 seeds ha^{-1}. While no yield differences were found in these studies, variation in cotton plant growth and plant maturity occurred in the different seeding rates.

Lower seeding rates can result in more mainstem nodes and monopodial branches, as well as heavier fruit. More bolls can also be set on monopodial branches and farther out on sympodial branches when grown at lower populations (Jones and Wells, 1997; Bednarz et al., 2000). Cotton planted at lower rates can also exhibit delayed maturity because fewer plants per land area result in less interplant competition. Lower seeding rates can have higher boll retention per plant compared to plants in higher densities because of higher carbohydrate levels in the leaves (Siebert et al., 2006). On the contrary, as population rates increase, fruiting site production, fruit retention, boll number and weight, and seed cotton per plant decrease (Bednarz et al., 2000; Bednarz et al., 2006). Regardless of the varying growth habits of cotton at different populations, the reason for overall yield stability is a linear relationship between decreasing plant populations, and increasing boll number and boll weight (Jones and Wells, 1998; Bednarz et al., 2000; Siebert et al., 2006).

On the other hand, fiber quality does seem to have the potential to vary with seeding rate. As seeding rates increase, micronaire values have been shown to decrease, primarily because of changes in maturity timing. Micronaire is the only lint quality parameter that has repeatedly shown to respond to seeding rate (Hawkins and Peacock, 1971, 1973; Bridge et al., 1973; Baker, 1976; Fowler and Ray, 1977; Buxton et al., 1979; Smith et al., 1979; Jones and Wells, 1997; Bednarz et al., 2000, 2005).

Nonetheless, the prevailing evidence shows that most yield and quality components are controlled more by cultivar than by crop management (Bednarz et al., 2005; Bednarz et al., 2006). For example, staple length and length uniformity have been shown not to be affected by seeding rates, but greatly influenced by cultivar (Bednarz et al., 2005; Bednarz et al., 2006). May (1999) has shown similar results and concluded that fiber length, fiber strength and micronaire were related to cultivar and environment, and that fiber properties are primarily genetic. Siebert et al. (2006) also concluded that various planting densities ranging from 33,975 to 152,883 plants ha^{-1} had no affect on fiber quality properties.

Despite publications that continuously suggest that lint quality is primarily genetic and is minimally affected by environmental changes that could be created by variable seeding rates, many of these reports do include a statement that some environmental effect altered lint quality. This effect of environment, but not seeding rate, on lint quality is somewhat puzzling considering that others have also found changes in within field environments to affect lint quality (Corwin et al., 2003; Ping et al., 2005; Stanislav et al., 2006; Terra et al., 2006; Ge et al., 2008). If we assume that plant density changes solar interception, early season evapotranspiration, temporal soil water interactions, and plant morphology, the question arises, "*What within field environmental changes affect lint quality that are not being altered by plant density?*" This study will not address or measure all these environmental factors, but will look at soil moisture dynamics.

Environmental effects on cotton lint yield and quality

Regardless of cultivar, environment has an effect on cotton fiber yield and quality. Water stresses, temperature, and solar radiation all affect yields and quality.

Performance of agricultural crops is commonly limited by water and altered by water stress. By lowering seeding rates, available water per plant would increase, especially in soils with low water holding capacities. Looking at irrigation studies might elucidate potential yield and quality responses. Overall, irrigation extends vegetative growth periods, delays cutout by up to seven days, and produces not only larger bolls, but more bolls on distal sympodial positions. Irrigation can also increase lint yield by as much as 35% when compared to dryland produced cotton (Pettigrew, 2004a). Cotton grown under dryland, water stressed conditions, can reduce overall plant stature by reducing leaf area index up to 35%, which can result in a decrease of solar radiation interception by 8%, and ultimately reduce the amount of flowers per plant as well as flowering period. Effects from the reduced leaf amount, size, ability to intercept solar radiation, and flowering amount and period can reduce the number of bolls per unit ground area up to 30% (Pettigrew, 2004b).

While differences in plant growth habits and yields exist between cotton grown under irrigated and dryland conditions, the effect of the two systems on fiber quality is not well known. Irrigation has been shown to increase micronaire and fiber length up to 11 and 2%, respectively, while fiber strength, uniformity and elongation have shown inconsistent responses to both irrigated and dryland conditions (Pettigrew, 2004a). Deficit irrigation is a concept that reduces water applied to the crop, but is expected to reduce excess losses to evaporation and runoff from over application of irrigation water, while increasing the crop's water use efficiency. Studies conducted under deficit irrigation at application rates of 100 to 75% of potential crop evapotranspiration have shown no significant effect on yield. Fiber quality responses to deficit irrigation have been inconsistent, showing significant differences in some years, while not being affected in others (Enciso et al., 2003; Basal et al., 2009). The main effect of irrigation and water availability to cotton has been increases in yield, while some fiber quality effects from both irrigated and water stressed conditions have been inconsistent. These findings may help confirm that fiber quality variability is more a function of cultivar, temperature, and/or solar radiation variations rather than water stress.

Plant densities might affect local temperature environments within a field due to the decrease in the number of plants per unit land area. Temperature variations in controlled growth chamber studies have had mixed effects on cotton lint yield and quality. Lower temperatures, day/nighttime temperatures of 25/17°C, early in the season produce plants with more vegetative branches and can also reduce mainstem elongation, leaf area growth, and biomass accumulation (Reddy et al., 1992a). Cotton grown at 25°C during boll formation can increase fiber length, but decrease fiber length uniformity (Reddy et al., 1999). Reduced temperatures of just 1.5°C were shown to decrease micronaire as well as fiber strength (Pettigrew, 2008).

Warmer regions of the Cotton Belt normally produce cotton with reduced boll size, maturation periods, and yields compared to the more temperate regions (Pettigrew, 2008). Long term excessive heat exposure is detrimental to square retention, boll development, boll maturation, boll size, and fiber quality. In general, higher day and nighttime temperatures can result in reduced square retention (Reddy et al., 1992b). Particularly at 40°C, squares abscise, resulting in less flower retention (Pettigrew, 2008).

Reduction in boll size and shorter boll maturation periods have been observed at temperatures above 25°C, while boll growth increased with temperatures up to 25°C then declined after that threshold temperature (Reddy et al., 1999). For fiber quality, increases in temperature can produce cotton lint with higher micronaire values, strength indices, and length uniformity (Reddy et al., 1999; Pettigrew, 2008).

Solar radiation is another environmental factor like temperature which cannot be controlled by management, but does have an effect on cotton lint yield and quality. Reddy et al. (2004) concluded that a combination of both elevated temperature and ultraviolent light resulted in severe boll loss and yield reductions on uniform plant stands in a growth chamber. Findings of Gao et al. (2003) and Reddy et al. (2004) agree that enhanced ultraviolent light in a growth chamber, levels 9.5% higher than average, reduced plant height, leaf area, and carbohydrate assimilation. Growth chamber studies examining increased solar radiation amounts resulted in reductions in cotton biomass, dry matter weight, lint yield, and fiber quality. Field studies have generally focused on interception of solar radiation by uniform plant stands under different row configurations and not variable seeding rates. Skip-row cotton has shown to intercept more light per land area and have a faster growth rate than conventionally spaced (l-m) cotton (Baker and Meyer, 1966). Uniform distribution of light is obtained from narrow row spacing and cotton planted at higher populations. Row orientation relative to polar north and south and the angle of the sun relative to space play an important role in the amount of light intercepted at the field scale and vary depending on the area of the Cotton Belt in which a study is being conducted (Zhang et al., 2008).

CHAPTER III

MATERIALS AND METHODS

This study was conducted on the Texas AgriLife Research Field Laboratory at the IMPACT (integrated management, precision agriculture, and conservation tillage) Center in Burleson County, TX, during 2008 and 2009. In 2008 a 20.24 ha field, and in 2009 an adjacent 36.44 ha field were used for the experiment. Each field will be referred to by site-year (IMPACT-08, IMPACT-09). Both fields have center-pivot irrigation, and are under a cotton-corn rotation using conventional tillage practices. The Texas Boll Weevil Eradication Program is also being implemented on the site. Cotton variety D&PL 164 BGII/RRF (Bollgard II, Round-up Ready Flex) (Delta and Pine Land Company, Scott, MS) was planted into 762-mm spaced rows on April 1, 2008 and April 7, 2009 at three seeding rates (74,100; 98,800; and 123,500 seeds ha^{-1}). Each seeding rate was replicated in 16-row strips eight times across the field in 2008 and twelve times in 2009. The strips were blocked and order of seeding rates were chosen randomly so that each seeding rate would have full representation as the soils vary across the field (Fig. 1). Because lower phosphorus was found in the sandier soils, IMPACT-08 was fertilized (side dressed), as recommended by the Texas AgriLife Extension Soil, Water, and Forage Testing Laboratory, with isobutylidene diurea (20-10-0) at a rate of 448 kg ha^{-1} (89 kg of elemental N ha^{-1} and 44 kg of elemental P_2O_5 ha^{-1}) at the fourth leaf stage. IMPACT-09 was broadcast pre-season with triple super phosphate (0-46-0) at a rate of 110 kg ha^{-1} (45 kg of elemental P_2O_5 ha^{-1}) and side-dressed with urea ammonium nitrate

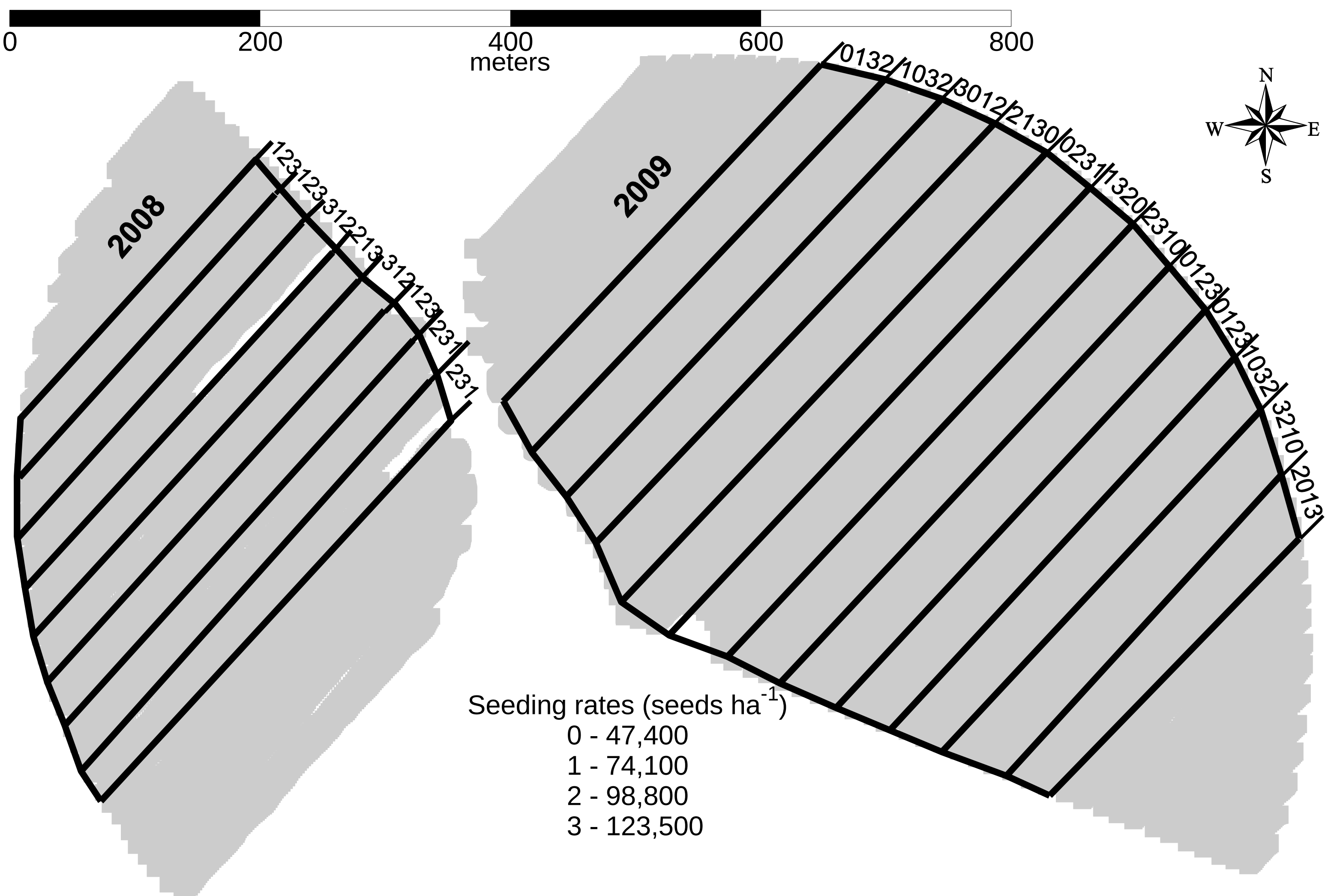

Fig. 1. Schematic of seeding rate blocks with 16-row strips labeled in order of planting within each block, for IMPACT-08 and -09, Burleson, Co, TX.

(32-0-0) at a rate of 280 kg ha^{-1} (89 kg of elemental N ha^{-1}) at the fourth leaf stage. All other chemical applications were made by the Texas AgriLife Research Farm Services and followed conventional practices for the area. Daily values of maximum and minimum temperature and precipitation were measured by a United States Department of Agriculture (USDA) weather station 50 m from the IMPACT-08 site, and 1 km from the IMPACT-09 site. Because the weather station was moved in 2009, precipitation was measured using a tipping bucket rain gauge installed next to the IMPACT-09 field. Heat units were calculated by subtracting 15.5°C from the daily average temperature.

The soils mapped on IMPACT-08 are Yahola sandy loam (Coarse loamy, mixed, superactive, calcareous, thermic Udic Ustifluvent), Weswood silt loam and silty clay loam (Fine silty, mixed, superactive, thermic Udifluventic Haplustept), and Belk clay (Fine, mixed, thermic Entic Hapludert). IMPACT-09 has Roetex Clay (Very-fine, mixed, active, thermic Aquic Hapludert), in addition to the three other soils.

The bulk soil electrical conductivity (EC_a) map used in the experiment was made in the fall of 2007 using an EM38DD electrical conductivity meter surveying in 10-m transects with a logging interval of one second (Geonics, LTD., Mississauga, Ontario, Canada). Recommended calibration techniques and a sunshield for the EM38DD were also used during the survey (Robinson et al., 2004). The vertical dipole EC_a values on IMPACT-08 and IMPACT-09 ranged from 14 to 122 mS m^{-1}. Using the map, three soil zones were delineated, 13 to 53, 54 to 75, and 76 to 122 mS m^{-1} using an unsupervised fuzzy k-means classification of the EC_a values (Ping et al., 2005; Terra et al., 2006). The classification was made in RGui (R Core Development Team, 2004) using the “kmeans” function. The soil data and cotton lint yield and quality measurement sites were selected using a stratified random selection, where the three EC_a zones were the stratification for seeding rates. Though locations were chosen randomly, modifications were made to avoid edge effect of soil properties in each EC_a zone and seeding rate. Site locations randomly assigned within 15-m of a EC_a zone border were moved toward the middle of the EC_a zone so that no observation was within 15-m of a soil EC_a zone border, and each measurement location was situated to be in the middle rows of a 16-row seeding rate strip.

A total of 27 locations were selected for collecting soil and cotton yield data. Twelve sites in each of the three EC_a zones were selected with three replications per seeding rate. An additional replicate for each EC_a zone and seeding rate was added at the end of the season for cotton lint yield and quality measurements. For IMPACT-09, an additional seeding rate of 49,400 seeds ha^{-1} was added, totaling 36 soil data and cotton lint yield and quality measurement locations, with an additional cotton lint yield and quality replicate for each EC_a zone and seeding rate added at the end of the season (Fig. 2). Post-emergence stand densities were quantified by measuring three feet of row across twelve rows near each measurement site. Target seeding rates and actual seeding rates for IMPACT-08 and IMPACT-09 are reported in Table 1.

After planting and stand establishment 3.81-cm diameter soil cores were collected, in the middle of the bed at each measurement site, using a tractor-mounted Giddings probe (Giddings Machine Company, Windsor, CO). After cores were taken, a

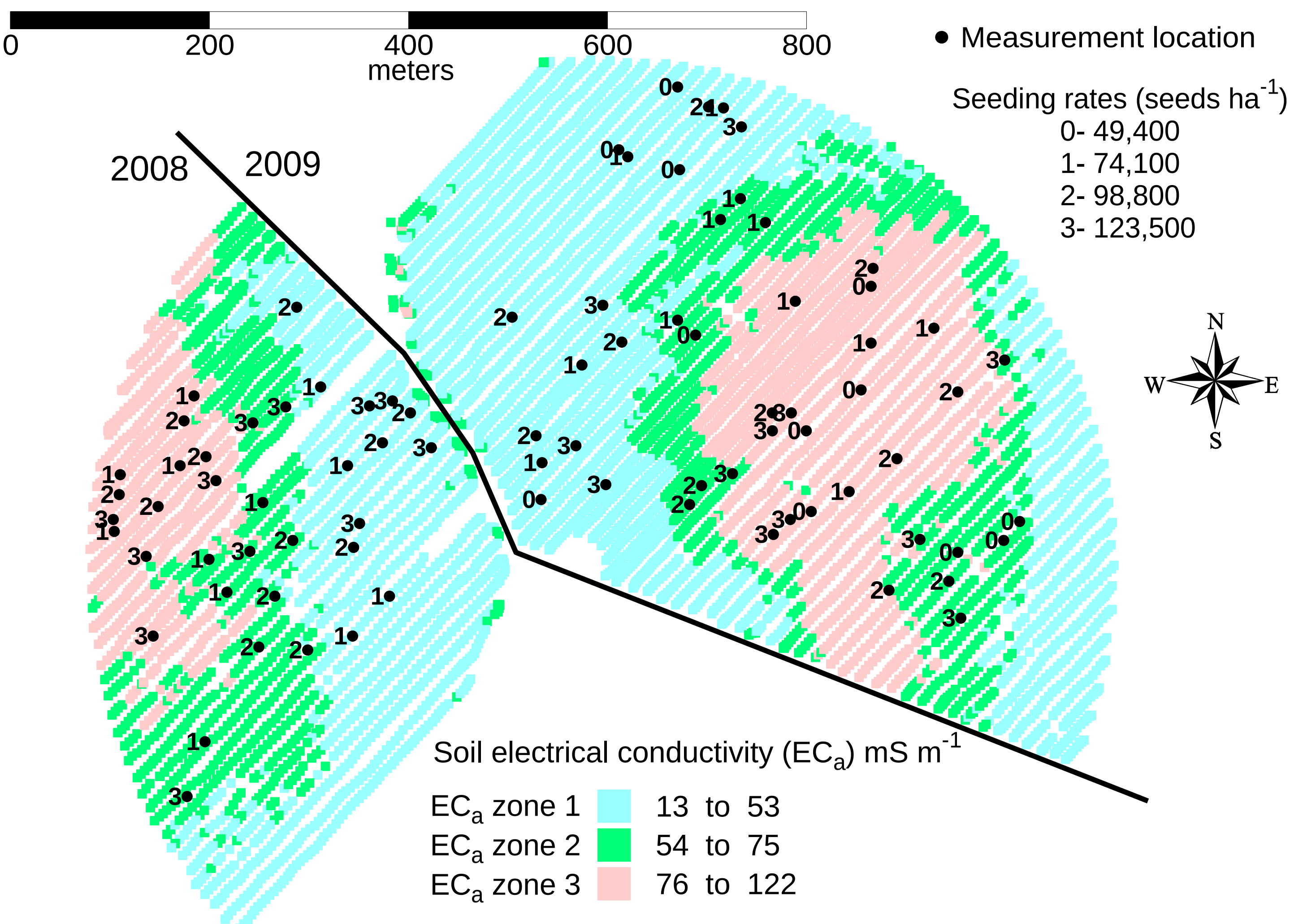

Fig. 2. Soil electrical conductivity (EC_a) map of IMPACT-08 and -09 classified into three zones using unsupervised fuzzy k-mean classification of EC_a. Measurement locations are labeled by seeding rate.

Table 1. Target and actual seeding rates for IMPACT-08 and -09. Each actual seeding rate is an average of four replicates within each EC_a zone and target seeding rate.

EC_a zone	49,400	74,100	98,800	123,500
	----------seeds ha^{-1}----------			
		Actual seeding rate IMPACT-08		
1	------------------	66,900(9)†	94,000(2)	107,200(6)
2	------------------	68,500(10)	92,500(8)	114,400(8)
3	------------------	85,300(20)	97,600(3)	118,000(8)
		Actual seeding rate IMPACT-09		
1	42,200(2)	78,900(7)	102,000(9)	139,500(12)
2	43,800(2)	86,100(5)	107,200(12)	117,600(6)
3	40,200(15)	72,900(12)	90,500(6)	115,300(8)

† number in parenthesis indicates the coefficient of variation (CV%) for the four replicates within each EC_a zone and actual seeding rate.

5.08-cm auger cleaned out excess soil and 5.08-cm (inside diameter) aluminum access tubes were installed to a depth of 150 cm. Soil cores were sectioned into 20-cm increments, except for the top 30 cm, e.g. 0 to 30, 30 to 50, 50 to 70…130 to 150 cm. Soil core sections were air dried, ground, and passed through a 2-mm sieve. Soil texture was determined using the hydrometer method (Gee and Or, 2002); sands were wet sieved. Complete particle size analysis data can be found in Appendix A.

Soil water measurements were collected at each of the 27 and 36 measurement sites for IMPACT-08 and IMPACT-09, respectively, using a neutron moisture sensor, CPN 503 DR (Campbell Pacific Nuclear, Concord, CA). Measurements were taken at 20-cm increments, from 20 to 120 cm deep. The moisture sensor was calibrated using in situ volumetric water content measurements at field capacity and a relatively dry soil moisture condition. Dry soil calibrations were made in late summer 2007 in a low, medium, and high EC_a soil, while similar wet soil calibrations were made in early 2009. At each calibration site and moisture content, soil moisture measurements were collected using the neutron moisture sensor at 20, 40, 60, 80, 100, and 120 cm deep. Once sensor measurements were completed, four sets of 7.62-cm diameter soil cores were removed to a depth of 130 cm, on four sides of the aluminum access tube. The 7.62-cm diameter cores were sectioned into 10 cm increments, weighed immediately, oven dried at 105°C, and weighed dry.

Volumetric water content (m^3 m^{-3}) of the soils at each calibration site was then calculated by averaging the four nearby cores at each depth. A calibration equation was then developed at each calibration site by fitting a linear equation between the measured volumetric soil water content and the neutron moisture sensor count ratio. The root mean square error (RMSE) values for the calibrations were 0.023, 0.011, and 0.016 m^3 m^{-3} for the sandy, silty, and clayey sites, respectively, meaning the measurement accuracy of the neutron moisture measurements was about 0.02 m^3 m^{-3} (Fig. 3). Particle size analysis was also conducted for each calibration site. Calibration equations for each of the 27 measurement sites in 2008 and 36 in 2009 were selected based on matching the particle size of the calibration to the particle size of the measurement sites.

To estimate plant available water (PAW) for each measurement site, an estimate of permanent wilting point for each soil was needed. Gravimetric soil water content was measured at -1500 KPa (-15 bar, or permanent wilting point) on a subset of soil samples (n = 41) ranging in clay content from 7 to72% using the SC-10A thermocouple psychrometer (Decagon Devices, Pullman, WA) (Andraski and Scanlon, 2002). The gravimetric water content (g g^{-1}) was measured and converted to volumetric (m^3 m^{-3}) using the bulk densities of the soil samples taken during the neutron probe calibrations. Once the soil samples at -1500 KPa were converted to volumetric water content, a polynomial relationship between volumetric water content at -1500 KPa and the clay content was used to estimate the volumetric water content at permanent wilting point for all measurement locations in the study (Fig. 4). Plant available water for each measurement location was estimated using the linear equation. The amount of PAW in the soil profile at each measurement site was estimated by subtracting the highest measured water content in the field using the neutron probe from the water content at -1500 KPa (permanent wilting point). The soil was assumed at field capacity during the

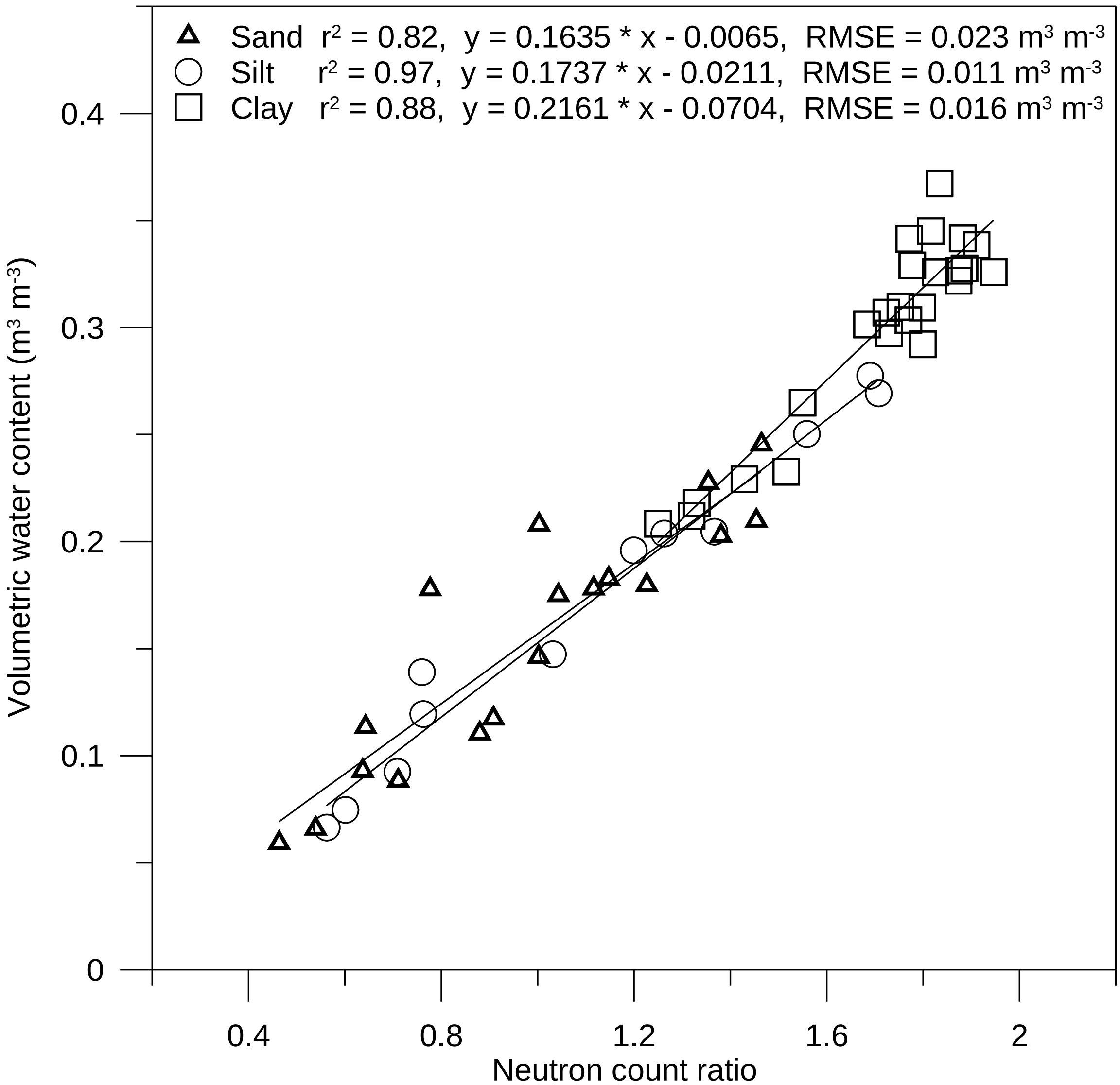

Fig. 3. Calibration equations used to convert neutron moisture measurements to volumetric water content for each soil texture. RMSE is root mean square error for each calibration equation.

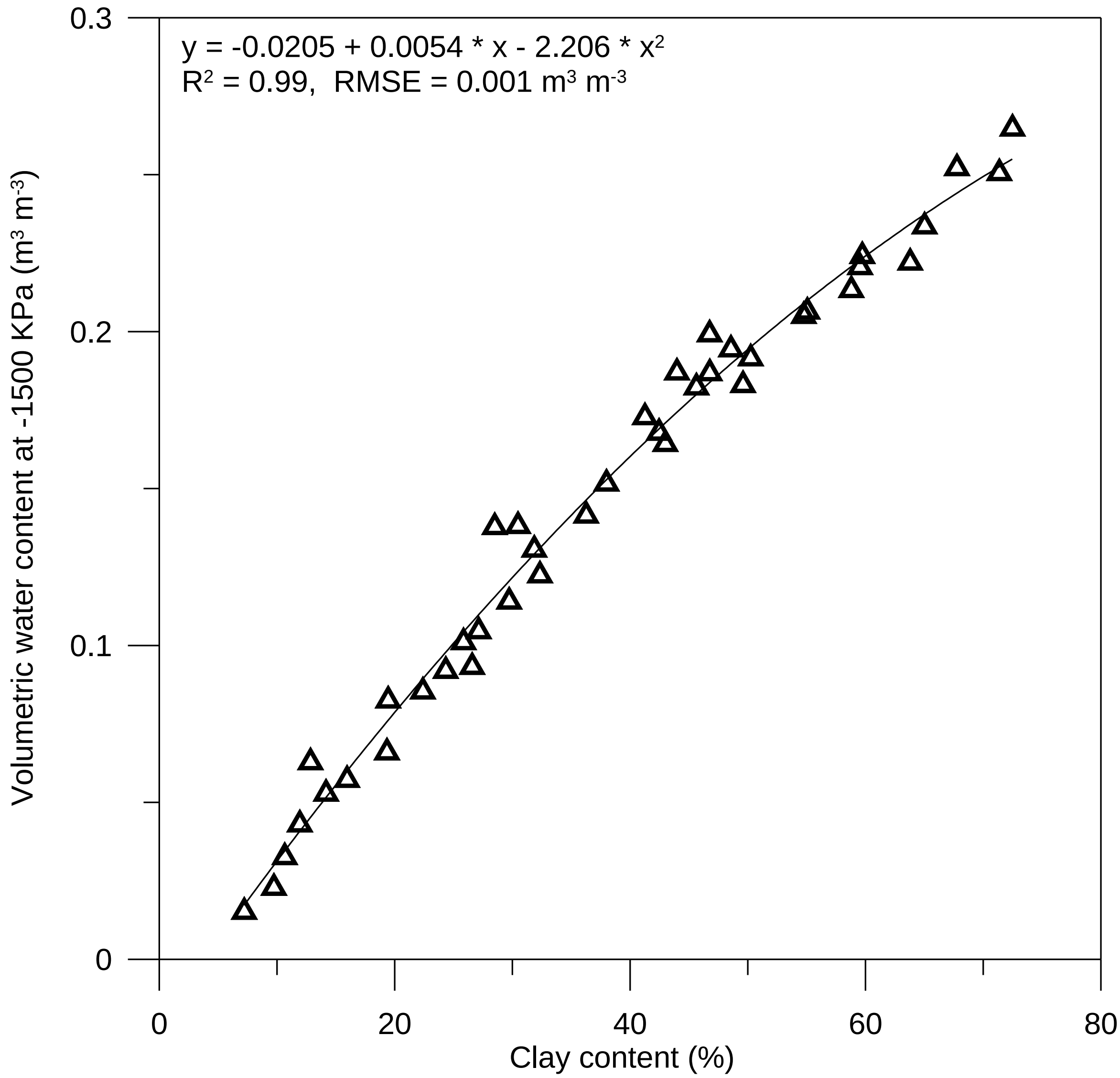

Fig. 4. Calibration equation used to estimate volumetric water content at wilting point of IMPACT-08 and -09 soils using clay content (%).

first day a neutron moisture measurement was taken. Values of cumulative soil water use were calculated by subtracting the volumetric water content of the soil during each measurement day from the volumetric water content of the soil at field capacity.

Cotton growth rate was monitored using the COTMAN plant mapping program (University of Arkansas, Fayetteville, AR). COTMAN was used to measure nodes above first square, nodes above white flower, and interpolate when boll fill period occurred. Measurements were only collected on a weekly basis and dates pertaining to first flower, peak flower, and boll fill period are estimates.

Ten days after defoliation, each of the 36 and 48 measurement sites were hand-harvested on September 2, 2008 and September 9, 2009, respectively. At each site, 5.5 m of three rows of cotton plants were harvested by cutting plants in the row containing the neutron access tube, and one row on each side. Whole plants were put into tarps and marked with the location identification number, and then transported to the lab for processing and weighing. In the lab, bolls were hand-picked, weighed, and then ginned using a 10-saw Eagle Cotton floor gin (Continental Gin Company, Pratteville, AL).

After ginning, the lint was weighed and the bulk samples of lint were sub-sampled for 0.15 kg of lint (according to testing facility requirements). These samples were tested at the Fiber and Biopolymer Research Institute, Texas Tech University, (Lubbock, TX). These samples were High Volume Instrument (HVI) and Advanced Fiber Information System (AFIS) tested for lint quality.

SAS statistical software (SAS, 2002), was used to analyze lint yield and quality data using proc GLM (General Linear Model) and protected Fischer's tests at an $\alpha <$

0.05. Plant available water and cumulative soil water use between EC_a zones, seeding rates, soil depths, dates of the measurements and all interactions were analyzed using proc mixed and protected Fischer's test at an $\alpha < 0.05$. All regression analysis was performed using the "spdep" package in RGui (R Development Core Team, 2004).

CHAPTER IV

RESULTS AND DISSCUSSION

Weather data

The 47-yr. average rainfall for the months of April through August in College Station, TX is 431 mm. Cumulative rainfall for the same period during the summers of 2008 and 2009 was 398 and 278 mm, respectively, which was 33 and 153 mm below the 47-yr. average (Fig. 5). Overall, both 2008 and 2009 were dry resulting in irrigation beginning in early June and applied weekly until physiological crop cutout (nodes above white flower, NAWF=5).

The 47-yr. average minimum and maximum temperatures for College Station, TX for the months of April to August are 20°C and 32°C, respectively. The minimum and maximum temperatures for 2008 were below the historical average for most of the growing season, while the summer of 2009 had above average nighttime minimum and daytime maximum temperatures throughout the entire growing season (Table 2). The warmer temperatures in 2009 resulted in more growing degree days ($DD_{15.5}$) than 2008. The total amount of $DD_{15.5}$ received in 2008 and 2009 was 2664 and 2929, respectively (Fig. 6).

Plants in IMPACT-09 accumulated 50% more growing degree days during first flower, peak flower, and boll fill periods compared to plants in IMPACT-08 (Fig 6, Table 3). Furthermore, maximum temperatures during this time period were 3 to 4°C warmer in 2009. Such stress events would result in the plant not dedicating energy

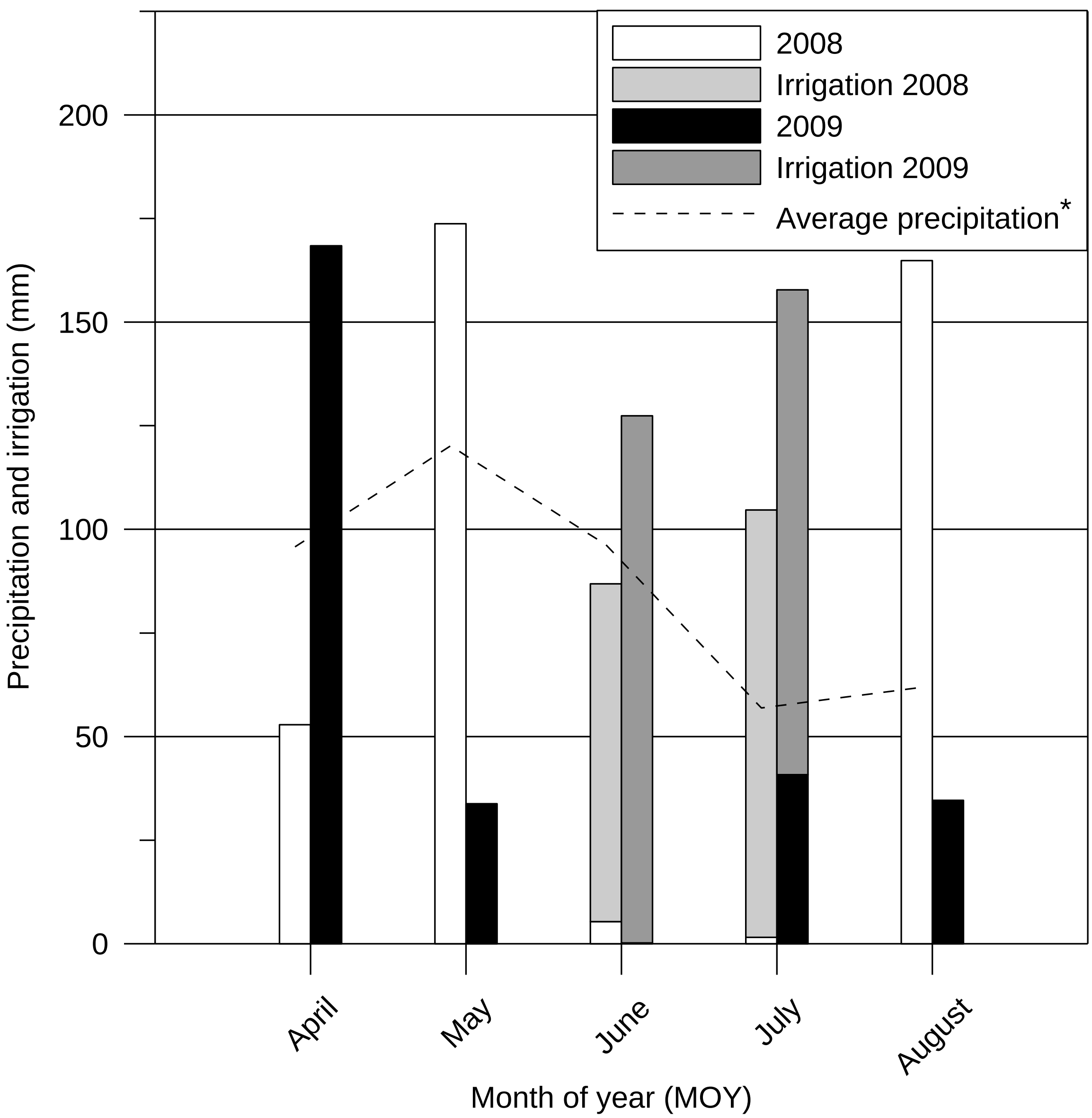

Fig. 5. Monthly precipitation and irrigation for 2008 and 2009. * indicates a 47-year precipitation average for College Station, TX.

Table 2. Summary of maximum and minimum temperatures for growing seasons 2008 and 2009 and the 47-year average for College Station, TX.

Growing season	April	May	June	July	August
	---------------------------Maximum Temperature °C---------------------------				
2008	25	29	32	34	35
2009	26	31	36	37	37
47-yr. average	26	29	33	35	35
	---------------------------Minimum Temperature °C---------------------------				
2008	14	18	22	23	23
2009	15	20	23	25	23
47-yr. average	14	18	22	23	23

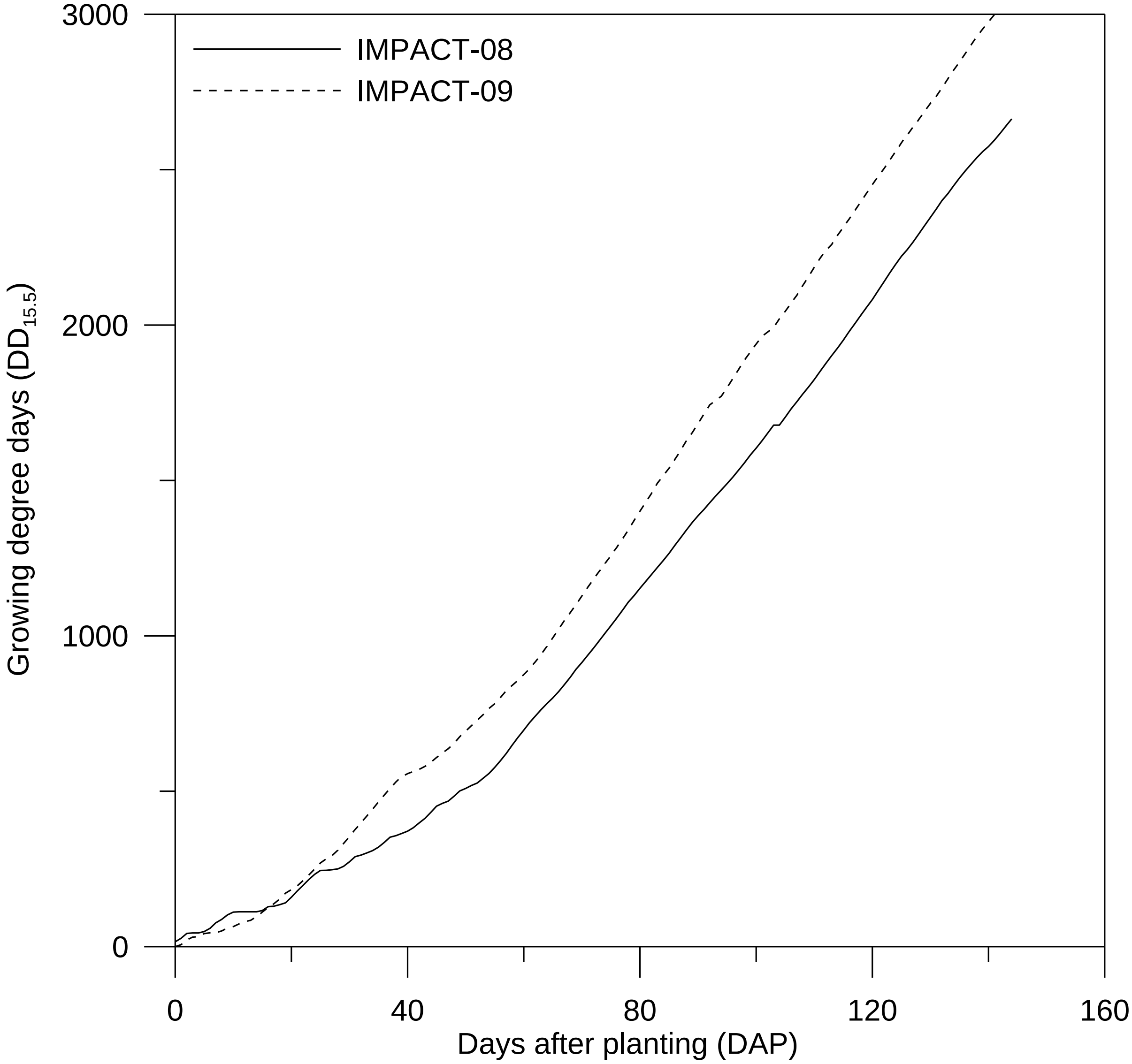

Fig. 6. Cumulative growing degree days ($DD_{15.5}$) as a function of days after planting for 2008 and 2009.

Table 3. Physiological stage, date, days after planting, and growing degree days accumulated up to each stage based on COTMAN data for IMPACT-08 and -09.

Physiological Stage	Date	Days after planting	Growing degree days accumulated
		IMPACT-08	
First flower	June 3-6†	63-66	760-820
Peak flower	June 16	76	1060
Boll fill	June 23-July 14	83-104	1220-1680
		IMPACT-09	
First flower	June 6-8	61-63	875-915
Peak flower	June 21	76	1300
Boll fill	June 26-July 21	81-104	1400-2040

† Date at which each physiological stage occurred is an estimate based on field measurements.

toward reproductive growth, but more toward responding to stress. Elevated temperatures can decrease maturation periods and boll size, as well as increase square and boll abscission, which all reduce yield (Reddy et al., 1992, 1999). At temperatures above 35°C, which frequently occurred in June and July 2009, the rubisco activase enzyme constrains the photosynthetic potential in leaves (Salvucci and Crafts-Brandner, 2004a, 2004b).

Due to the dry, hot summers of both 2008 and 2009, 25.4 mm of irrigation was applied weekly as recommended by the Texas AgriLife Farm Service. Irrigation was applied for seven weeks beginning on June 12 in 2008, and for eight weeks beginning on June 2 in 2009. The total amount of water received, either through precipitation or irrigation was 576 and 481 mm in 2008 and 2009, respectively.

Soil properties and apparent electrical conductivity (EC_a)

The soils in IMPACT-08 and -09 ranged from well drained Ustifluvents with high permeability to somewhat poorly drained Hapluderts with low permeability. While both IMPACT-08 and -09 included different fields, each was similar in the range of soil types. IMPACT-08 contained soils with clay contents ranging from 20 to 48 %, and clay contents between each EC_a zone were significantly different (Table 4). IMPACT-09 soil clay content ranged from 16 to 53 % and contained significance between the three EC_a zones as well (Table 4). Soil EC_a had a strong linear response to soil clay content. The response was the same in both fields with an r^2 value of 0.86 (Fig. 7).

The estimated soil water holding capacities for EC_a zones 1, 2, and 3 were 327, 390, and 449 mm on the IMPACT-08 site and 278, 405, and 475 mm on the IMPACT-

Table 4. Average clay content, soil water holding capacity, and plant available water for IMPACT-08 and -09 partitioned into three apparent electrical conductivity (EC_a) zones.

EC_a zone	Clay content	Soil water holding capacity	Plant available water
	------------%----------	---------mm---------	---------mm---------
		IMPACT-08	
1	20C†	327C	204
2	31B	390B	216
3	48A	449A	214
		IMPACT-09	
1	16C	278C	177B
2	37B	405B	199A
3	53A	475A	192AB

† A, B, and C indicate significant differences between EC_a zone within each site-year (p-value < 0.05).

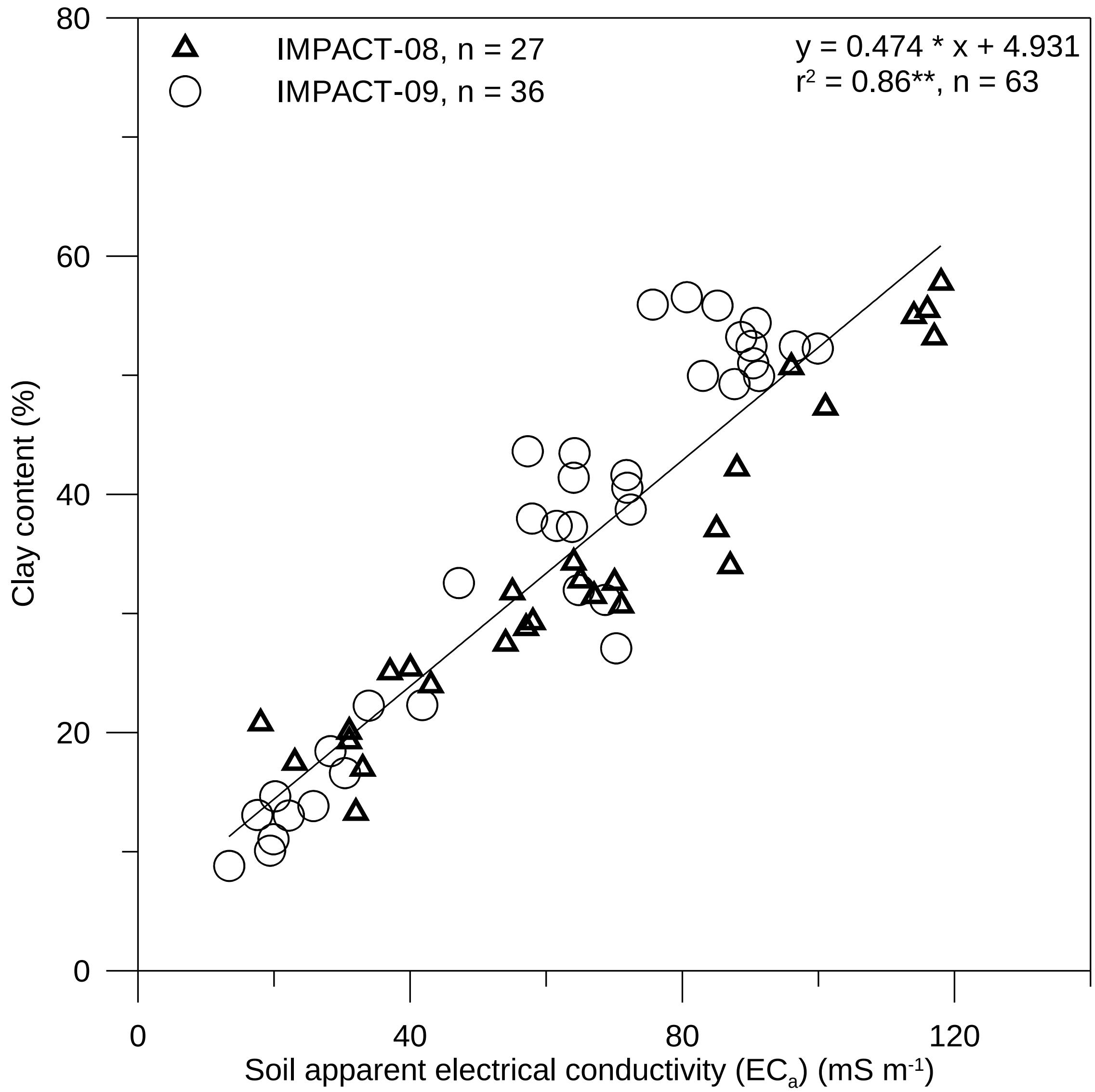

Fig. 7. Soil clay content (%) averaged from 0 to 130 cm deep as a function of soil apparent electrical conductivity (EC_a) for IMPACT-08 and -09. ** indicates significance at $\alpha < 0.01$.

09 site, respectively. Each EC_a zone for IMPACT-08 and -09 had different soil water holding capacities (Table 4). The estimations of soil water holding capacity are intended to represent soil water content at field capacity, but could vary based on history and amount of precipitation received in the winter and spring prior to planting.

The relationship between soil EC_a and soil water holding capacity during both 2008 and 2009 is a second order polynomial (Fig. 8). Slight differences in the trend between soil EC_a and soil water holding capacity in IMPACT-08 and -09 likely illustrate differences in water recharge histories of the fields. Soil water holding capacities in 2008 are higher than 2009. In fact, 2009 may not have reached field capacity by the beginning of the season, spring 2009. This could have been the case for IMPACT-09 considering the area had above normal temperatures and below normal precipitation during the winter months prior to planting. Regression, with both IMPACT-08 and -09 combined, indicated a polynomial trend R^2 of 0.87 (p-value < 0.001).

The estimated maximum PAW for EC_a zones 1, 2, and 3 were 204, 216, and 214 mm for IMPACT-08 and 177, 199, and 192 mm for IMPACT-09, respectively. The maximum amount of plant available water was not significantly different between EC_a zones for IMPACT-08. For IMPACT-09, EC_a zone 2 contained significantly more plant available water than EC_a zone 1 (Table 4).

Soil EC_a measurements were not correlated well to PAW. Because soil EC_a measurements are strongly correlated to soil clay content and soil water holding capacity, our PAW calculations essentially removed information on clay content (Fig. 4). It is logical that soil EC_a and PAW are weakly correlated.

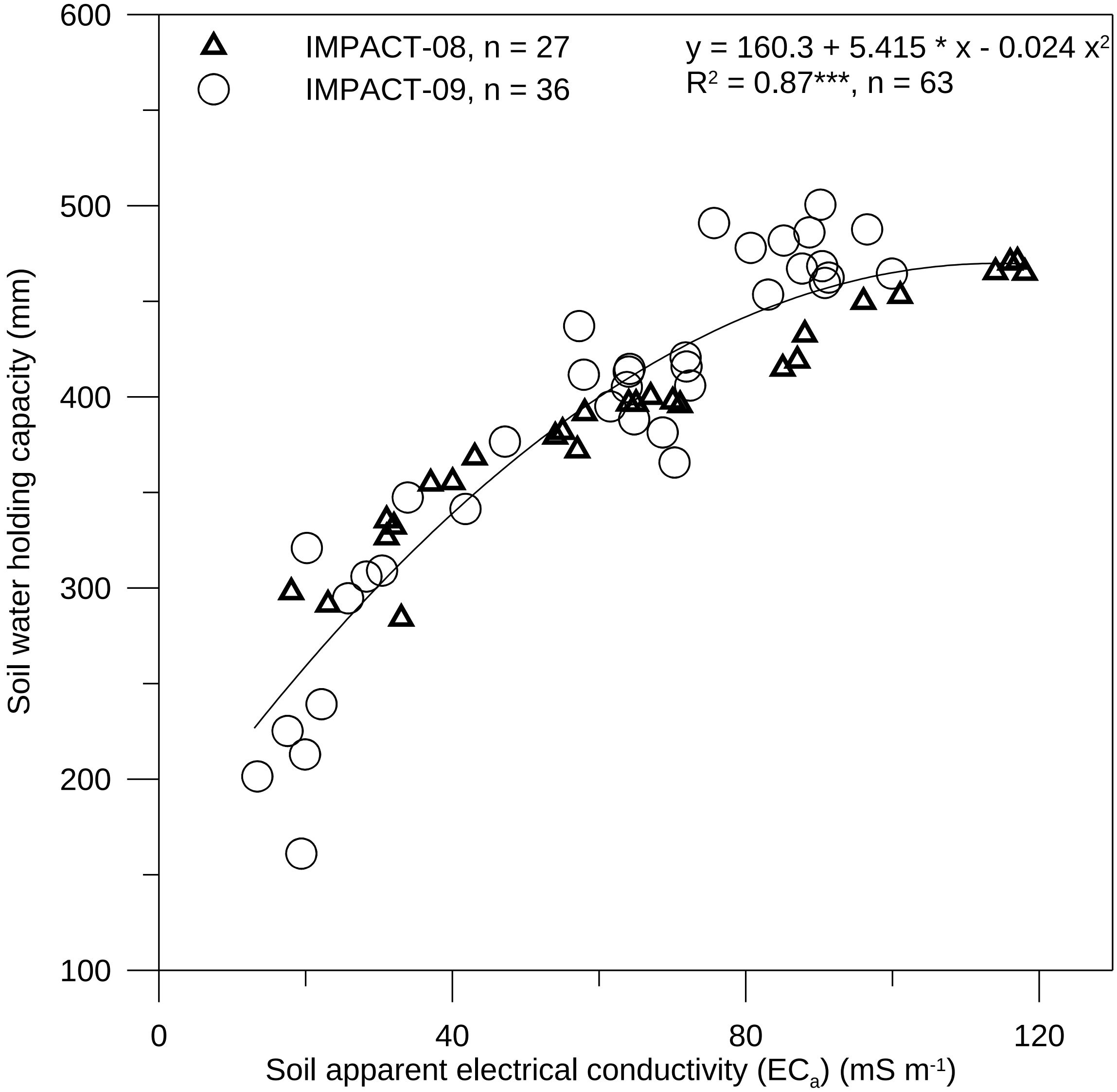

Fig. 8. Soil water holding capacity as a function of soil apparent electrical conductivity (EC_a) for IMPACT-08 and -09. *** indicates significance at $\alpha < 0.001$.

The strong relationships between soil clay content and soil EC_a as well as soil water holding capacity and soil EC_a for both IMPACT-08 and -09 indicate that in our study sites, the soil EC_a responded predominately to soil texture (Rhoades et al., 1976; Harvey and Morgan, 2009). The in-field variability captured by the soil EC_a measurements reflects the variability in soil clay content, and in turn the variability of soil water holding capacity.

Plant available water (PAW)

There was no effect of variable seeding rates on the rate at which PAW was used within the EC_a zones; therefore, statistical analysis of plant available water was combined within each EC_a zone, n=9 for IMPACT-08 and n=12 for IMPACT-09. Subsequently, PAW and cumulative soil water use is regarded to and reported by only EC_a zone.

The total amount of PAW from 10 to 130 cm deep was not significantly different across the three EC_a zones, indicating that regardless of the EC_a zone, the IMPACT-08 field began the growing season with relatively the same amount of soil water available to the plant, 211 mm (Table 5). Analysis of PAW at individual depths indicated significant differences by date and between EC_a zones. The large differences by date and EC_a zones occurred in the 40-, 60- and 80-cm depth increments. In most instances, the overall trend for the 40-, 60- and 80-cm depths was that as the season progressed, the amount of PAW was significantly less in EC_a zone 1 when compared to EC_a zones 2 and 3 (Fig. 9). Nonetheless, actual plant wilting, an indicator of water stress, was observed only within EC_a zone 1 during the month of July. Considering a neutron probe error of 0.02 m^3 m^{-3},

Table 5. Total plant available water (PAW) (0-130 cm) for each EC_a zone at each date for IMPACT-08 and -09.

Date 2008	EC_a zone 1	EC_a zone 2	EC_a zone 3	Date 2009	EC_a zone 1	EC_a zone 2	EC_a zone 3
	--------------mm----------------				----------------mm----------------		
		IMPACT-08				IMPACT-09	
20-May	204Aa†	216Aa	214Aa	19-May	165Ab	199Aa	183Aab
27-May	198Aa	212Aa	206Aa	1-Jun	166Ab	197Aa	187Aab
9-Jun	174Bb	189Bab	196ABa	8-Jun	149ABb	194Aa	186Aa
15-Jun	158Bb	170Cab	181BCa	15-Jun	122BCb	180Bab	192Aa
23-Jun	137Cb	145Dab	162CDa	22-Jun	116CDb	165Cab	180Aa
1-Jul	121CDb	127Eb	147DEa	30-Jun	100CDb	140Dab	161Ba
7-Jul	109DEb	115Fb	133Ea	7-Jul	85Da	132Dab	152Ba
14-Jul	91EFb	96Gab	111Fa	13-Jul	165Ab	117Eab	127Ca
21-Jul	77Fb	83Hb	100Fa	20-Jul	166Ab	99Fa	96Da

† Means within a column followed by the same uppercase letter or in a row (within each site-year) followed by the same lowercase letter are not statistically different (p-value < 0.05).

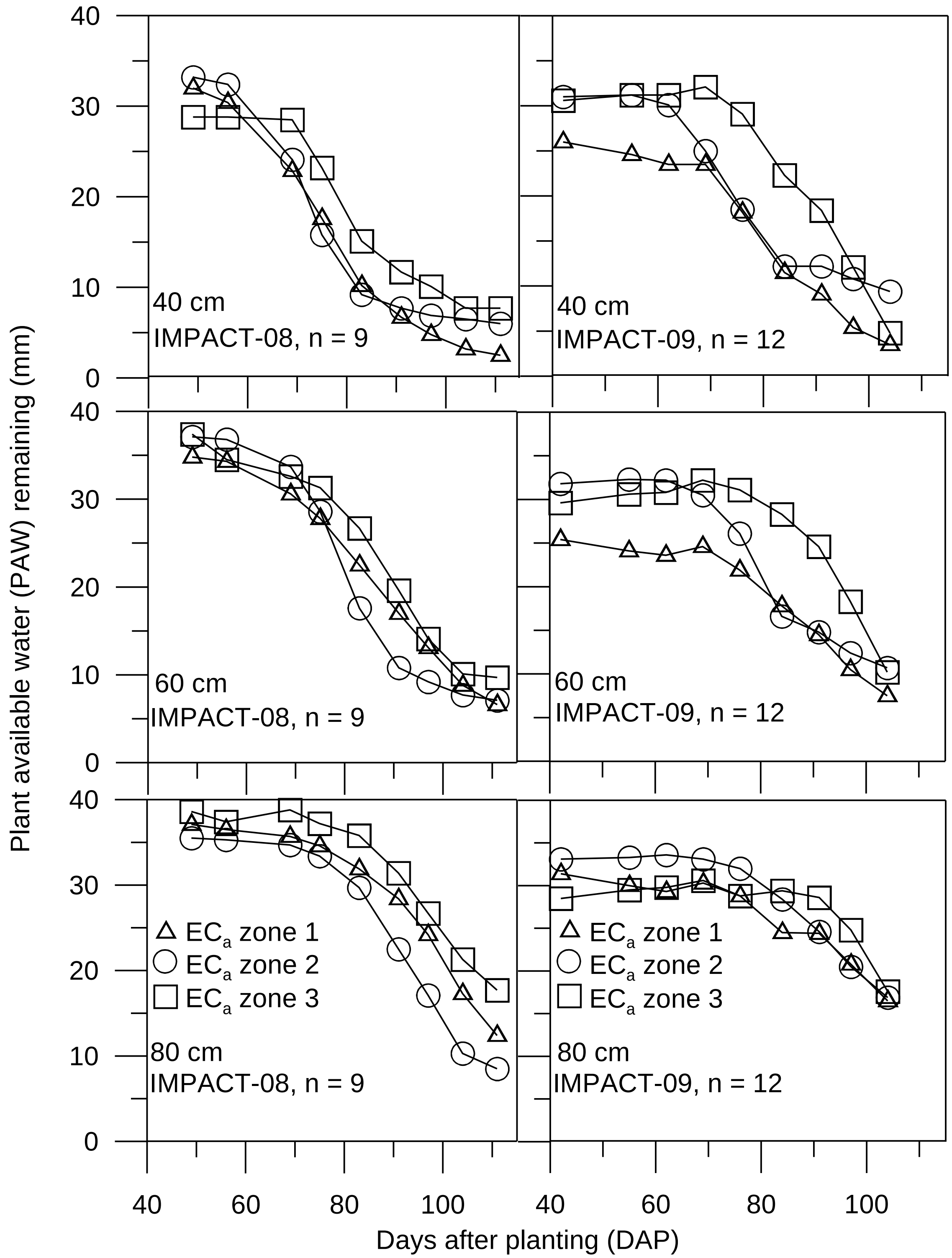

Fig. 9. Plant available water (PAW) remaining (mm) as a function of days after planting (DAP) for IMPACT-08 and -09, depths 40- 60- and 80-cm.

PAW changes of ≤ 4 mm are within the instrument error. PAW differences in the 100- to 120-cm range and between EC_a zones were negligible. It is likely that water was used at these depths after moisture measurements were stopped (NAWF = 5).

Total PAW in EC_a zones 1, 2, and 3 for IMPACT-09 was 177, 199, and192 mm, respectively. The total PAW of EC_a zone 1 was significantly less than EC_a zone 2. All EC_a zones for IMPACT-08 contained 15 to 24 mm more plant available water at the time moisture measurements began when compared to IMPACT-09 (Table 5).

Despite the fact that IMPACT-09 contained less PAW compared to IMPACT-08 at the point when moisture measurements were first taken, PAW of IMPACT-09 followed similar trends between EC_a zones and date. PAW at depths 80-, 100-, and 120-cm was not significantly different across the EC_a zones, indicating that roots were not forced to use water extensively from those depth increments. Water was likely utilized at the 80-, 100-, and 120-cm depths after cessation of both irrigation and moisture measurements (NAWF = 5).

Overall, EC_a zone 3 contained significantly more PAW compared to EC_a zones 1 and 2, throughout the season (Table 5). This observation would suggest that EC_a zone 3 was never water deficient for both IMPACT-08 and -09, and input costs could be decreased through reduced irrigation. Similar to IMPACT-08, IMPACT-09 plants in EC_a zone 1 exhibited wilting during July. Based on PAW and ease of accessible water, lint yield should have been greatest in EC_a zone 2, regardless of seeding rate and site-year. Complete PAW analysis can be found in Appendix B.

Soil water use and cotton development

Cumulative soil water use was analyzed for differences across EC_a zones and by date. Seeding rate did not affect soil water use; therefore, all analyses were performed by EC_a zone. Soil water use values represent only the loss of soil water storage and therefore do not include water from precipitation, irrigation, and overland flow.

Although IMPACT-08 and -09 were not statistically comparable, year to year variations in soil water use were seen. Generally, plants in IMPACT-08 used more soil water in all EC_a zones. However, IMPACT-08 also received 95 mm more water than IMPACT-09 (Fig. 5).

Cumulative soil water use in EC_a zones 1 and 2 indicates that the plants within these zones began to use stored soil water at first flower (Tables 3 and 6). In comparison, EC_a zone 3 did not begin to use stored soil water until peak flower, a week later (Tables 3 and 6). Once boll fill began, plants in all EC_a zones used significant amounts of soil water weekly (Tables 3 and 6). At the end of the season, plants in EC_a zones 1 and 2 used significantly more soil water (19 and 25 mm, respectively) than plants in EC_a zone 3 (Table 6). Based on cumulative soil water use, it was not evident that plants in EC_a zone 3 were water stressed at any point in the season and did not need to use more soil water for the plants to develop.

In IMPACT-09, similar trends were observed; however, irrigation was initiated 10 days earlier and calculations of cumulative soil water use in EC_a zone 3 indicated potential subsurface lateral movement of water. Plants in EC_a zones 1 and 2 did not use stored soil water until peak flower and plants in EC_a zone 3 were two weeks behind in

Table 6. Cumulative soil water use (0-130 cm) for each EC_a zone at each date for IMPACT-08 and -09.

Date 2008	EC_a zone 1	EC_a zone 2	EC_a zone 3	Date 2009	EC_a zone 1	EC_a zone 2	EC_a zone 3
	--------------mm----------------				----------------mm----------------		
		IMPACT-08				IMPACT-09	
20-May	0A†a‡	0Aa	0Aa	19-May	0Aa	0Aa	0Aa
27-May	5Aa	6Aa	2Aa	1-Jun	8ABa	4Ab	3Ac
9-Jun	29Ba	27Ba	12ABa	8-Jun	12ABa	7Ab	4Ac
15-Jun	45Ca	46Ca	22Bb	15-Jun	11Ba	19Ba	3Ab
23-Jun	67Da	70Da	43Cb	22-Jun	28Ca	34Ca	10Ab
1-Jul	82Ea	88Ea	57Db	30-Jun	54Da	59Da	27Bb
7-Jul	95Fa	101Fa	69Eb	7-Jul	61Da	67Da	36Bb
14-Jul	112Gb	120Ga	90Fc	13-Jul	77Ea	82Ea	55Cb
21-Jul	126Ha	132Ha	107Gb	20-Jul	92Fa	100Fa	88Da

† Means within a column followed by the same uppercase letter or in a row (within each site-year) followed by the same lowercase letter are not statistically different (p-value < 0.05).

soil water use (Tables 3 and 6). In EC_a zone 3 no soil water was ever lost below 90 cm and from 70-80 cm only 10 mm of water was lost. Local topography (i.e. EC_a zone 3 encompassed a closed depression) and soil moisture readings indicate that EC_a zone 3 was accumulating water through subsurface lateral flow. Cumulative soil water use was not significantly different between EC_a zones, although plants in EC_a zone 2 used about 10 mm more soil water.

For IMPACT-08, soil water use in EC_a zones 1 and 2 at the 40-, 60-, and 80-cm depths were significantly higher throughout the season compared to EC_a zone 3 (Fig. 10). Water use at 40- to 80-cm depths suggests that plants in EC_a zones 1 and 2 established roots deeper in the soil profile earlier in the season to meet water use demands. The plants in EC_a zone 3 were meeting water demand from shallower depths longer into the season. If plants in EC_a zone 3 were not as limited for water, they could spend more energy on fruit development rather than extending root growth during the fruiting stage. Further, evidence that plants within EC_a zone 1were water stressed during the reproductive stage was observed through plant wilting during July. Similar observations were made for IMPACT-09.

Though plants in EC_a zone 3 ultimately used the same amount of soil water the water was pulled at more shallow depths in the soil profile, and prior to NAWF = 5. The rooting depth of the plants within EC_a zone 3 was two weeks behind plants in EC_a zones 1 and 2 (Table 6). Based on soil water use at 40-, 60-, and 80-cm depths EC_a zone 2 supplied more soil water to the plants. At 40 cm EC_a zones 1 and 2 were similar; at 60 cm EC_a zone 2 supplied more soil water in late June and all July; and at 80 cm EC_a

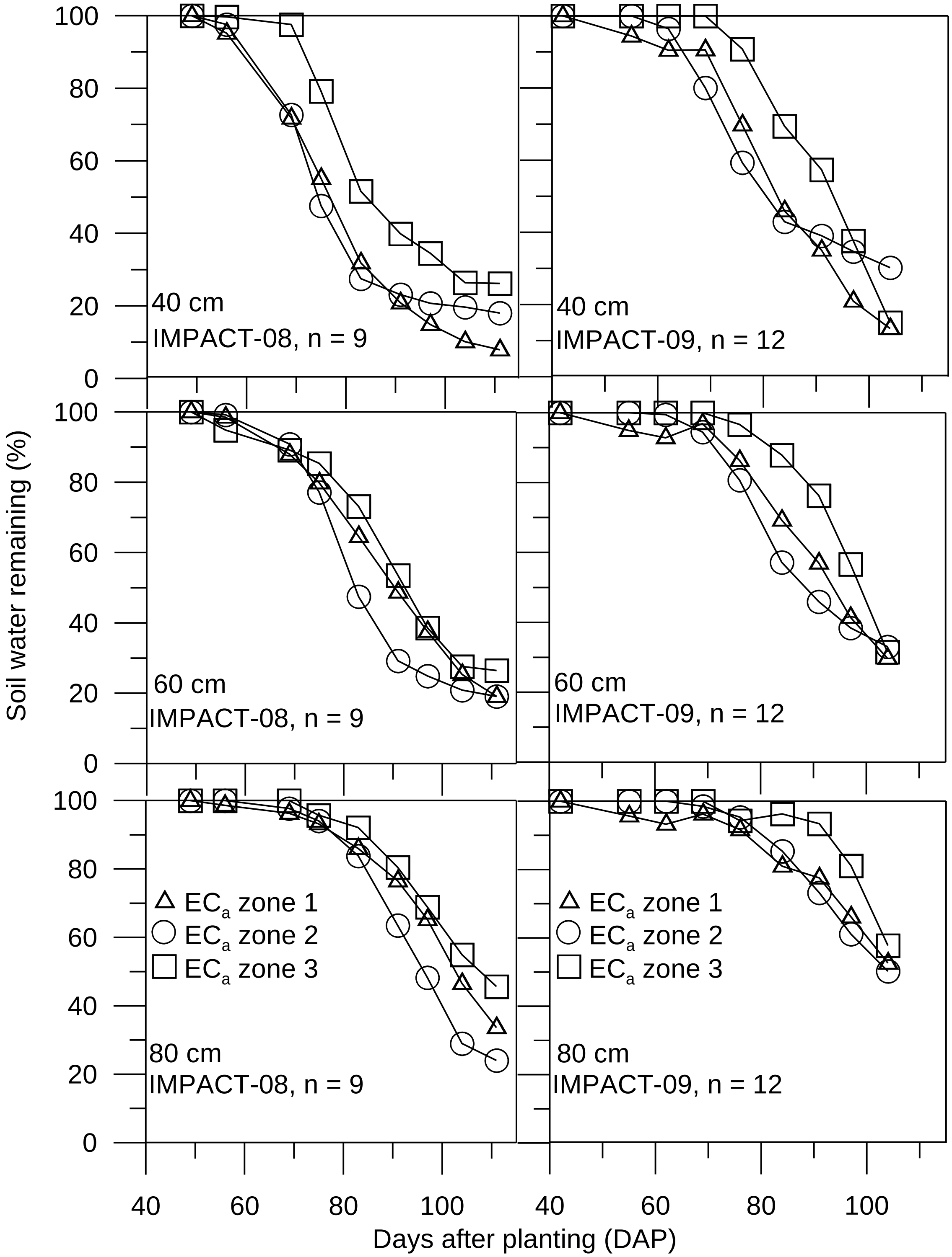

Fig. 10. Soil water remaining (%) as a function of days after planting (DAP) for IMPACT-08 and -09, depths 40- 60- and 80-cm.

zones 1 and 2 were similar (Fig. 10) Complete soil water use analysis can be found in Appendix C.

Cotton lint yield

Lint yield was higher for IMPACT-08 compared to IMPACT-09. In general, seeding rate had no affect on lint yield. Two instances suggest some yield benefits to lower seeding rates, e.g. 74,100 seeds ha^{-1} in IMPACT-08 and 49,400 seeds ha^{-1} in IMPACT-09 (Table 7). Variable rate seeding studies over the last decade have all concluded that cotton lint yield does not vary at seeding rates from 19,992 to 152,833 seeds ha^{-1}. Lack of lint yield variability is primarily attributed to plant compensation; lower plant populations produce more and larger bolls compared to higher populations (Jones and Wells, 1998; Bednarz et al., 2000; Bednarz et al., 2005; Siebert et al., 2006). EC_a zone clearly influenced lint yield both years. Further analysis will elucidate the plant-water interactions that influenced lint yield.

Cotton lint yield is shown to increase with soil properties such as clay content, water holding capacity, and sometimes EC_a (Ping et al., 2005; Iqbal et al., 2005; Terra et al., 2006). Results of this study agree with the literature. In IMPACT-08, where temperature most likely did not inhibit photosynthesis and therefore transpiration, lint yield increased linearly with clay content (Fig. 11). However, in IMPACT-09 where it is suspected that high temperatures inhibited transpiration, lint yield increased with clay content up to 40% clay (Fig 11). Though there is more variation about the trendline in IMPACT-09, there is a single linear relationship between lint yield in both years and water holding capacity (Fig. 12). Surprisingly, total PAW was relatively uniform across

Table 7. Average of the lint yield measurements from IMPACT-08 and -09. Average values represent the four replications within each seeding rate and EC_a zone.

Seeding rate	EC_a zone 1	EC_a zone 2	EC_a zone 3
-------seeds ha^{-1}------		----kg ha^{-1}----	
		IMPACT-08	
74,100	1237.9Ab†	1089.7Ab	1481.0Aa
98,800	960.8Bb	1046.5Ab	1309.1Aa
123,500	999.5Bb	1121.9Ab	1306.5Aa
		IMPACT-09	
49,400	731.4Ab	1316.9Aa	1259.0Aa
74,100	777.4Ac	970.2Bb	1209.2Aa
98,800	692.3Ab	1039.7Ba	1115.5Aa
123,500	844.8Ab	1080.9Ba	1106.2Aa

† Means within a column followed by the same uppercase letter or in a row followed by the same lowercase letter are not statistically different at $\alpha = 0.05$.

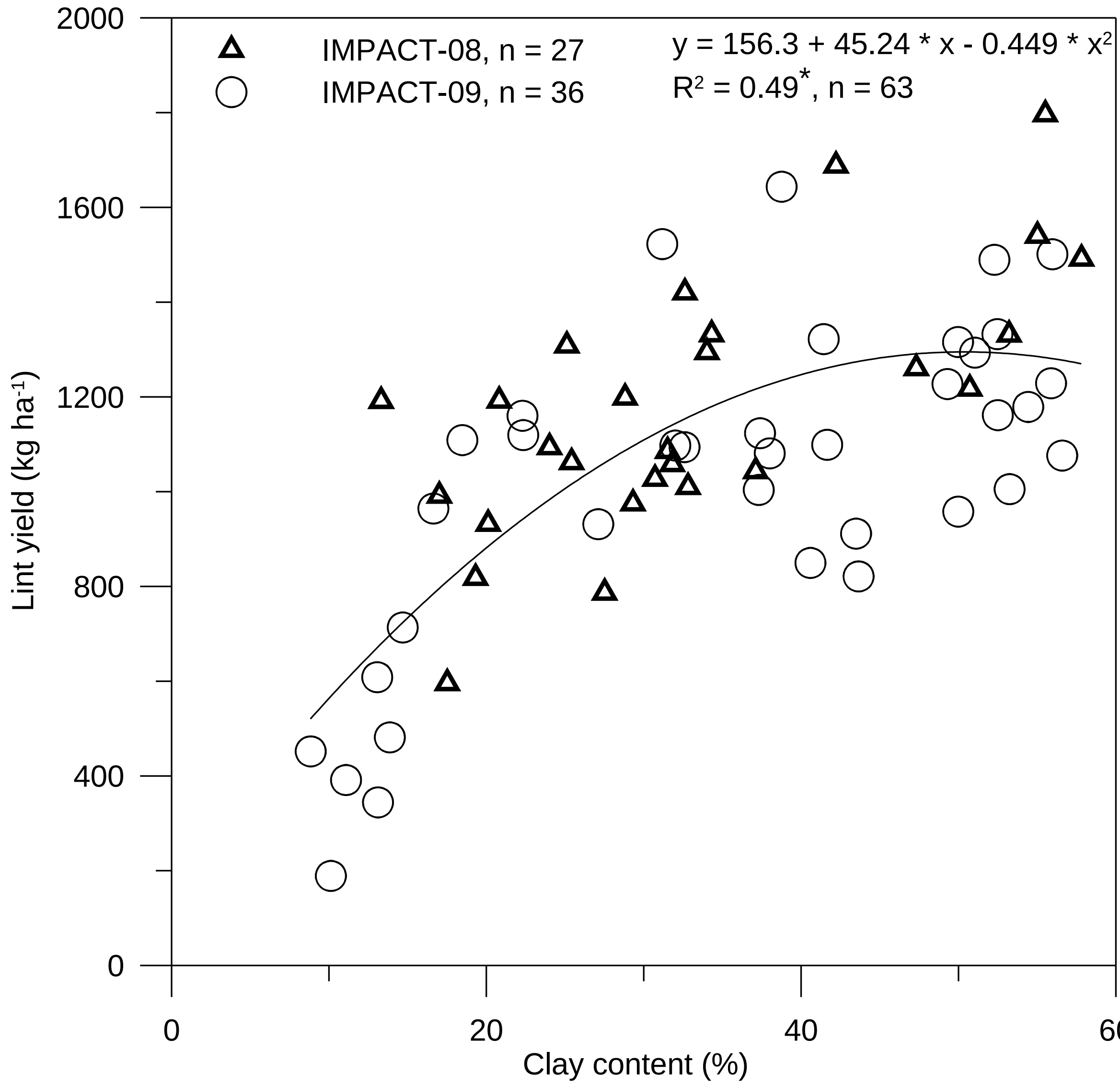

Fig. 11. Lint yield as a function of clay content for IMPACT-08 and -09. * indicates significance at $\alpha < 0.05$.

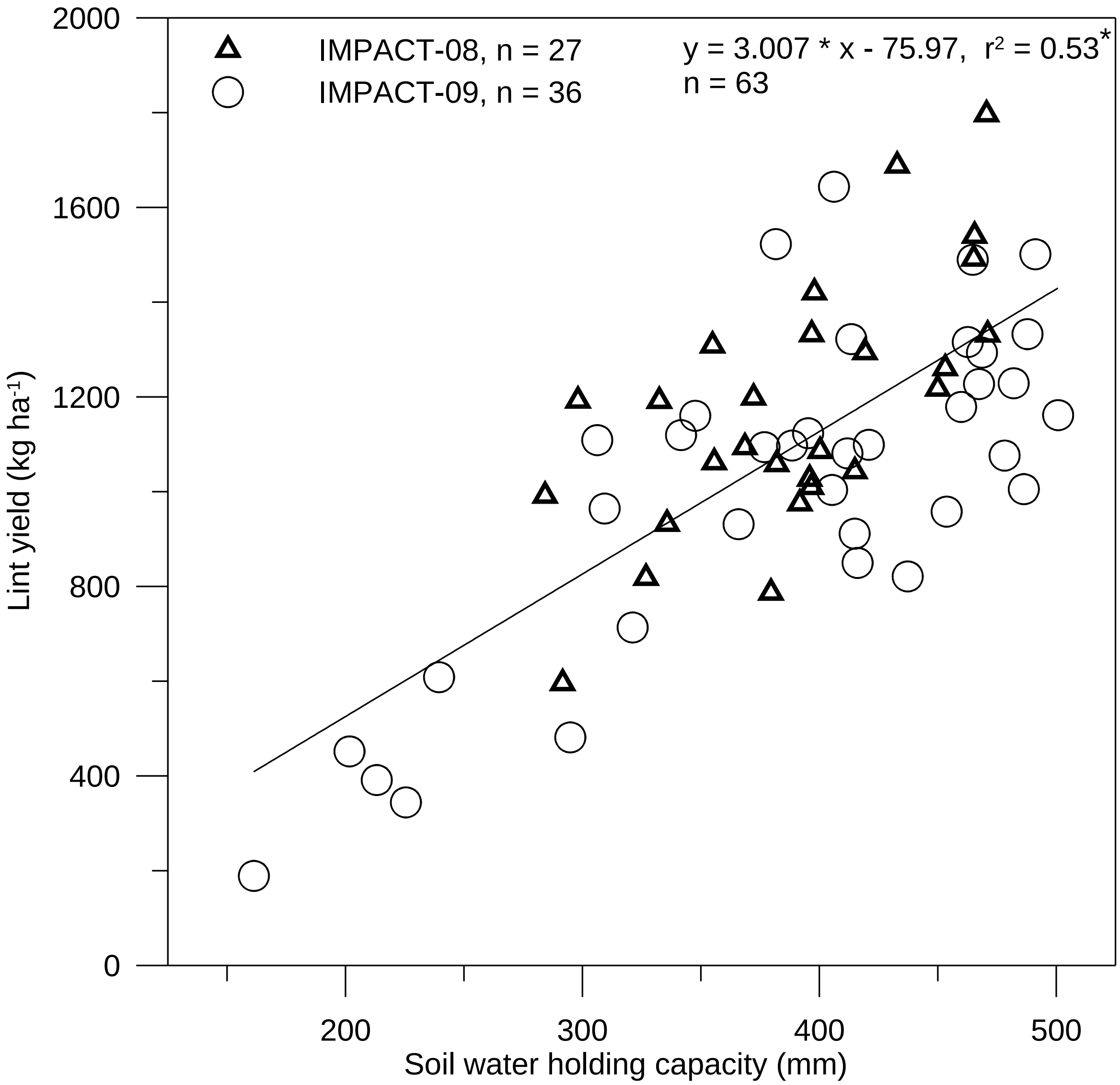

Fig. 12. Lint yield as a function of soil water holding capacity for IMPACT-08 and -09. * indicates significance at $\alpha < 0.05$.

EC_a zones for both IMPACT-08 and -09, and lint yield was not correlated to PAW in the soil profile (Fig. 13, Ockerby et al. (1993) and Corwin et al. (2003).

In agricultural soils, clay content and water holding capacity are often the factors that soil apparent electrical conductivity measurements respond to (Kachanowski et al., 1988; Sheets and Hendrickx, 1995). Lint yield was correlated to the soil apparent electrical conductivity measurements as well (Fig. 14), indicating that soil apparent electrical conductivity measurements of IMPACT-08 and -09 could be used to indicate variable zones of lint yield on a year to year basis. If soil apparent electrical conductivity measurements are going to be utilized for predicting crop response, analysis of soil properties is necessary for proper interpretations.

While total PAW in the soil profile did not influence yield, the rate and depth at which soil water was extracted by the plant did appear to influence yield. In IMPACT-08 and -09, EC_a zone 3 used the least soil water over the growing season (Table 6), and EC_a zone 3 had significantly higher yields both years (Table 7). Because EC_a zone 3 was using less soil water, the plants within this zone were not likely physiologically limited by water during the reproductive stage when water demand is the highest (Hons and McMichael, 1986).

EC_a zone 1 generally had the smallest yield, e.g. 2 and 22% less than EC_a zones 2 and 3, respectively in IMPACT-08 and ~34% less than both EC_a zones in IMPACT-09 (Table 7). The lower lint yields can be attributed to more soil water being required by the plants in EC_a zone 1, earlier in the season and when fruiting was occurring. The plant likely partitioned more energy to root deeper into the soil profile to meet water

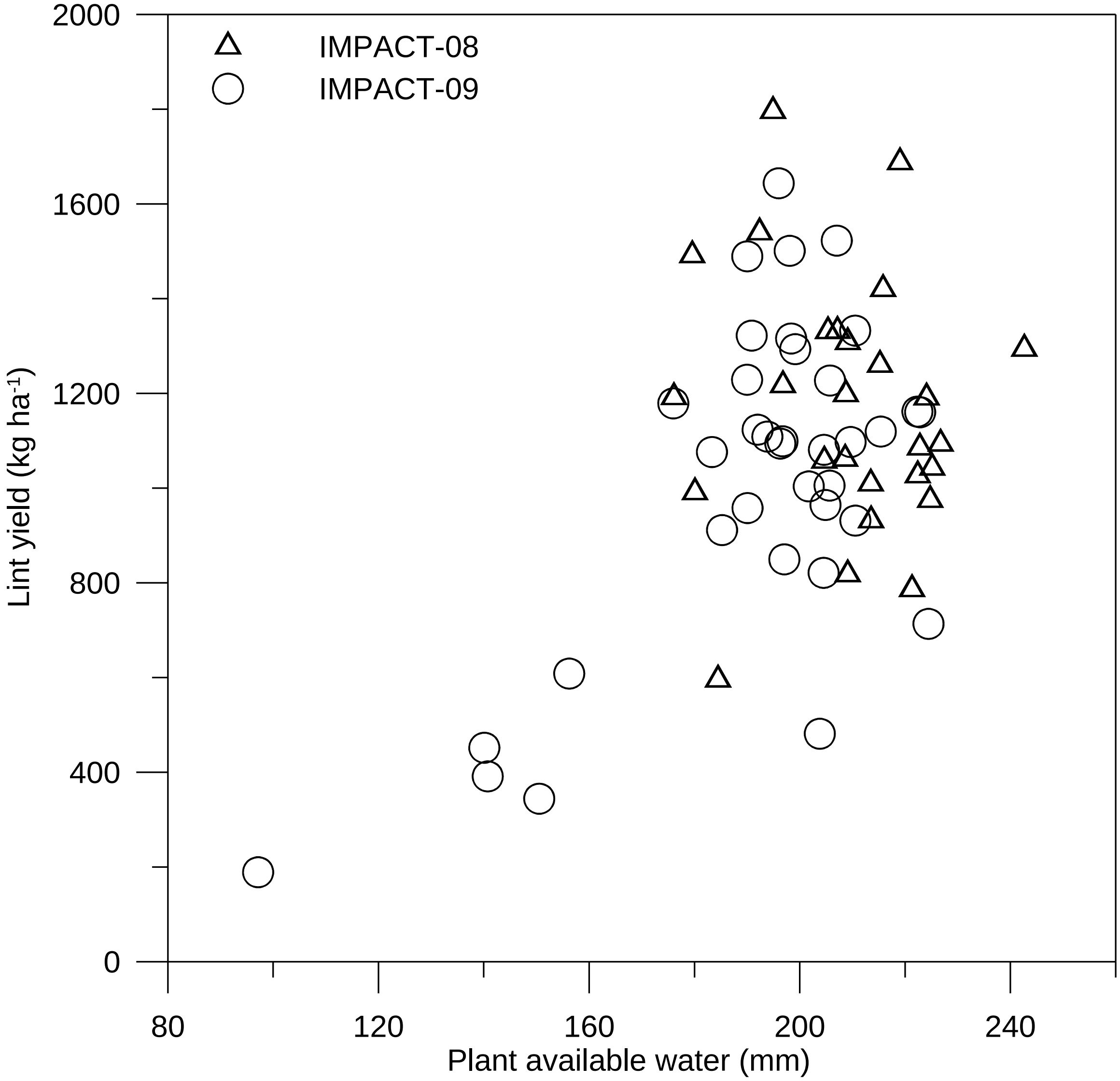

Fig. 13. Lint yield as a function of plant available water for IMPACT-08 and -09.

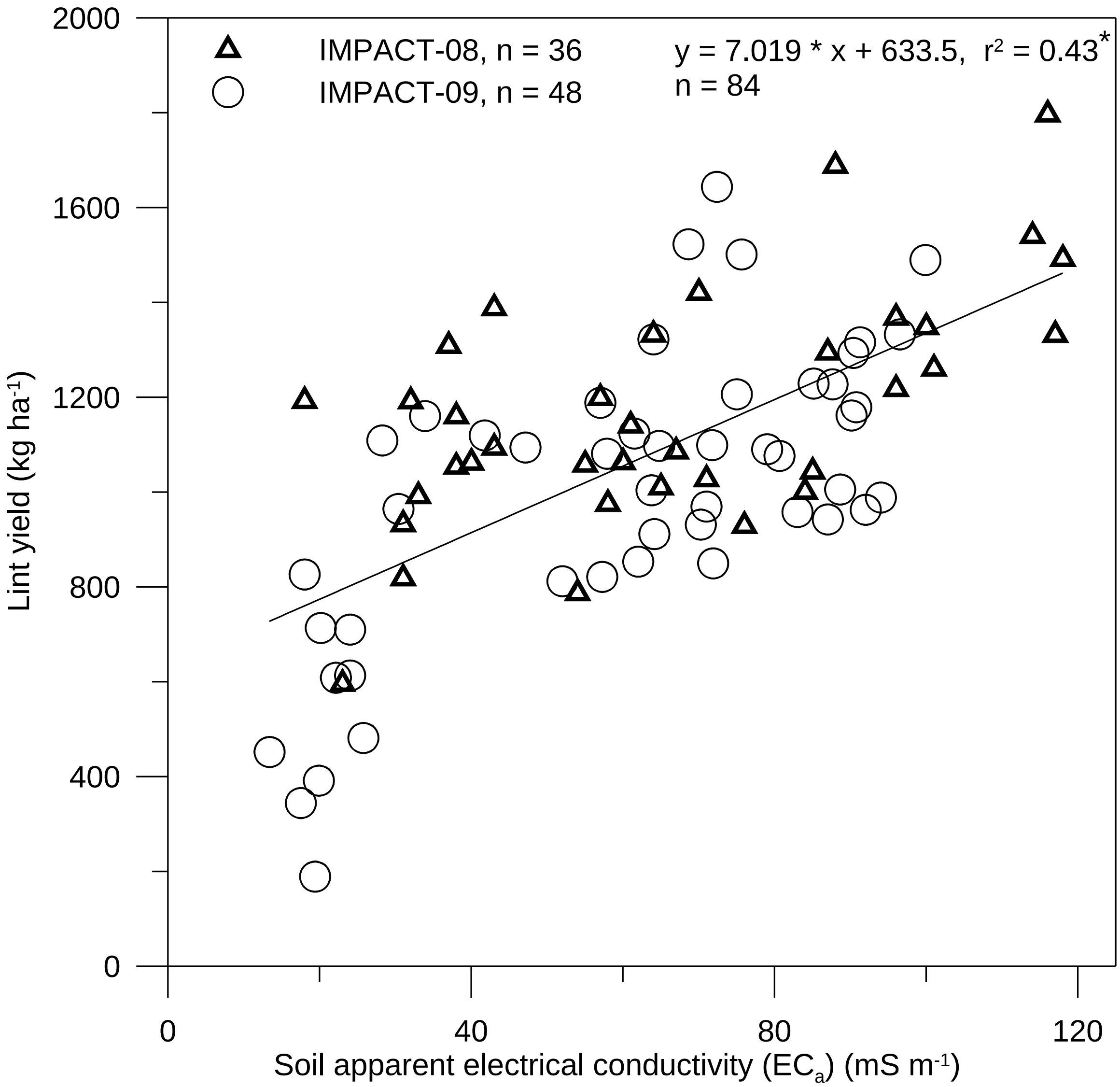

Fig. 14. Lint yield as a function of soil apparent electrical conductivity (EC_a) for IMPACT-08 and -09. * indicates significance at $\alpha < 0.05$.

demands (Fig. 10) (Hons and McMichael, 1986). In IMPACT-08, EC_a zone 2 yielded 20% less lint than EC_a zone 3; in IMPACT-09 the difference in lint yield was less at 6% (Table 7). The smaller difference in lint yield between EC_a zones 2 and 3 in IMPACT-09 are possibly attributed to higher temperatures; hence the soil water differences between EC_a zones was less of a factor. Soil water use data indicate that plants grown in EC_a zone 2 used more soil water at deeper depths and earlier in the season compared to EC_a zone 3 (Fig. 10). While plants grown in EC_a zone 2 were never observed to wilt, they also rooted deeper into the soil profile than plants in EC_a zone 3, in both years.

In summary, increases in lint yield as EC_a zone increases can be attributed to which date and at what depth water was used from the soil profile. In general, plants in EC_a zone 3 did not extract water from very deep in the soil profile; hence, EC_a zone 3 had the largest lint yield in both years. For both site-years, EC_a zone 1 pulled more water from deeper depths earlier in the season, leading to the assumption that during the flowering and boll fill period when water demands were the greatest, the plants were required to partition more energy towards rooting deeper into the soil profile compared to EC_a zone 3. If water was limiting the plant at this time, the crop may have experienced reductions in photosynthesis and nutrient uptake (Salvucci and Crafts-Brandner, 2004a, 2004b, and Li et al., 2001, 2002). When EC_a zone 1 was rooting deeper into the soil profile to meet water demands, EC_a zone 3 had adequate moisture at shallower depths. EC_a zone 3 could then partition energy into fruiting and fruit development as compared to root growth during the reproductive stages.

The rate at which water was utilized from the soil profile was the main factor identified that influenced yield for each site-year separately. IMPACT-08 generally yielded more on average across all EC_a zones when compared to IMPACT-09. This occurrence can be explained through the precipitation and temperature data. IMPACT-08 received more precipitation (398 mm) throughout the season (Fig. 5), and temperatures (Table 2) were also lower during June and July (32 and 34°C), compared to IMPACT-09 precipitation (278 mm) and temperatures (36 and 37°C) (Fig. 5 and Table 2). Weather differences from the 2008 and 2009 growing season resulted in a higher rate of growing degree day accumulation for IMPACT-09 (Fig. 6), thus resulting in heat stress to the plants, which could possibly reduce yields (Salvucci and Crafts-Brandner, 2004a, 2004b).

Irrigation within EC_a zone 3 could possibly be reduced without reductions in yield, while irrigation in EC_a zone 1 should be increased to meet water demands of the crop. Consequently, yields to that of cotton grown in EC_a zone 3 still might not be achievable.

Results indicate that reduction of seeding rates can be implemented, regardless of soil type, and maximum lint yields can be obtained. While large variations in lint yield across EC_a zones were witnessed, up to 38% less in some cases, each EC_a zone seems to have a yield threshold under uniform irrigation. Overall differences in lint yield across EC_a zones can be explained through soil water use differences within the three EC_a zones.

Cotton fiber quality

While yield drives overall profits in cotton production, cotton fiber quality may become more important with increasing competition from artificial fibers and high quality demands from textile mills. The lint quality parameters that determine lint price were distinctly different in IMPACT-09. Micronaire was higher, and fibers were stronger and more uniform (Tables 8-10). Though fiber length and elongation do not factor into lint price, fiber length is important for spinning quality. Both fiber length and elongation were lower in IMPACT-09 (Tables 11 and 12). In no case, site-year or EC_a zone, was seeding rate significant on any fiber quality parameters. EC_a zone 3 most consistently scored premium values for micronaire, fiber length, and strength. EC_a zone 1 consistently scored premium values for micronaire in both years and fiber strength in IMPACT-09.

The most important and discussed fiber quality parameter is micronaire, which is a combination of both fiber fineness and maturity, and determines how well lint will hold dye once the fibers are woven into fabric (Benedict et al., 1999). Currently, lint prices can be discounted based on micronaire values below 3.4 and above 5.0, and receive a premium if between 3.7 and 4.2 (USDA, 2009).

Micronaire on average was 16 % higher in 2009 when compared to 2008, a fact that can be attributed to the warmer and drier conditions in 2009 (Table 2 and Fig. 5) (Pettigrew, 2004a and 2008). In IMPACT-08, EC_a zones 1 and 3 had premium micronaire values and were significantly different from micronaire in EC_a zone 2 (Table 8). If it can be assumed that the plant is pulling water out of the soil to reach potential

Table 8. Average of the micronaire measurements from IMPACT-08 and -09. Average values represent the four replications within each seeding rate and EC_a zone.

Seeding rate	EC_a zone 1	EC_a zone 2	EC_a zone 3
-------seeds ha^{-1}------		----value----	
		IMPACT-08	
74,100	3.5Ab†	3.2Ac	**4.0**Aa
98,800	**4.0**Aa‡	3.5Ab	**4.1**Aa
123,500	**3.7**Ab	3.5Ac	**3.9**Aa
		IMPACT-09	
49,400	**4.1**Ab	4.6Aa	4.5Aa
74,100	**4.2**Ab	4.6Aa	4.6Aa
98,800	**4.1**Ac	4.7Aa	4.4Ab
123,500	**3.8**Ac	4.9Aa	4.4Ab

† Means within a column followed by the same uppercase letter or in a row followed by the same lowercase letter are not statistically different at $\alpha = 0.05$.
‡ Means in **bold** indicate premium fiber micronaire values.

Table 9. Average of the fiber strength measurements from IMPACT-08 and -09. Average values represent the four replications within each seeding rate and EC_a zone.

Seeding rate	EC_a zone 1	EC_a zone 2	EC_a zone 3
-------seeds ha^{-1}------		--------kN m kg^{-1}--------	
		IMPACT-08	
74,100	260.0Ab†	265.3Ab	**284.2**Aa‡
98,800	254.6Ab	250.0Ab	**286.7**Aa
123,500	250.0Ab	259.0Ab	**277.3**Aa
		IMPACT-09	
49,400	**279.3**Ab	**287.9**Ab	**317.5**Aa
74,100	**278.6**Ab	**286.1**Ab	**301.8**Aa
98,800	**277.6**Ac	**289.1**Ab	**299.7**Aa
123,500	**283.7**Ab	**289.6**Ab	**322.0**Aa

† Means within a column followed by the same uppercase letter or in a row followed by the same lowercase letter are not statistically different at $\alpha = 0.05$.
‡ Means in **bold** indicate premium fiber strength values.

Table 10. Average of the fiber length uniformity measurements from IMPACT-08 and -09. Average values represent the four replications within each seeding rate and EC_a zone.

Seeding rate	EC_a zone 1	EC_a zone 2	EC_a zone 3
-------seeds ha^{-1}------	-----------------------------------	---%---	-----------------------------------
		IMPACT-08	
74,100	81.5Ab†	81.8Ab	**83.3**Aa‡
98,800	81.8Ab	82.4Aab	**83.1**Aa
123,500	81.8Ab	83.1Aa	82.4Aab
		IMPACT-09	
49,400	82.1Ac	**83.0**Ab	**84.0**Aa
74,100	82.4Ab	82.1Ab	**83.2**Aa
98,800	81.1Ab	**82.6**Aa	**83.5**Aa
123,500	81.9Ab	**82.8**Aa	**84.3**Aa

† Means within a column followed by the same uppercase letter or in a row followed by the same lowercase letter are not statistically different at $\alpha = 0.05$.
‡ Means in **bold** indicate premium fiber length uniformity values.

Table 11. Average of the fiber length measurements from IMPACT-08 and -09. Average values represent the four replications within each seeding rate and EC_a zone.

Seeding rate	EC_a zone 1	EC_a zone 2	EC_a zone 3
-------seeds ha^{-1}------	------------------------------------	-mm-	------------------------------------
		IMPACT-08	
74,100	28.7Ab†	29.5Ab	30.5Aa
98,800	28.7Ab	29.1Ab	30.4Aa
123,500	28.6Ab	30.0Aa	30.1Aa
		IMPACT-09	
49,400	27.7Ac	28.4Ab	29.8Aa
74,100	28.3Ab	27.9Ab	29.0Aa
98,800	27.6Ac	28.4Ab	29.1Aa
123,500	28.4Ab	28.3Ab	29.9Aa

† Means within a column followed by the same uppercase letter or in a row followed by the same lowercase letter are not statistically different at $\alpha = 0.05$.

Table 12. Average of the fiber elongation measurements from IMPACT-08 and -09. Average values represent the four replications within each seeding rate and EC_a zone.

Seeding rate	EC_a zone 1	EC_a zone 2	EC_a zone 3
-------seeds ha^{-1}------		-------------------------------------%-------------------------------------	
		IMPACT-08	
74,100	8.2Aa†	8.3Aa	8.2Aa
98,800	8.1Aa	8.0Aa	8.2Aa
123,500	8.3Aa	8.1Aa	8.3Aa
		IMPACT-09	
49,400	5.8Aa	5.6Ab	5.3Ac
74,100	5.4Ab	6.0Aa	5.2Ac
98,800	5.8Aa	5.6Ab	5.1Ac
123,500	5.7Aa	5.6Aa	4.9Ab

† Means within a column followed by the same uppercase letter or in a row followed by the same lowercase letter are not statistically different at $\alpha = 0.05$.

evaporative demand (PET), then at NAWF = 5, plants in EC_a zone 2 were more successful (132 mm soil water) at reaching PET than plants in EC_a zones 1 and 3 (126 mm and 107 mm, respectively) (Table 6). Perhaps plants in EC_a zone 2 did not mature as quickly as plants in the other two EC_a zones because of less water stress. In IMPACT-09, lint in EC_a zone 1 had premium, and lower micronaire values, which were significantly different from lint in the other two EC_a zones (Table 8). The assumption was that hotter conditions present at IMPACT-09 contributed to the overall higher micronaire values of the lint across all EC_a zones compared to IMPACT-08. While lint in EC_a zones 2 and 3 had higher than premium micronaire values, this could be attributed to more soil water available for longer into the season coupled with the higher temperatures. Assumedly plants and lint grown within EC_a zone 1 were water stressed and the crop finished fruit production; however, due to the higher temperatures it just so happened that the lint from plants within EC_a zone 1 received premiums for micronaire. The literature reports mixed interactions between micronaire and/or growing environment, yield, and cultivar. Findings would suggest that an interaction of soil water availability to the plants and temperature during the fruiting cycle influence micronaire.

Producers can have their lint prices discounted or given premiums based on fiber strength values. In IMPACT-08, fiber strength in EC_a zone 3 was premium and significantly higher than fibers in EC_a zones 1 and 2 (Table 9). The fiber strength in EC_a zones 1 and 2 were within the base range. On average, fiber strength measurements were 9% higher in IMPACT-09 than IMPACT-08; therefore, lint in all EC_a zones had premium values for strength. IMPACT-09 fiber strength in EC_a zone 3 was significantly higher than EC_a zones 1 and 2 (Table 9). The higher than average temperatures during the summer of 2009 could explain the increases in fiber strength. Studies have illustrated that increases in temperature result in higher fiber strength measurements (Reddy et al., 1999; Pettigrew, 2008). Soil water use can explain higher fiber strength in EC_a zone 3 for IMPACT-08 and -09. Plants growing in EC_a zone 3 used less soil water, thus more soil water was available for fiber development late in the season (Salvucci and Crafts-Brandner, 2004a, 2004b).

Lastly, fiber length uniformity is the third fiber parameter that factors into the loan rate of cotton lint. For both IMPACT-08 and -09, all length uniformity measurements were either in the base or premium range. Fiber in EC_a zone 3, IMPACT-08, had significantly higher and premium length uniformity. A similar trend between EC_a zones occurred in IMPACT-09, but lint in EC_a zone 2 had some significantly higher and premium length uniformity (Table 10). Though the literature does not address the associations with length uniformity and environment, these results suggest that available soil water after NAWF = 5 might improve length uniformity.

Though fiber length does not affect lint price, longer fibers have better spinning properties. Fiber length was significantly longer in EC_a zone 3, in IMPACT-08 and -09 (Table 11). Again, longer fibers in EC_a zone 3 can be attributed to soil water use. EC_a zone 3 used the least amount of soil water before cutout thus more water was available for fiber development.

Fiber elongation in IMPACT-08 was the same across EC_a zone; the mean was 8.1 (Table 12). Fiber elongation was significantly lower in EC_a zone 3 in IMPACT-09. Most noticeable, IMPACT-08 fibers had 33 % higher elongation when compared to IMPACT-09. Though the literature does not address the associations with fiber elongation and environment, these results suggest that higher temperatures might reduce the fiber elongation parameter.

CHAPTER V

SUMMARY AND CONCLUSIONS

Differences in cotton lint yield and quality were evident across the different soil types present on the study sites, regardless of the fact all inputs i.e. variety, irrigation, fertilizer, and pesticide applications were uniform. Seeding rates did not affect cotton lint yield or quality, but evidence would suggest that soil water availability throughout the season was an important component driving both yield and quality.

Clay content and water holding capacity of the soil was successfully mapped for IMPACT-08 and -09. Plant available water was not mapped by soil EC_a. Using the EM38DD and subsequent EC_a map, different zones were correctly identified, based on clay content and water holding capacity of the soil across the landscape. Both clay content and water holding capacity increased significantly as EC_a zones increased. Total PAW was not significantly different across EC_a zones for IMPACT-08, but for IMPACT-09, EC_a zone 1 was significantly lower than EC_a zone 2.

Lowering seeding rates did not significantly affect the amount of soil water used within all soil types. Total soil water use was significantly less for plants grown within EC_a zone 3, in IMPACT-08, while soil water use by plants grown within EC_a zone 3 for IMPACT-09 was numerically less than plants in EC_a zones 1 and 2. Because EC_a zone 3 plants used less soil water throughout the season, more water was available for the plants during the reproductive stage. Plants in EC_a zones 1 and 2 used more soil water deeper in the soil profile earlier in the season compared to plants in EC_a zone 3 for IMPACT-08 and -09.

Seeding rates generally had no effect on lint yield, except for two cases. In EC_a zone 1, the 74,100 seeds ha^{-1} rate yielded significantly more lint than the two larger seeding rates in IMPACT-08, and the 49,400 seeds ha^{-1} rate within EC_a zone 2, IMPACT-09, yielded significantly more lint than the three larger seeding rates.

EC_a zones were also successful in identifying differences in lint yield and quality for both IMPACT-08 and -09. In IMPACT-08 and -09, lint yield increased with EC_a zone, with EC_a zone 3 yielding significantly more lint than EC_a zone 1. Though temporal soil water use throughout the season best explained differences in lint yield within the field, temperature likely explains between year variability. On average, IMPACT-08 yielded more lint than IMPACT-09, likely due to warmer temperatures during the summer of 2009 and the subsequent reduced photosynthesis possibly present during the fruiting cycle in IMPACT-09.

The fiber quality parameters measured (micronaire, strength, uniformity, length, and elongation) were not significantly affected by seeding rate. Significant differences in fiber quality were only measured between EC_a zones in both years. While fiber quality differences between IMPACT-08 and -09 likely can be attributed to the environmental conditions present in 2009, EC_a zone affect was similar between years. Plants grown within EC_a zone 3 generally produced higher quality fibers.

In conclusion, 1) Reducing seeding rates by soil type indicated that maximum yields can be reached regardless of soil type, while fiber quality remains unaffected; 2)

Total soil water use was not different among seeding rates, although soil types each had their unique soil water use characteristics; and 3) As soil water was available later into the growing season and at shallower depths higher lint yields and fiber qualities were observed.

Findings from this research suggest that in order to fully understand cotton plant and soil type interactions on cotton lint yield and quality, observations on a dryland cropping system might be useful. In hindsight, more extensive physiological measurements should also be conducted along with temporal soil moisture measurements.

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APPENDIX A

Complete particle size analysis of soil samples from IMPACT-08 and -09

Site†	Depth	Sand	Silt	Clay
	-------cm-------		-------------------------%-------------------------	
		IMPACT-08		
111	0-30	13.9	62.7	23.4
111	30-50	29.7	55.9	14.5
111	50-70	27.0	57.2	15.8
111	70-90	15.3	70.3	14.5
111	90-110	12.7	68.6	18.7
111	110-130	36.0	47.9	16.1
112	0-30	13.2	61.2	25.6
112	30-50	7.0	70.0	23.0
112	50-70	9.6	65.7	24.7
112	70-90	21.2	53.9	24.9
112	90-110	19.4	60.7	19.9
112	110-130	4.3	61.3	34.4
113	0-30	7.9	59.6	32.5
113	30-50	5.7	65.7	28.6
113	50-70	13.6	66.4	20.1
113	70-90	21.7	56.5	21.8
113	90-110	17.0	60.3	22.7
113	110-130	5.0	69.8	25.2
121	0-30	22.1	60.0	17.9
121	30-50	35.1	48.3	16.6
121	50-70	39.5	42.3	18.2
121	70-90	41.1	40.6	18.3
121	90-110	46.6	36.3	17.0
121	110-130	45.8	37.2	17.0
122	0-30	3.1	67.0	29.9
122	30-50	3.5	71.8	24.7
122	50-70	21.8	57.0	21.2
122	70-90	16.0	65.6	18.4
122	90-110	13.7	66.3	19.9
122	110-130	2.1	67.9	29.9
123	0-30	26.8	52.0	21.2
123	30-50	39.8	43.8	16.4
123	50-70	41.6	46.1	12.3
123	70-90	21.0	60.7	18.2
123	90-110	40.4	42.2	17.4
123	110-130	44.7	38.9	16.4

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------		--------------------------%--------------------------	
131	0-30	15.8	62.2	22.0
131	30-50	33.8	49.9	16.3
131	70-90	16.5	65.7	17.8
131	90-110	15.1	61.5	23.3
131	110-130	28.8	51.8	19.4
132	0-30	14.3	58.4	27.3
132	30-50	21.5	57.4	21.1
132	50-70	50.1	36.1	13.8
132	70-90	16.1	63.5	20.4
132	90-110	14.5	64.3	21.2
132	110-130	18.4	60.8	20.8
133	0-30	10.0	62.4	27.6
133	30-50	21.5	58.7	19.9
133	50-70	29.3	55.0	15.7
133	70-90	10.5	65.9	23.6
133	90-110	17.9	66.5	15.7
133	110-130	35.9	45.6	18.5
211	0-30	6.2	50.7	43.1
211	30-50	28.5	38.7	32.9
211	50-70	36.6	41.8	21.7
211	70-90	8.6	58.0	33.4
211	90-110	45.7	35.6	18.7
211	110-130	4.8	56.0	39.3
212	0-30	9.2	55.8	35.0
212	30-50	11.9	61.6	26.5
212	50-70	13.1	60.2	26.7
212	70-90	6.3	60.1	33.6
212	90-110	1.5	54.0	44.5
212	110-130	1.2	59.5	39.4
213	0-30	2.5	49.6	47.9
213	30-50	4.1	62.5	33.3
213	50-70	30.5	48.1	21.4
213	70-90	13.5	55.6	30.9
213	90-110	7.4	66.1	26.5
213	110-130	1.7	61.4	36.9
221	0-30	5.8	61.5	32.7
221	30-50	1.7	67.9	30.4
221	50-70	5.4	65.3	29.3
221	70-90	12.6	61.5	25.9
221	90-110	2.9	69.2	27.9
221	110-130	0.7	54.9	44.4

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------	-------------------------	%	-------------------------
222	0-30	5.5	61.3	33.2
222	30-50	6.5	69.3	24.2
222	50-70	19.5	60.7	19.8
222	70-90	4.9	65.8	29.3
222	90-110	11.9	65.6	22.4
222	110-130	1.0	62.9	36.1
223	0-30	5.2	61.0	33.8
223	30-50	6.1	67.2	26.6
223	50-70	7.4	68.6	24.0
223	70-90	2.7	67.1	30.2
223	90-110	2.8	68.8	28.3
223	110-130	3.0	67.0	30.0
231	0-30	4.2	60.7	35.1
231	30-50	20.9	54.9	24.2
231	50-70	23.1	57.7	19.2
231	70-90	7.9	70.3	21.8
231	90-110	2.5	61.1	36.4
231	110-130	1.2	59.9	38.9
232	0-30	2.3	52.8	44.9
232	30-50	6.5	63.5	30.0
232	50-70	5.5	66.2	28.3
232	70-90	5.2	62.4	32.4
232	90-110	1.0	86.6	12.5
232	110-130	1.4	62.6	36.0
233	0-30	2.1	51.5	46.3
233	30-50	3.9	59.2	36.9
233	50-70	0.8	60.0	39.2
233	70-90	6.2	62.7	31.2
233	90-110	10.5	68.6	20.9
233	110-130	8.9	70.2	20.9
311	0-30	2.1	40.9	57.0
311	30-50	1.0	38.1	60.9
311	50-70	0.8	31.5	67.7
311	70-90	1.4	46.8	51.8
311	90-110	1.0	52.1	46.9
311	110-130	1.3	53.1	45.5
312	0-30	1.9	48.3	49.8
312	30-50	0.8	41.1	58.2
312	50-70	0.8	54.6	44.7
312	70-90	1.8	58.2	40.1
312	90-110	18.7	16.1	65.2

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------		--------------------------%--------------------------	
312	110-130	2.3	51.2	46.6
313	0-30	2.4	39.0	58.6
313	30-50	1.3	35.0	63.8
313	50-70	1.0	26.5	72.5
313	70-90	1.5	42.9	55.6
313	90-110	1.8	56.3	42.0
313	110-130	1.1	58.6	40.3
321	0-30	2.1	42.5	55.4
321	30-50	0.8	35.0	64.3
321	50-70	0.7	34.3	65.0
321	70-90	1.7	57.1	41.2
321	90-110	1.6	57.1	41.3
321	110-130	1.2	46.6	52.2
322	0-30	1.9	41.8	56.3
322	30-50	1.1	43.0	55.9
322	50-70	1.0	56.7	42.3
322	70-90	1.5	55.9	42.6
322	90-110	1.5	59.9	38.6
322	110-130	1.2	50.9	47.8
323	0-30	3.3	43.8	52.9
323	30-50	17.0	50.3	32.7
323	50-70	4.4	58.6	37.0
323	70-90	53.1	34.5	12.3
323	90-110	9.1	54.1	36.8
323	110-130	4.8	62.5	32.7
331	0-30	2.5	46.8	50.7
331	30-50	1.1	51.1	47.8
331	50-70	10.9	58.3	30.8
331	70-90	41.7	39.2	19.1
331	90-110	6.8	55.1	38.1
331	110-130	1.5	62.4	36.1
332	0-30	2.4	40.0	57.6
332	30-50	0.9	31.6	67.4
332	50-70	0.6	28.0	71.3
332	70-90	1.2	44.5	54.3
332	90-110	3.1	47.9	49.0
332	110-130	1.1	51.8	47.1
333	0-30	2.8	40.9	56.3
333	30-50	7.4	45.2	47.4
333	50-70	29.6	49.0	21.4
333	70-90	6.0	56.2	37.8

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------	--------------------------	%	--------------------------
333	90-110	1.8	53.6	44.6
333	110-130	5.4	48.8	45.7
		IMPACT-09		
101	0-30	25.1	52.5	22.4
101	30-50	25.4	57.1	17.6
101	50-70	9.9	72.5	17.6
101	70-90	15.8	64.8	19.4
101	90-110	8.3	73.3	18.3
101	110-130	10.5	74.1	15.4
102	0-30	21.0	58.3	20.7
102	30-50	37.7	46.3	15.9
102	50-70	75.1	14.2	10.6
102	70-90	82.2	6.8	11.0
102	90-110	79.6	10.7	9.7
102	110-130	16.4	63.5	20.1
103	0-30	24.3	59.4	16.3
103	30-50	41.4	45.8	12.8
103	50-70	70.7	18.7	10.6
103	70-90	83.7	6.6	9.7
103	90-110	83.4	6.9	9.7
103	110-130	92.5	0.3	7.2
111	0-30	25.2	53.8	21.0
111	30-50	40.2	43.1	16.7
111	50-70	86.6	6.2	7.2
111	70-90	85.7	6.2	8.1
111	90-110	53.9	33.5	12.5
111	110-130	79.9	7.1	13.0
112	0-30	9.9	60.4	29.7
112	30-50	7.1	65.8	27.1
112	50-70	20.7	57.5	21.8
112	70-90	42.4	43.1	14.5
112	90-110	9.7	72.1	18.2
112	110-130	15.8	61.8	22.4
113	0-30	26.9	54.2	18.9
113	30-50	57.9	28.6	13.6
113	50-70	84.3	8.9	6.9
113	70-90	87.9	6.2	5.9
113	90-110	85.4	9.0	5.6
113	110-130	80.4	9.8	9.7
121	0-30	44.1	43.0	12.9
121	30-50	75.0	18.1	6.9

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------	--------------------------	%	--------------------------
121	50-70	72.5	20.3	7.2
121	70-90	86.9	7.5	5.6
121	90-110	62.2	28.1	9.7
121	110-130	60.3	29.0	10.6
122	0-30	18.2	60.7	21.1
122	30-50	31.4	52.3	16.3
122	50-70	49.9	39.8	10.3
122	70-90	76.6	16.2	7.2
122	90-110	40.8	46.9	12.3
122	110-130	68.6	20.4	11.0
123	0-30	8.8	53.4	37.7
123	30-50	7.7	52.6	39.7
123	50-70	7.5	56.3	36.2
123	70-90	5.7	56.7	37.5
123	90-110	16.2	58.0	25.8
123	110-130	47.1	34.5	18.5
131	0-30	20.5	59.7	19.8
131	30-50	17.0	64.5	18.5
131	50-70	65.2	25.4	9.4
131	70-90	34.6	51.3	14.2
131	90-110	56.5	34.1	9.4
131	110-130	35.3	52.8	11.9
132	0-30	17.0	51.7	31.4
132	30-50	18.2	51.2	30.5
132	50-70	30.1	52.0	17.9
132	70-90	18.6	64.2	17.2
132	90-110	15.3	65.2	19.5
132	110-130	29.8	52.8	17.4
133	0-30	15.1	58.3	26.6
133	30-50	21.1	61.8	17.0
133	50-70	34.9	47.8	17.4
133	70-90	33.6	47.1	19.3
133	90-110	72.5	17.8	9.7
133	110-130	75.1	15.2	9.7
201	0-30	4.3	49.0	46.7
201	30-50	1.1	51.3	47.6
201	50-70	0.6	54.5	44.8
201	70-90	1.2	59.5	39.3
201	90-110	16.1	59.6	24.3
201	110-130	3.4	66.9	29.7
202	0-30	8.5	57.5	34.0

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------		--------------------------%--------------------------	
202	30-50	2.8	62.1	35.0
202	50-70	1.3	48.9	49.8
202	70-90	1.8	48.3	50.0
202	90-110	2.1	48.6	49.3
202	110-130	6.9	50.4	42.7
203	0-30	2.4	53.8	43.8
203	30-50	1.9	60.6	37.5
203	50-70	17.0	58.5	24.5
203	70-90	34.7	44.4	20.9
203	90-110	7.4	68.1	24.5
203	110-130	17.5	46.8	35.7
211	0-30	8.4	55.8	35.8
211	30-50	3.9	60.1	35.9
211	50-70	2.0	68.3	29.7
211	70-90	1.0	51.8	47.2
211	90-110	1.5	53.8	44.7
211	110-130	11.5	57.6	30.9
212	0-30	9.6	59.9	30.5
212	30-50	4.4	68.1	27.5
212	50-70	1.6	60.9	37.6
212	70-90	0.7	59.5	39.8
212	90-110	0.7	51.3	48.1
212	110-130	1.3	54.3	44.4
213	0-30	7.5	57.3	35.2
213	30-50	2.6	52.8	44.6
213	50-70	0.9	49.3	49.8
213	70-90	3.5	44.1	52.4
213	90-110	3.0	56.1	40.9
213	110-130	4.5	56.5	39.0
221	0-30	11.6	51.1	37.4
221	30-50	10.1	57.9	32.1
221	50-70	3.2	54.9	41.9
221	70-90	3.1	56.2	40.7
221	90-110	1.8	48.7	49.5
221	110-130	3.1	54.9	42.0
222	0-30	14.4	50.8	34.8
222	30-50	24.5	46.9	28.6
222	50-70	8.6	63.0	28.5
222	70-90	2.2	53.9	44.0
222	90-110	0.7	52.5	46.7
222	110-130	3.8	55.0	41.2

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------		--------------------------%--------------------------	
223	0-30	4.6	53.0	42.4
223	30-50	4.1	57.9	38.0
223	50-70	2.3	60.1	37.6
223	70-90	6.1	63.4	30.5
223	90-110	11.1	58.4	30.6
223	110-130	42.5	44.6	12.9
231	0-30	2.2	49.2	48.6
231	30-50	1.1	50.2	48.7
231	50-70	0.7	53.2	46.0
231	70-90	1.5	62.2	36.2
231	90-110	5.0	62.6	32.3
231	110-130	2.8	59.3	38.0
232	0-30	3.0	46.4	50.6
232	30-50	1.5	43.4	55.1
232	50-70	1.9	46.9	51.2
232	70-90	5.1	63.1	31.8
232	90-110	20.7	55.7	23.6
232	110-130	1.3	62.5	36.2
233	0-30	2.9	59.0	38.1
233	30-50	15.5	58.0	26.4
233	50-70	9.4	63.9	26.8
233	70-90	12.3	60.7	27.0
233	90-110	8.5	71.8	19.7
233	110-130	2.9	72.5	24.6
301	0-30	3.5	43.0	53.6
301	30-50	1.3	43.0	55.7
301	50-70	0.7	45.7	53.7
301	70-90	0.7	41.6	57.7
301	90-110	1.0	40.0	59.0
301	110-130	0.9	43.5	55.6
302	0-30	1.5	42.3	56.3
302	30-50	0.7	41.6	57.7
302	50-70	0.8	44.8	54.4
302	70-90	0.6	39.7	59.7
302	90-110	0.5	43.9	55.6
302	110-130	0.6	47.4	52.1
303	0-30	5.4	49.5	45.0
303	30-50	2.4	45.3	52.3
303	50-70	1.0	50.4	48.6
303	70-90	1.1	48.4	50.5
303	90-110	1.4	49.4	49.2

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------	----------------------------	%	----------------------------
303	110-130	0.9	45.0	54.1
311	0-30	3.0	46.7	50.2
311	30-50	1.2	50.8	47.9
311	50-70	0.7	44.5	54.7
311	70-90	1.4	46.0	52.6
311	90-110	1.1	45.9	53.1
311	110-130	0.5	44.5	55.0
312	0-30	2.6	45.3	52.1
312	30-50	1.2	40.1	58.8
312	50-70	1.0	41.0	58.0
312	70-90	0.7	47.3	52.1
312	90-110	0.6	50.3	49.1
312	110-130	0.5	43.1	56.4
313	0-30	1.8	40.6	57.7
313	30-50	0.9	38.8	60.2
313	50-70	0.7	45.6	53.7
313	70-90	0.6	42.1	57.3
313	90-110	0.9	39.6	59.5
313	110-130	0.8	48.2	51.0
321	0-30	2.6	43.6	53.8
321	30-50	1.1	45.2	53.7
321	50-70	1.1	44.7	54.2
321	70-90	0.9	49.5	49.6
321	90-110	1.2	55.8	43.0
321	110-130	0.6	53.8	45.6
322	0-30	2.5	46.0	51.6
322	30-50	1.4	43.9	54.7
322	50-70	1.1	41.5	57.4
322	70-90	1.2	41.6	57.2
322	90-110	3.4	47.2	49.4
322	110-130	2.2	53.2	44.6
323	0-30	3.7	50.9	45.4
323	30-50	1.5	50.0	48.6
323	50-70	1.0	48.0	50.9
323	70-90	0.9	48.6	50.5
323	90-110	1.0	48.8	50.2
323	110-130	0.8	49.1	50.1
331	0-30	2.7	49.6	47.8
331	30-50	2.5	42.9	54.5
331	50-70	1.0	46.2	52.8
331	70-90	1.8	44.4	53.8

Appendix A cont.

Site	Depth	Sand	Silt	Clay
	-------cm-------		---------------------------%---------------------------	
331	90-110	1.3	42.1	56.6
331	110-130	1.0	45.1	53.9
332	0-30	3.3	49.0	47.6
332	30-50	1.9	42.4	55.7
332	50-70	0.9	45.4	53.8
332	70-90	1.0	46.4	52.7
332	90-110	0.8	42.8	56.3
332	110-130	0.9	50.3	48.9
333	0-30	4.9	50.2	44.9
333	30-50	2.1	43.3	54.6
333	50-70	0.9	44.4	54.7
333	70-90	1.3	50.4	48.3
333	90-110	0.8	46.1	53.1
333	110-130	0.9	48.6	50.6

† Site identification numbers refer to EC_a zone, seeding rate, and replication number, respectively.

APPENDIX B

Complete Plant Available Water Analysis for IMPACT-08 and -09

Mean plant available water of EC_a zone 1for each date and depth increment, IMPACT-08.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
				mm			
20-May	204A†a‡	27.4Ac	32.0Aab	34.8Aa	37.1Aa	35.3Aa	36.9Aa
27-May	198Aa	24.8Ac	30.4Aab	34.3Aa	36.5Aa	35.2Aa	36.9Aa
9-Jun	174Bb	13.8Bb	22.9Ba	30.6ABa	35.7Aa	34.3Aa	36.6Aa
				irrigation initiated June 12			
15-Jun	158Bb	9.1Cb	17.6Cab	27.8BCa	34.6Aa	33.5Aa	35.8ABa
23-Jun	137Cb	5.6CDb	10.2Db	22.5CDab	31.9ABab	32.0ABa	34.7ABa
1-Jul	121CDb	4.9Db	6.7DEb	17.0DEa	28.4BCa	30.4ABa	34.2ABb
7-Jul	109DEb	4.4Db	4.8Eb	13.1EFa	24.2Ca	28.3BCa	33.8ABCb
14-Jul	91EFb	4.1Db	3.2Eb	8.8FGa	17.3Dab	25.0BCa	32.7BCa
21-Jul	77Fb	3.8Db	2.5Eb	6.6Ga	12.4Dab	21.4Ca	30.5Ca

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 1 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Mean plant available water of EC_a zone 2 for each date and depth increment, IMPACT-08.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--mm--						
20-May	216A†a‡	30.8Ab	33.2Aa	37.1Aa	35.5Aa	39.8Aa	39.5Aa
27-May	212Aa	28.9Ab	32.4Aa	36.8Aa	35.3Aa	39.8Aa	39.2Aa
9-Jun	189Bab	17.3Bab	24.1Ba	33.7Aa	34.7Aa	39.6Aa	39.2Aa
--*irrigation initiated June 12*--							
15-Jun	170Cab	13.3Ca	15.8Cb	28.6Ba	33.4Aa	39.4Aa	38.8Aa
23-Jun	145Dab	12.0CDa	9.2Db	17.6Cb	29.7Bb	38.31ABa	38.4Aa
1-Jul	127Eb	11.4CDa	7.7Dab	10.8Da	22.5Cb	36.4ABa	38.2Aa
7-Jul	115Fb	10.4Da	6.9Dab	9.2DEb	17.1Db	32.9BCa	38.0Aa
14-Jul	96Gab	9.3Da	6.5Dab	7.7DEa	10.3Eb	26.9CDa	35.0ABa
21-Jul	83Hb	8.7Da	6.0Dab	7.1Ea	8.5Eb	22.2Da	30.7Ba

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 2 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Mean plant available water of EC_a zone 3 for each date and depth increment, IMPACT-08.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--mm--						
20-May	214A†a‡	34.9Aa	28.8Ab	37.4Aa	38.6Aa	33.8ABa	40.6Aa
27-May	206Aa	33.7Aa	28.8Aa	34.5Aa	37.4ABa	34.1ABa	37.1ABa
9-Jun	196ABa	21.8Ba	28.5Aa	32.6ABa	38.8Aa	36.2Aa	38.3ABa
------------------------------------*irrigation initiated June 12*------------------------------------							
15-Jun	181BCa	16.0Ca	23.2Ba	31.3ABa	37.2ABa	35.2Aa	37.6ABa
23-Jun	162CDa	12.3CDa	15.1Ca	26.7BCa	35.8ABa	35.1Aa	37.1ABa
1-Jul	147DEa	12.6CDa	11.7CDa	19.6CDa	31.4BCa	34.6ABa	37.6ABab
7-Jul	133Ea	13.0CDa	10.1Da	14.1DEa	26.7CDa	32.2ABa	36.9ABab
14-Jul	111Fa	9.9Da	7.7Da	10.1Ea	21.3DEa	26.9BCa	35.1Ba
21-Jul	100Fa	9.3Da	7.7Da	9.7Ea	17.7Ea	22.2Ca	33.4Ba

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 3 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Mean plant available water of EC_a zone 1 for each date and depth increment, IMPACT-09.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	---mm---						
19-May	177A†b‡	28.1Ab	26.0Ab	25.4Ab	31.4Aa	34.9Aa	31.2Aa
1-Jun	169Ab	25.6Ab	24.6Ab	24.1Ab	30.0Aa	34.4ABa	30.7Aa
---*irrigation initiated June 2*---							
8-Jun	165Ab	24.2Ab	23.5ABb	23.6ABb	29.3Aa	34.2ABa	30.3Aa
15-Jun	166Ab	23.6Ab	23.5ABb	24.6Ab	30.3Aa	34.0ABa	30.0Aa
22-Jun	149ABb	16.9Bb	18.2Bb	21.9ABb	28.8Aa	33.5ABa	30.0Aa
30-Jun	122BCb	9.6Ca	11.5Cb	17.8BCb	24.5ABa	29.5ABa	29.0Aa
7-Jul	116CDb	8.9Ca	9.1CDb	14.5CDb	24.4ABa	30.7ABa	28.3Aa
13-Jul	100CDb	7.2Ca	5.4Db	10.5DEb	20.8BCa	28.8ABa	27.1Aa
20-Jul	85Da	5.5Cb	3.5Db	7.5Ea	16.5Ca	26.3Ba	25.8Aa

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 1 (p-value < 0.05).
‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Mean plant available water of EC_a zone 2 for each date and depth increment, IMPACT-09.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--mm--						
19-May	199A†a‡	32.0Aa	31.0Aa	31.8Aa	33.1Aa	34.5Aa	36.5Aa
1-Jun	197Aa	28.4Bab	31.2Aa	32.3Aa	33.3Aa	34.7Aa	36.8Aa
------------------------------------*irrigation initiated June 2*------------------------------------							
8-Jun	194Aa	25.6Bab	30.1Aa	32.2Aa	33.6Aa	34.9Aa	37.5Aa
15-Jun	180Bab	20.4Cb	25.0Bb	30.5Aa	33.1Aa	34.8Aa	36.7Aa
22-Jun	165Cab	16.1Db	18.5Cb	26.1Bb	32.0Aa	35.0Aa	37.2Aa
30-Jun	140Dab	11.7DEa	12.2Db	16.6Cb	28.4Ba	33.9Aa	36.7Aa
7-Jul	132Dab	13.1Ea	12.2Db	14.8CDb	24.6Ca	31.2Aa	36.4Aa
13-Jul	117Eab	11.1Ea	10.8Dab	12.4CDb	20.5Da	27.0Ba	34.8ABa
20-Jul	99Fa	9.8Ea	9.4Da	10.7Da	16.9Ea	20.6Ca	31.3Bab

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 2 (p-value < 0.05).
‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Mean plant available water of EC_a zone 3 for each date and depth increment, IMPACT-09

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--mm--						
19-May	183A†ab‡	32.4Aa	30.6Aa	29.6Aab	28.5Aa	28.8Cb	33.0Ba
1-Jun	187Aab	29.8Aa	31.2Aa	30.6Aa	29.5Aa	29.8ABCb	36.1ABa
------------------------------------*irrigation initiated June 2*------------------------------------							
8-Jun	186Aa	28.5ABa	31.2Aa	30.8Aa	29.8Aa	31.1ABa	34.7ABa
15-Jun	192Aa	29.5Aa	32.1Aa	32.2Aa	30.6Aa	31.5Aa	36.5Aa
22-Jun	180Aa	24.2Ba	29.1Aa	31.1Aa	28.8Aa	31.4Aa	35.6ABa
30-Jun	161Ba	15.4Ca	22.3Ba	28.3ABa	29.4Aa	30.0ABCa	35.8ABab
7-Jul	152Ba	13.5Ca	18.4Ba	24.6Ba	28.6Aa	30.7ABa	36.5Aa
13-Jul	127Ca	7.1Da	12.1Ca	18.3Ca	24.8Ba	29.3BCa	35.8ABa
20-Jul	96Da	3.1Db	4.8Db	10.2Da	17.6Ca	26.1Ca	34.1ABa

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 3 (p-value < 0.05).
‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

APPENDIX C

Complete Soil Water Use Analysis for IMPACT-08 and -09

Cumulative soil water use of EC_a zone 1 for each date and depth increment, IMPACT-08.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	----------------	----------------	----------------	mm	----------------	----------------	----------------
20-May	0A†a‡	0Aa	0Aa	0Aa	0Aa	0Aa	0Aa
27-May	5Aa	2.6Aa	1.5Aa	0.5Aa	0.5Aab	0Aa	0.1Aa
9-Jun	29Ba	13.7Ba	9.0Ba	4.2Ba	1.4ABa	1.0ABa	0.3Aa
----------------	----------------	----------------	*irrigation initiated June 12*	----------------	----------------	----------------	----------------
15-Jun	45Ca	18.3Ca	14.3Ca	7.0Ba	2.5ABa	1.7ABa	1.2ABa
23-Jun	67Da	21.9CDa	21.8Da	12.3Cb	5.2BCa	3.2BCa	2.3BCa
1-Jul	82Ea	22.6Da	25.3DEa	17.9Db	8.7CDab	4.8CDa	2.8BCDa
7-Jul	95Fa	23.1Da	27.2EFa	21.7Eb	12.9Dab	6.9Da	3.1CDa
14-Jul	112Gb	23.4Da	28.7EFa	26.0Fa	19.8Eab	10.2Eab	4.3Da
21-Jul	126Ha	23.6Da	29.5Fa	28.2Fa	24.6Fa	13.9Fab	6.5Eab

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 1 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Cumulative soil water use of EC_a zone 2 for each date and depth increment, IMPACT-08.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--mm--						
20-May	0A†a‡	0Aa	0Aa	0Aa	0Aa	0Aa	0Aa
27-May	6Aa	1.9Aab	0.8Aab	0.3Aa	0Aa	0Aa	0.2Aa
9-Jun	27Ba	13.5Ba	9.1Ba	3.4Ba	0.6Aa	0Ab	0.3Aa
--------------------------------------*irrigation initiated June 12*----------------------------------							
15-Jun	46Ca	16.9Ca	17.4Ca	8.5Ca	1.9ABab	0.3ABb	0.6Aa
23-Jun	70Da	18.7CDa	24.1Da	19.5Da	5.6Ba	1.3ABb	1.2Aa
1-Jul	88Ea	19.4Da	25.5Da	26.3Ea	12.8Ca	3.2Ba	1.3Aab
7-Jul	101Fa	20.4DEa	26.3Da	27.9EFa	18.2Da	6.8Ca	1.5Aab
14-Jul	120Ga	21.5Ea	26.7Da	29.3Fa	25.0Ea	12.7Da	4.4Ba
21-Jul	132Ha	22.1Ea	27.3Dab	30.0Fa	26.8Ea	17.4Ea	8.8Ca

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 2 (p-value < 0.05).
‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Cumulative soil water use of EC_a zone 3 for each date and depth increment, IMPACT-08.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--mm--						
20-May	0A†a‡	0Aa	0Aa	0Aa	0Aa	0Aa	0Aa
27-May	2Aa	0.1Ab	0Ab	0Ab	0.6ABa	0Aa	0.9ABa
9-Jun	12ABa	8.8Bb	0Ab	0.7Ab	0.6ABb	0Ab	1.5ABa
--------------------------------------*irrigation initiated June 12*----------------------------------							
15-Jun	22Bb	16.2Ca	2.4Bb	0.4Ab	1.0ABb	0.5Ab	1.5ABa
23-Jun	43Cb	22.5Da	11.9Cb	4.3ABc	1.7Bb	0.7Ab	1.5ABa
1-Jul	57Db	23.0Da	16.4Cb	11.2BCc	3.8Cb	0.7Ab	1.6ABb
7-Jul	69Eb	23.4Da	17.6Cb	17.4CDc	7.2Db	1.4ABb	1.6ABb
14-Jul	90Fc	25.8Da	19.4Cb	23.9Da	14.1Eb	5.3Bb	1.6ABb
21-Jul	107Gb	26.2Da	19.5Cb	24.7Da	21.9Fa	12.0Ca	3.1Bb

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 3 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Cumulative soil water use of EC_a zone 1 for each date and depth increment, IMPACT-09.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--mm--						
19-May	0A†a‡	0Aa	0Aa	0Aa	0Aa	0Aa	0Aa
1-Jun	8ABa	2.4ABa	1.5Aa	1.3Aa	1.4Aa	0.5Aa	0.6Aa
-----------------------------------*irrigation initiated June 2*-----------------------------------							
8-Jun	12ABa	3.8Bb	2.5Aa	1.8Aa	2.1Aa	0.8Aa	0.9Aa
15-Jun	11Ba	4.4Bb	2.5Ab	0.8Aa	1.2Aa	1.0Aa	1.2ABa
22-Jun	28Ca	11.2Cab	7.9Bb	3.5Ab	2.6ABa	1.4Aa	1.2ABCa
30-Jun	54Da	18.4Da	15.5Ca	8.4Bb	5.4BCa	3.7Ba	2.6BCDa
7-Jul	61Da	19.2DEa	16.9CDab	10.9Bb	7.1Ca	4.2BCa	2.9CDa
13-Jul	77Ea	20.8DEb	20.6DEa	14.9Cab	10.6Da	6.1Ca	4.2DEa
20-Jul	92Fa	22.5Eb	22.5Ea	17.8Ca	14.9Ea	8.7Da	5.4Ea

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 1 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Cumulative soil water use of EC_a zone 2 for each date and depth increment, IMPACT-09.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	--------------------	--------------------	--------------------	mm	--------------------	--------------------	--------------------
19-May	0A†a‡	0Aa	0Aa	0Aa	0Aa	0Aa	0Aa
1-Jun	4Ab	3.6Ba	0Ab	0Ab	0Ab	0Ab	0Ab
----------	----------	----------	*irrigation initiated June 2*	----------	----------	----------	----------
8-Jun	7Ab	6.4Ba	1.0Ab	0Ab	0Ab	0Ab	0Ab
15-Jun	19Ba	11.6Ca	6.1Ba	1.2Aa	0Ab	0Ab	0Ab
22-Jun	34Ca	15.9Da	12.5Ca	5.7Ba	1.1Aab	0Ab	0Ab
30-Jun	59Da	20.3Ea	18.7Da	14.6Ca	4.5Ba	1.1ABb	0.1Ab
7-Jul	67Da	18.8DEa	18.9Da	17.0CDa	8.5Ca	3.2Ba	0.2Ab
13-Jul	82Ea	20.9Eb	20.2Da	19.4DEa	12.6Da	7.5Ca	1.7Bb
20-Jul	100Fa	22.1Eb	21.6Da	21.1Ea	16.2Ea	13.9Da	5.2Ca

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 2 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

Cumulative soil water use of EC_a zone 3 for each date and depth increment, IMPACT-09.

Date	Total	20 cm	40 cm	60 cm	80 cm	100 cm	120 cm
	----------mm----------						
19-May	0A†a‡	0Aa	0Aa	0Aa	0Aa	0Aa	0Aa
1-Jun	3Ac	2.6Aa	0Ab	0Ab	0Ab	0Ab	0Ab
----------*irrigation initiated June 2*----------							
8-Jun	4Ac	3.9Ab	0Ac	0Ab	0Ab	0Ab	0Ab
15-Jun	3Ab	3.0ABb	0Ac	0Ab	0Ab	0Ab	0Ab
22-Jun	10Ab	8.2Bb	1.4Ac	0Ac	0Ab	0Ab	0Ab
30-Jun	27Bb	17.0Ca	8.3Bb	1.2ABc	0Ab	0Ac	0Ab
7-Jul	36Bb	18.9Ca	12.2Bb	5.0Bc	0Ab	0Ab	0Ab
13-Jul	55Cb	25.4Da	18.5Ca	11.3BCb	3.7Bb	0Ab	0Ac
20-Jul	88Da	29.3Db	25.8Da	19.4Da	10.9Cb	2.7Bc	0Ac

† Means followed by different capital letters (A, B) indicate significant differences between date within EC_a zone 3 (p-value < 0.05).

‡ Means followed by different lowercase letters (a, b) indicate significant differences between the three EC_a zones (p-value < 0.05).

APPENDIX D

Variable Rate Seeding in Cotton: On-Farm Evaluation in the Brazos River Floodplain

Introduction

This study was completed in companion with the research conducted at the Texas Agrilife Research Field Laboratory-IMPACT center during 2008 and 2009. Similarities and differences in the two sites will be addressed, although statistically the two sites were not compared.

To be profitable, cotton producers in the Brazos River Floodplain must manage seeding rates and agronomic practices efficiently. With the introduction of transgenic cotton and the ever changing traits, seed costs have continued to increase as well as the price of inorganic fertilizers and fuel. The increases in seed, fertilizer, and fuel cost have left producers looking for ways to decrease inputs while still achieving maximum outputs from their cotton crops. The first place for the producer to evaluate the amount of inputs he/she introduces to their fields would be the seed itself. The average cost of a bag of cotton seed depending on the traits included can range from $300 to $500. The commonly planted seeding rates in the Brazos River Floodplain range from 118, 560 to 123,500 seeds ha^{-1}, implying that cotton sold at 250,000 seeds per bag could plant around 2 hectares. If seeding rates can be reduced and still achieve yield and quality potential, producers potentially could cut input costs through spending less money on seed. This article will not evaluate actual cost savings between different seeding rates in cotton, but focus more on the feasibility of reduced seeding rates and its affect on cotton yield and quality in the Brazos River Floodplain.

The soil variability within the Brazos River Floodplain provides a challenge for producers. Soil textures in a single field can range from sandy loams to clays. The variability within fields challenges producers through management, fertilization, and irrigation scheduling. If seeding rates can be reduced on some or all soil types, seed and possible irrigation savings (water and energy) could be possible. What needs to be done is an evaluation of different seeding rates and the crops performance on a range of soil types within a field.

Site characteristics and seeding rates

A field was selected in both 2008 and 2009 based on soil survey maps, which indicated that Weswood silt loam and silty clay loam, Highbank silty clay loam, and Ships clay were present in the fields. The fields present at the IMPACT center include Weswood silt loam and silty clay loam, but not the Highbank and Ships soil series. Belk and Roetex clay are present at the IMPACT center and are of similar mineralogy as the Ships soil series. Yahola sandy loam is also present at the IMPACT center, indicating that the fields there are more variable than the fields used for this evaluation of variable rate seeding. Each field was under conventional tillage practices and a cotton-corn rotation, center pivot irrigated, and covered by the Texas Boll Weevil Eradication Program, which was the case for the IMPACT center as well. All inputs such as fertilizer, pesticides, and irrigation were made at the discretion of the producer and were similar for 2008 and 2009. Soil variability was validated using an EM38DD electrical conductivity meter, which nondestructively maps clay content and water content of the soils in the Brazos River Floodplain. Electrical conductivity mapping indicated that two apparent electrical conductivity (EC_a) zones of variability were present in both of the fields. In comparison, the IMPACT center contained three soil zones. The EC_a zones on the Scamardo fields were admirable to EC_a zones 2 and 3 at the IMPACT center based on soil series.

In each of the two EC_a zones, three seeding rates (74,100; 98,800; and 123,500 seeds ha^{-1}) were planted (D&PL 161 RRF/BGII) (Delta and Pine Land Company, Round-up Ready Flex/Bollgard II). The variety planted at the IMPACT center was D&PL 164 RRF/BGII. In each of the EC_a zones and seeding rates, four measurement locations were selected at random to evaluate differences in cotton lint yield and quality. 24 measurements locations were selected for each year of the study.

Cotton lint yield and seeding rates

Statistically, lint yield in 2008 was significantly different between the two EC_a zones, IMPACT-08 and -09 followed the same trend. Essentially, as the electrical conductivity of the soil increases (clay content and water content of the soil increase), so does lint yield. Evaluation of the seeding rate differences within each EC_a zone, indicated that no significant difference in lint yield were present when seeding rates ranged from 74,100 to 123,500 seeds ha^{-1}.

Table 1. Averages of four replications for each EC_a zone and seeding rate for 2008.

EC_a zone	Seeding rate (seeds ha^{-1})	Lint yield (kg ha^{-1})
	74,100	2245B
1	98,800	2460B
	123,500	2196B
2	74,100	2725A

2	98,800	2421A
	123,500	2661A

A,B indicate significant differences between EC_a zones.

In 2009, lint yield differences between soil zone and seeding rate were mixed. The different EC_a zones showed significant yield differences only at the 74,100 and 98,800 seed ha^{-1} rates. Within EC_a zone 1, the 74,100 seeds ha^{-1} rate yielded significantly more than the higher seeding rates within EC_a zone 1, but yielded significantly less than the higher seeding rates in EC_a zone 2.

Table 2. Averages of four replications for each EC_a zone and seeding rate for 2009.

EC_a zone	Seeding rate (seeds ha^{-1})	Lint yield (kg ha^{-1})
1	74,100	1956Aa
	98,800	1631Bb
	123,500	1852ab
2	74,100	1699Bb
	98,800	1903Aa
	123,500	1944a

A, B indicates significant differences between EC_a zones.
a, b indicates significant differences between seeding rates within each EC_a zone.

Cotton lint quality and seeding rates

In 2008, Micronaire and length uniformity values were statistically higher in EC_a zone 2 when compared to EC_a zone 1. No differences were witnessed between seeding rates. Although differences in micronaire and length uniformity were seen between the two EC_a zones, all readings would indicate a base or premium price towards a producers loan rate.

Fiber length, strength, and elongation all showed no difference across EC_a zones and/or the three seeding rates.

Table 3. Averages of four replications for each EC_a zone and seeding rate for 2008.

EC_a zone	Seeding rate (seeds ha^{-1})	Micronaire	Length (mm)	Strength (kN m kg^{-1})	Uniformity (%)	Elongation (%)
1	74,100	4.40B	30.7	275	83.5B	8.25
	98,800	4.55B	31.2	276	84.2B	8.48
	123,500	4.47B	31.0	274	84.3B	8.58
2	74,100	4.54A	31.8	282	84.9A	8.40
	98,800	4.62A	31.5	281	84.7A	8.03
	123,500	4.83A	31.0	276	84.6A	8.40

A,B indicates significant differences between EC_a zones.

In 2009, Micronaire differences were only seen across EC_a zone 1 and 2, at 98,800 seed ha^{-1}. Regardless of the difference, all values were within the base range for micronaire.

Fiber length, strength, uniformity, and elongation indicated no differences between EC_a zones and/or seeding rates.

Table 4. Averages of four replications for each EC_a zone and seeding rate for 2009.

EC_a zone	Seeding rate (seeds ha^{-1})	Micronaire	Length (mm)	Strength (kN m kg^{-1})	Uniformity (%)	Elongation (%)
1	74,100	4.6	30.5	317	84.9	4.8
	98,800	4.5b	30.5	307	84.3	4.9
	123,500	4.7	30.2	299	84.7	5.3
2	74,100	4.7	30.0	306	84.5	5.1
	98,800	4.8a	30.0	302	84.1	5.2
	123,500	4.9	30.2	305	84.8	5.3

A,B indicates significant differences between EC_a zones.

Fiber quality parameters such as micronaire, length, strength, and uniformity were all significantly different across EC_a zones in both 2008 and 2009 at the IMPACT center. Fiber elongation was also significantly different across EC_a zones in 2009. Fiber quality showed no response to variable seeding rates at the IMPACT center as well.

The higher variability in the fiber quality parameters across the EC_a zones at the IMPACT center could be attributed to the fact that more soil variability is present at the IMPACT center when compared to the sites used for this evaluation.

Effectiveness of variable rate seeding in cotton for the Brazos River Floodplain

By using the published soil survey maps and the electrical conductivity readings, variability of soil types within fields were identified for the field used in 2008 and 2009. Three seeding rates (74,100; 98,800; and 123,500 seeds ha^{-1}) were established in the area of the fields with the most soil variability to evaluate cotton lint yield and quality responses to various soil types and seeding rates.

In 2008, overall yield differences were seen between the two EC_a zones, EC_a zone 2 yielded more than EC_a zone 1. This difference in yield can be attributed to each soil type and its unique ability to store more or less water based on clay content. These findings are similar to that of IMPACT 2008 and 2009, which also had significant differences in lint yield across the EC_a zones. Within EC_a zone 1, the 74,100 seeds ha^{-1} rate yielded significantly more than the higher seeding rates within EC_a zone 1, but yielded significantly less than the higher seeding rates within EC_a zone 2. Although lint yield differences in 2009 were seen in this evaluation for the different seeding rates, it would still be justifiable to reduce seeding rates because cost saving on seed would offset the slight reduction in yield.

Fiber quality was minimally affected by EC_a zone and seeding rate, indicating that fiber quality differences are based on the genetics of each cultivar. In comparison, fiber quality differences were witnessed at the IMPACT center during both 2008 and 2009 across the three EC_a zones. This realization could be attributed to the fact that there is more soil variability present at the IMPACT center (an additional EC_a zone) when compared to the fields used for this portion of the study. Fiber quality differences on a year to year basis are mainly affected by environmental stresses (temperature, solar radiation, and temperature). Manipulating fiber quality by reducing seeding rates was not achievable.

The soil types in the Brazos River Floodplain range from sandy loams to clays. Regardless of soil types, it was witnessed that reducing seeding rates to 74,100 seeds ha^{-1} from 123,500 seeds ha^{-1} achieved the same lint yield and quality. This realization also occurred at the IMPACT center as well. Findings indicate that seed costs could almost be cut in half if 74,100 seeds ha^{-1} were to be planted.

While the soil survey maps paired with the soil apparent electrical conductivity map indicated variable soil zones, it did not indicate that a specific seeding rate would work better on one soil type compared to another. Since these maps indicate soil variability, they would show promise for other variable rate technologies, such as fertilization, pesticide application, and irrigation. The difference in yield and the trends witnessed from year to year and field to field stress the importance of on farm research and illustrates variations that can occur within each field, especially within floodplain agriculture.

VITA

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