A PRECISION AGRICULTURE APPROACH TO MANAGING COTTON FIBER QUALITY AS A FUNCTION OF VARIABLE SOIL PROPERTIES

A Seniors Scholars Thesis

By

SCOTT MICHAEL STANISLAV

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2008

Major: Agronomy

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Approved by:

Research Advisor: Cristine Morgan
Associate Dean for Undergraduate Research: Robert C. Webb

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ABSTRACT

A Precision Agriculture Approach to Managing Cotton Fiber Quality as a Function of Variable Soil Properties (April 2008)

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Cotton producers can maximize yield and fiber quality by understanding soil variability throughout the fields, thus receiving premium prices for the cotton lint. A better understanding of how soil water holding capacity affects cotton lint yield and quality can result in improved management practices that can maximize fiber quality while minimizing inputs. The objectives of this study were to 1) create management zones using a soil EC_a map, 2) test the usefulness of this map using measurements of lint quality and lint quantity in both irrigated and dryland fields, and 3) determine a relationship between soil water holding capacity fiber quality parameters.

The selected site was Texas A&M University's IMPACT center which is located nine miles west of College Station, TX in the Brazos River floodplain. In the 2006 and 2007 growing seasons, 24 measurement locations were selected in a dryland and irrigated cotton field, 12 locations in each field. The sites were selected using a map of soil EC_a, three EC_a categories and four replications. At each location soil texture, soil water holding capacity, and lint quality (HVI) and quantity were measured. The EC_a categories successfully identified significant differences in clay content water holding capacity, lint

yield, lint quality, and loan values. The 2006 season was relatively dry. Weather, soil variability, and management affected the yield and yield quality responses. Water availability was not a factor for lint yield or quality in 2007. In this situation, the soil was the primary factor for field heterogeneity. The cotton yield still responded to soil variability but lint quality and loan value was uniform. The uniformity of lint quality and non-uniformity of lint quantity leads to the conclusion that these soils have individual yield thresholds, but without water stress the quality threshold is uniform. This conclusion illuminates opportunities for precision management strategies. One management strategy that may result from this work is to reduce seeding rates in lower production areas of the field, if the plants will compensate for yield to still reach the soil's yield potential, perhaps less competition for water would improve lint quality.

DEDICATION

I dedicate this undergraduate thesis to my mother, Karen, and my brother, Kyle, for their unconditional love, support, and understanding. They motivate me to work diligently and encourage me when times are difficult.

I also dedicate this thesis in memory of my late father, Mike, whose support I dearly miss.

ACKNOWLEDGEMENTS

I would like to acknowledge Dr. Cristine Morgan. She was very instrumental in bringing forth this thesis. Throughout my experience as an undergraduate research scholar, Dr. Morgan was of extreme patience and understanding. Dr. Morgan was always there when I needed her.

I would also like to thank Dr. Tom Hallmark of the Texas A&M University Soil and Crop Science Department, without him I would not have gained an interest in Soil Science and would not have had the opportunity to work with Dr. Morgan.

NOMENCLATURE

AFIS	Advance Fiber Information System
DAP	Days after Planting
°C	Degrees Celsius
°F	Degrees Fahrenheit
$	Dollars (United States currency)
EC_a	Bulk Soil Electrical Conductivity
GDD	Growing Degree Days
ha	Hectare
HVI	High Volume Instrument
kg	Kilogram
kN	Kilonewton
m	Meter
Mic	Micronaire
mm	Millimeter
mS	Millisiemens
NAWF	Nodes Above White Flower
PSA	Particle Size Analysis
%	Percent
WHC	Water Holding Capacity

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CHAPTER I

INTRODUCTION

Precision agriculture is a new concept that implements technologies that will allow producers to manage fields with variable soil properties on a site specific basis, with the goal of improving crop yield and revenues (Pierce and Nowak, 1999). The goal of precision agriculture is to increase profitability while decreasing inputs, improve plant--soil interactions, and to reduce the detriments brought about to the environment through intensive agricultural practices. Precision agriculture technologies have been popular in the Midwest in corn and soybeans because of yield monitors (Beal and Tian, 2001, Bermudez and Mallarino, 2002) and have been since the mid 1990s. Cotton yield monitors are still in development and have not been implemented because of inadequate results. In cotton production in Texas, yield monitors are not being used on a large scale basis at this time and not popular among producers because of their lack of reliability when compared to a grain yield monitor. Before precision agriculture technologies are implemented in cotton production, they must be proven cost effective.

Management zones

For precision agriculture to be implemented, producers must treat a field in site specific zones of management. The common management practice used presently utilizes treating the field as one uniform site, even though variability may exist across a

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The style of this thesis is that of Soil Science Society of America Journal landscape. Managing variability across a field can be done by delineating management zones based on soil properties that affect yield. For example, soil pH, exchangeable nutrients, clay content, and electrical conductivity (Ping et al., 2005, Terra et al., 2006). It is not practical to base management zones off of yield monitor data due to reliability purposes, and because of high yield variation from year to year due to climatic factors. Management zones could be used to determine various inputs of fertilizer, pesticides, irrigation, or seeding rate. Bulk soil electrical conductivity (EC_a) measurements have proven to be effective for constructing management zones because EC_a measurements can be obtained rapidly and efficiently, and EC_a responds directly to changes in soil properties (Fraisse et al., 2001).

Soil electrical conductivity is commonly used in precision agriculture because EC_a is easy to collect and the instruments are available commercially (Corwin et al., 2003). Electrical conductivity can be measured invasively using the Veris sensor (Veris Technologies, Salina, KS), or noninvasively using an EM38 sensor (Geonics Limited, Mississauga, Ontario, Canada). Soil EC_a measurements respond to clay content and type, solute concentration, temperature, and water holding capacities of the soil (McNeill, 1980). Both instruments send an electrical current downward into the soil, and the meter reads how much current is conducted through the soil. The EC_a values are positively related to increases in clay content, water content, and solute concentration.

Electrical conductivity maps can be easily obtained for large agricultural fields. Electrical conductivity maps are of a higher spatial resolution and usually show greater soil variability across a field compared to conventional soil survey maps, thus making EC_a a better tool for delineating management zones. One study attempted to delineate management zones using soil survey maps, but soil variability at finer resolutions than shown by the soil map limited the ability to provide effective management zones (Franzen et al., 2002).

Cotton yield and quality

In Texas cotton production, soil water storage is one of the most important soil properties that need to be accounted for in creating management zones. One main limiting factor for any crop is plant available water. Because EC_a maps soil water holding capacity in non-saline soils, EC_a maps are useful for precision agriculture in cotton (Sheets and Hendrickx, 1995). Across a field with high variability some areas of the crop can be water stressed, especially if the field consists of a sandy soil with low water holding capacities, when compared to a different part of the same field with clayey soils of higher water holding capacities. In the sandier regions of the field, you can expect prolonged moisture deficiency when compared to clayey soils during dry years. In higher water holding capacity regions of the field, the cotton plant can become water-logged during wet years, or irrigation scheduled for the sandier parts of the field. Knowing the water holding capacities of the field can not only save on irrigation inputs but can also help predict crop yields (Corwin et al., 2003).

To maximize profits in cotton fields, producers want to not only look at yield but also the quality of the lint. Therefore, the relationship between both cotton lint yield and quality and variable soil properties needs to be understood. Cotton yield and quality are related to numerous soil properties. These properties include available water, soil texture, soil fertility, and soil pH. In most situations, fertility and pH can be managed with inputs, while soil water varies with weather and irrigation. A study conducted by Iqbal et al. (2005) determined that available water was one of the leading causes to cotton lint yield variation in a dryland setting. Terra et al. (2006) and Corwin et al. (2003) used EC_a to map variability in clay content, and water holding capacity of the soil which was correlated to cotton lint yield. Lint yield variation can also be related to topographical features such as elevation and slope (Bronson et al., 2003; Cox et al., 2005).

Cotton lint quality determines the price of the cotton, hence soil water content can be just as important as cotton lint quality. Lint quality is determined by measuring multiple parameters. Lint quality is dependent on lint micronaire. Looking at environment and lint quality, micronaire is the primary focus because it is viewed as a quality indicator. Some studies have shown that in dry, hot years early planting dates can increase yield, fiber length and maturity (micronaire), due mainly to the fact that later in the year less water is available to the crop (Davidonis et al., 2004). Low micronaire values indicate immature fibers, while high micronaire values indicate mature fibers. When the cotton is under stress late in the season, the plant creates micronaire values that are too high and reduce lint prices. If the plant is not under stress, the lint is immature with low micronaire. Pettigrew (2004) demonstrated that irrigation can produce more bolls higher up on the main stem, extend flowering periods, increase micronaire, and produce 2% longer fibers when compared to dryland cotton. Johnson et al. (2002) reported a strong relationship between fiber length and soil moisture as well as a relationship between soil moisture and HVI fiber quality parameters such as length, micronaire, strength, elongation, and uniformity. Fiber length can also be influenced by daytime and nighttime temperatures. Irrigation along with favorable growing conditions also produces higher yield which is correlated to higher fiber quality (Ping et al., 2004).

In general, yield and quality are determined by a complex combination of factors. As these studies have suggested, yield and quality are influenced by irrigation, soil fertility, soil pH, soil EC, pressures from insects and weeds, and environmental factors including rainfall and temperature. Revenues for a cotton crop are driven by yield and lint quality, which can vary in a field according to soil properties. Identifying management zones based on soil variability may provide a basis for site specific management. Implementing precision management technologies such as variable rate applications of irrigation, fertilizer, pesticides, and seeding rates, a producer may minimize inputs in poorly producing parts of the field and maximize outputs in highly productive parts of the field. The objectives of this study were to 1) create management zones using a soil EC_a map, 2) test the usefulness of this map using measurements of lint quality and lint quantity in both irrigated and dryland fields, and 3) determine a relationship between soil water content and fiber quality parameters.

CHAPTER II

MATERIALS AND METHODS

This study was conducted at the Texas A&M University AgriLife Research farm in Burleson County, TX during the summers of 2006 and 2007. In 2006, a 20.24 ha irrigated field and a 12.15 ha dryland field were used for the experiment. In 2007, a 25.43 ha irrigated field and a 16 ha dryland field was used. The irrigated fields are under center pivot irrigation. The sites are under a cotton-corn rotation and conventional tillage practices. The boll weevil eradication program is also being implemented on the site. Delta Pine 455 BGRR (Bollgard/Roundup Ready) was planted into 762 mm spaced rows on April 5, 2006 and April 10, 2007 at a rate of 123,500 seeds ha^{-1}. The fields were fertilized (side dressed), as recommended by the Texas A&M AgriLife Extension Soil, Water, and Forage Testing Laboratory, with urea ammonium nitrate (32-0-0) at a rate of 1633 kg ha^{-1} (436 kg of elemental N ha^{-1}) at the fourth leaf stage during both seasons. All pesticide applications were recommended and made by the Texas A&M University Farm Services. Daily values of maximum and minimum temperature, solar radiation and precipitation were measured by a USDA weather station situated 50 meters from the study sites.

The soils mapped on the sites consisted of Yahola sandy loam (Coarse loamy, mixed, superactive, calcareous, thermic Udic Ustifluvents), Weswood silt loam and silty clay loam (Fine silty, mixed, superactive, thermic Udifluventic Haplustepts), and Belk Clay

(Fine, mixed, thermic Entic Hapluderts). The 2007 study site consisted of Yahola sandy loam, Weswood silt loam and silty clay loam, Belk clay, and Roetex Clay (Very fine, mixed, active, thermic Aquic Hapluderts),

The soil electrical conductivity map used for the experiment was made during the spring of 2001 using an EM38 electrical conductivity meter (Geonics, LTD., Mississauga, Ontario, Canada). The EC values on the 2006 and 2007 fields ranged from 40-130 mS m^{-1}; Using this map three categories were delineated based on EC_a, 40-70, 70-100, and 100-130 mS m^{-1}. In 2006, EC values were divided into three equal number intervals. These were based on the number of EC values within each interval. 2007 points were chosen by delineating equal intervals between EC values. The EC_a zones were chosen somewhat arbitrarily; however EC_a zones were delineated using fuzzy k-means, after experimental design was chosen in 2007, and very similar zones were identified for 2006 and 2007 fields (Terra et al., 2006). Four measurement sites were randomly selected within each of the three EC_a categories for the dryland and irrigated fields, 12 total sites in the dryland field and 12 in the irrigated field. In summary, 2006 and 2007 each included 24 measurement sites (Fig. 1).

The EC map completed in the spring of 2001 was believed to possibly have some drift. Drift can occur due to the sun heating the EM 38 (Robinson et al., 2004). In the fall of 2007, after the completion of this project, a new EC map of the same site was made using recommended calibration techniques and a sunshield for the EM38. The new EC_a

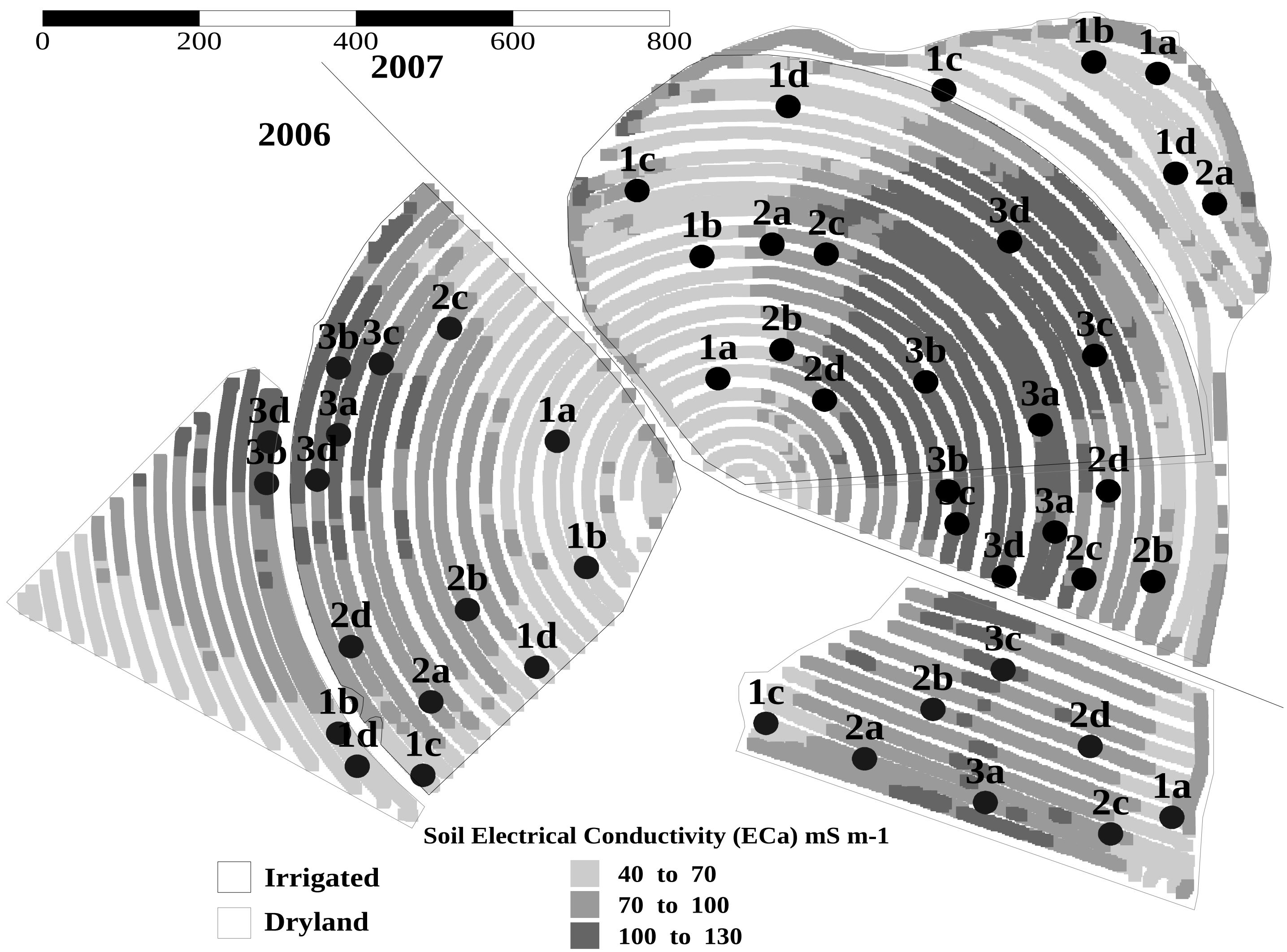

Fig. 1. Soil EC_a map of the experiment site classified in three categories with measurement sites included (2006-2007).

map resulted in similar EC_a categories, but the range of values was lower. Instead of values ranging from 40-130 mS m^{-1}, values ranged from 0-110 mS m^{-1}. After overlaying the new map, all 24 measurement locations for both years, remained in the same EC_a categories.

After planting and stand establishment 3.81 cm diameter soil cores were collected, in the middle of the bed, using a tractor-mounted Giddings probe (Giddings Machine Company, Windsor, CO). In each of the holes, 5.08 cm (inside diameter) aluminum access tubes were installed to a depth of 150 cm. Soil cores were sectioned into 30 cm increments, 0-30, 30-60, 60-90, 90-120, and 120-150 cm, and measured for particle size analysis using the hydrometer method (Gee and Or, 2002).

Soil water content measurements were collected at each of the 24 measurement sites using a neutron moisture gauge CPN 501 DR (Campbell Pacific Nuclear, Concord, CA). Measurements were taken at 20 cm increments, from 20 to 120 cm deep. The moisture gauge was calibrated using in-situ volumetric water content measurements at field capacity and a relatively dry soil moisture condition. In 2006 the gauge was calibrated in a low EC_a soil and a high EC_a soil. In 2007 the gauge was calibrated to a low, medium, and high EC_a soil. At each calibration site and moisture content, soil moisture measurements were collected using the gauge at 20, 40, 60, 80, 100, and 120 cm deep. Once gauge 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, oven dried at 105°C, and weighed dry. Volumetric water content (m^3/m^3) was calculated and used calibration equations were created. Particle size analysis was also done for each calibration site. Calibration equations for each of the 24 measurement sites were selected based on matching the particle size of the calibration to the particle size of the measurement sites.

Once the cotton began to set squares, measurements for the COTMAN Plant Mapping Program (University of Arkansas Division of Agriculture & Cotton Incorporated) were initiated. Square set and retention rate (squareman), and nodes above white flower (NAWF) (bollman) were recorded weekly when appropriate. These measurements were used for when to apply pesticides, irrigation water, and prepare for harvest.

One week after defoliation each of the 2006 and 2007 24 measurement sites were hand harvested on September 8, 2006 and September 25, 2007. At each site 1/1000th of an acre of cotton plants were harvested by cutting three rows of plants, two rows on either side of the aluminum access tubes. Plants were put into tarps and marked with the location identification number. Tarps containing the plants were transported to the lab for processing. For each of the 24 harvested sites, 10 representative plants were selected for boxmapping. The remaining plants at each measurement site were picked for lint. The 10 plants were harvested by node and node position. The node grouping consisted of vegetative, nodes 3-5, 6-10, 11-15, 16-20, and 21-25. Each node grouping also contained position 1, 2, and 3, except for the vegetative node position.

The bulk 1/1000th of an acre samples for each measurement site along with the boxmapped samples were ginned. The 24 bulk samples were ginned using a 10 saw Eagle Cotton floor gin (Continental Gin Company, Birmingham, AL). Boxmapped samples were ginned on a 20 saw table top gin (Porter Morrison and Sons, Dennis Manufacturing Company, Athens, TX). Boxmapping data will not be reported.

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 International Textile Center (Lubbock, TX) in 2006 and at Cotton Incorporated (Cary, NC) in 2007. These samples were High Volume Instrument (HVI) tested for lint quality. The boxmapped cotton samples were weighed and sub sampled to 0.005 kg (according to testing facility requirements). These samples were Advanced Fiber Information Systems (AFIS) tested in 2006 and 2007 at Cotton Incorporated.

SAS statistical software (SAS, 2002), was used to analyze yield quantity and quality using ANOVA and protected Fischers tests. All regression analysis was performed using the spdep package in RGui (c-ran.r_project.org).

CHAPTER III

RESULTS

Weather data

The 25-yr. average rainfall for the months of April through September in Burleson County, TX is 510 mm. Cumulative rainfall for the same period in 2006 and 2007 was 409 and 513 mm, 101 mm below and 3.5 mm above the 25 year average, respectively (Fig. 2). According to planting and harvest dates for each growing season, the 2007 growing season had 159 mm more rainfall than 2006. Overall, 2007 was a very wet season resulting in no water deficiency for crop growth.

The 25 year average daily minimum and maximum temperatures for Burleson County for the months of April through September are 19°C and 29°C. During the 2006 growing season, the average minimum and maximum temperatures for April through September were 20°C and 33°C (Fig. 3). For 2007 the average temperatures were 20°C and 31°C (Fig. 3). The 2006 and 2007 growing seasons accumulated 3093 and 2526 GDD, respectively (Fig. 4). The 2007 growing season can be summarized as wet and cloudy, especially when compared to 2006.

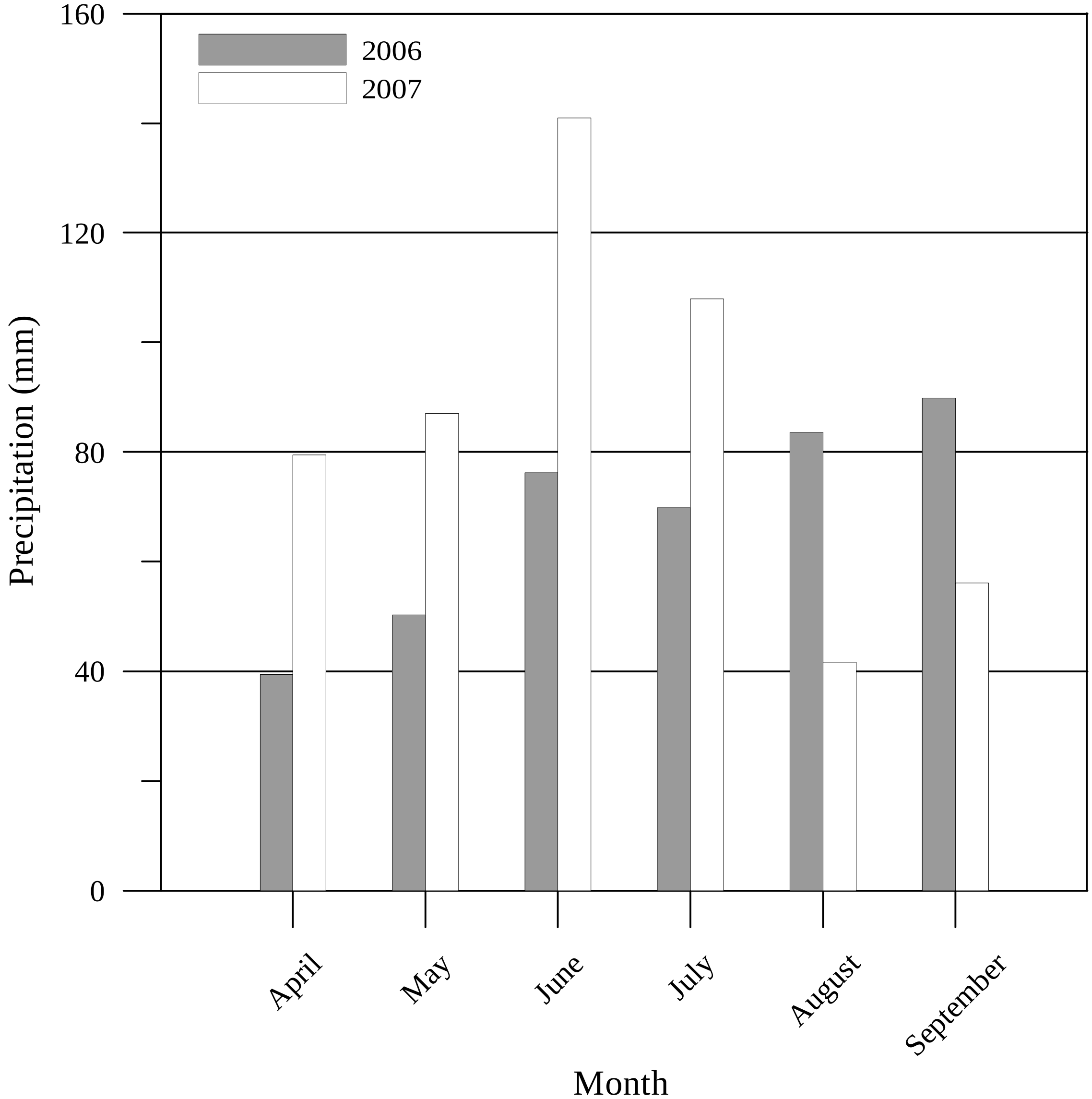

Fig. 2. Monthly precipitation for 2006 and 2007.

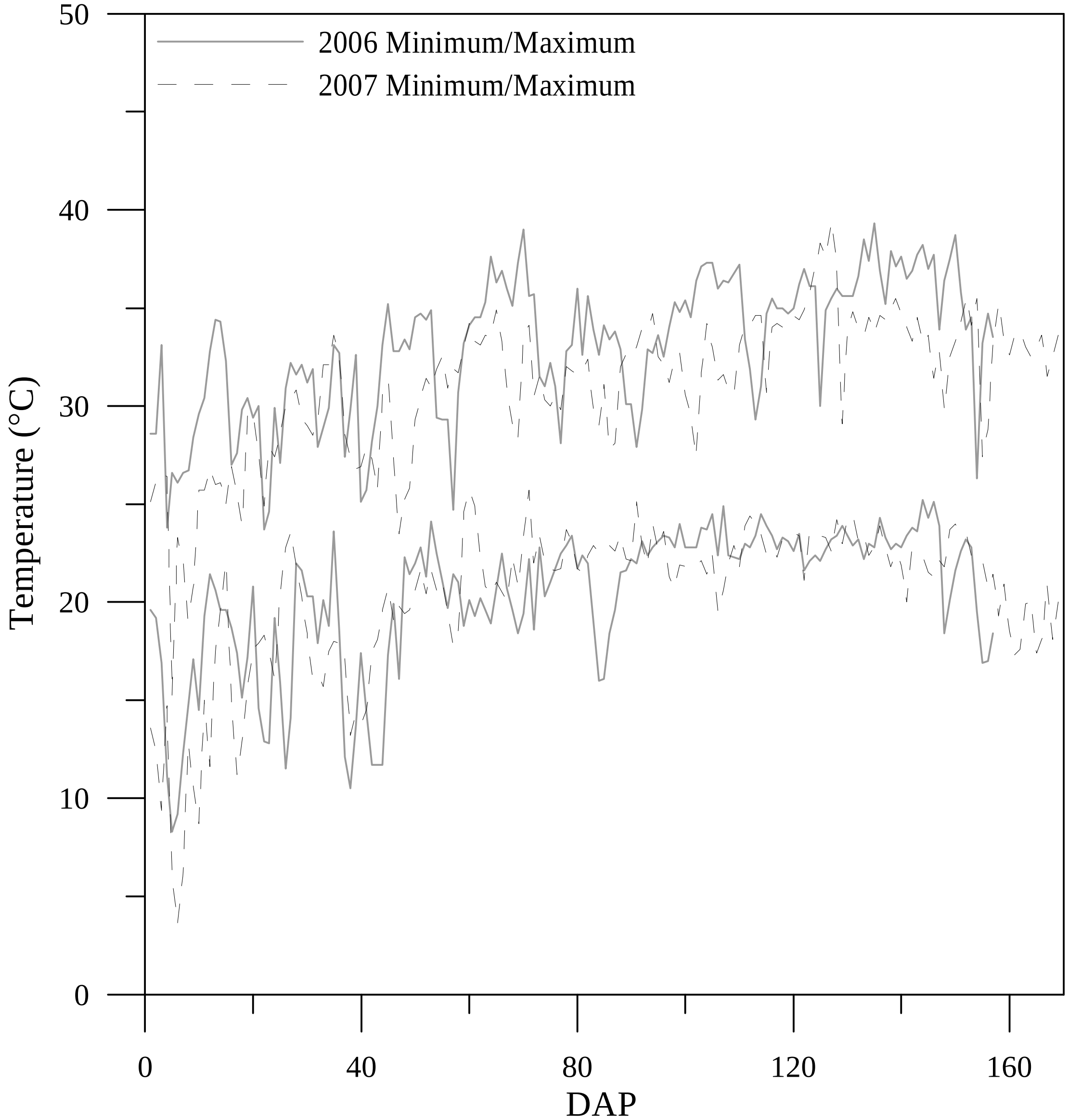

Fig. 3. Maximum and minimum temperatures (°C) as a function of days after planting (DAP) for 2006 and 2007.

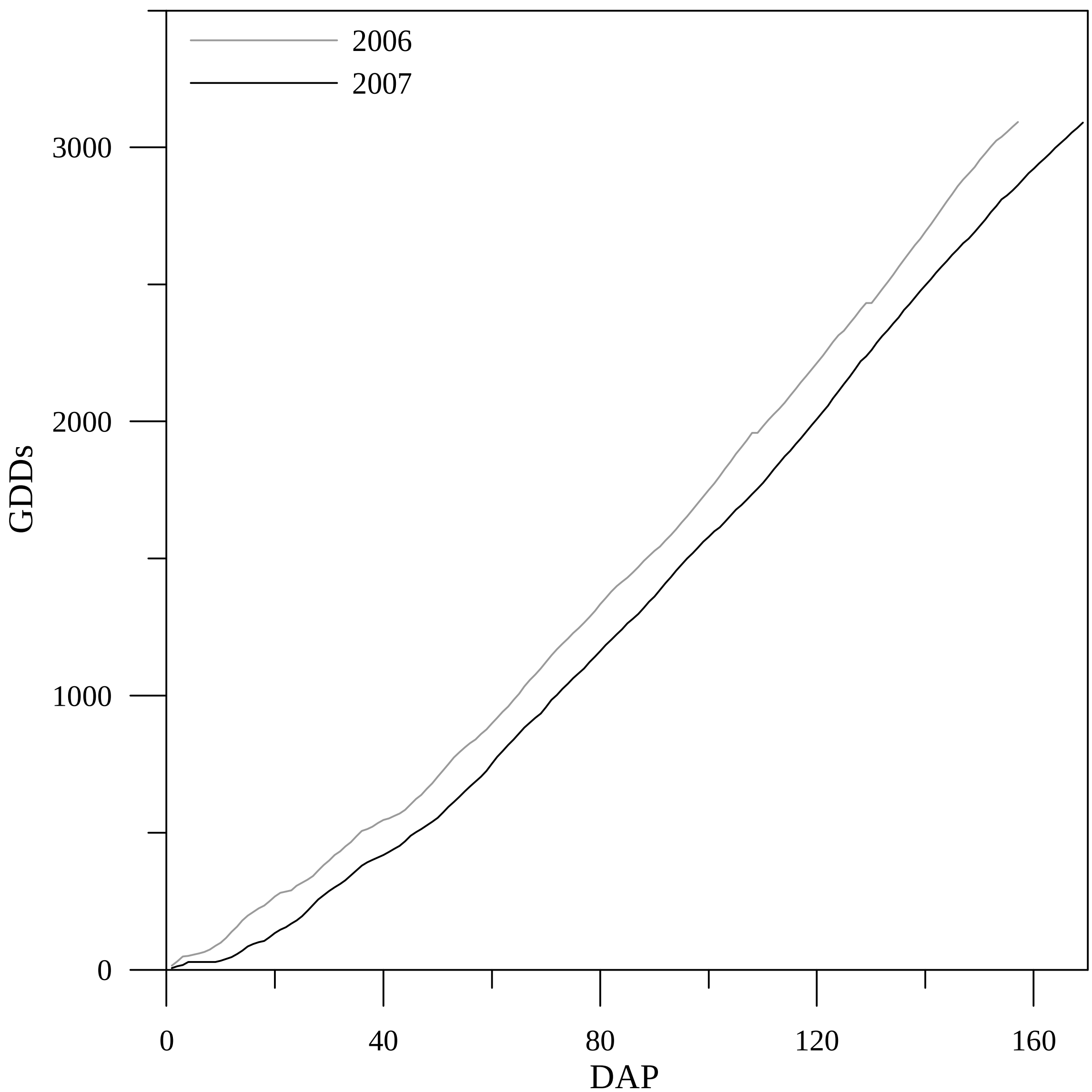

Fig. 4. Cumulative growing degree days (GDDs) as a function of days after planting (DAP) for 2006 and 2007.

Soil data and electrical conductivity

The soil in both the 2006 and 2007 fields ranged from well drained Ustifluvents with high permeability to somewhat poorly drained Hapluderts with low permeability. Though both 2006 and 2007 sites included different fields, all the fields had a similar range of soil types. In 2006, clay percentages in the dryland field ranged from 20 to 37 %. EC_a category 3 had significantly higher clay percentages than categories 1 or 2 (p-value <0.05, Table 1). The 2006 irrigated field had a higher clay range than the dryland field, 18 to 43 % clay., and the clay percentage was significantly different in all three categories (p-value < 0.05, Table 1). In 2007 the clay percentages in the dryland and irrigated fields ranged from 16 to 47 and 18 to 45 % clay, respectively All three EC_a categories were significantly different from each other in both fields (Table 2).

Linear regression shows that the EC_a for all four fields, 2006 and 2007, dryland and irrigated, was responding to clay content and soil moisture storage. The r^2 values for 2006 dryland and irrigated fields were 0.73 and 0.84 respectively (Fig. 5). In 2007, the relationship between soil EC_a values and clay content were even stronger; the r^2 value for the dryland and irrigated fields were 0.92, and 0.87 (Fig. 6).

Soil water holding capacity was calculated using the neutron probe calibration curves obtained during the wettest time period of the season along with neutron probe measurements at each of the 24 measurement sites during the wettest time period.

Table 1. Average (standard deviation) soil and cotton properties measured for 2006 dryland and irrigated fields divided into three EC_a (apparent electrical conductivity) categories.

ECa category	Clay content	Water holding capacity	Micronaire	Length	Uniformity	Strength	Elongation	Loan value	Lint yield	Lint value
	----%----	----mm----	---value---	---mm---	-----%-----	kN m kg^{-1}	-----%-----	---$ kg^{-1}---	---kg ha^{-1}---	---$ ha^{-1}---
					dryland					
1	20(4.3)$_b$	307(89.9)$_b$	3.30(0.1)$_a$	27.6(0.6)$_a$	81.3(1.3)$_{ns}$	265(11)$_{ns}$	5.08(0.5)$_b$	1.11(0.02)$_b$	847(365)$_{ab}$	925(389)$_{ab}$
2	21(2.3)$_b$	258(14.8)$_b$	3.40(0.2)$_a$	26.9(1.0)$_a$	81.3(0.6)$_{ns}$	266(17)$_{ns}$	5.1(0.3)$_b$	1.10(0.00)$_b$	471(36)$_b$	531(39)$_b$
3	37(3.0)$_a$	422(59.9)$_a$	3.70(0.3)$_b$	29.9(1.2)$_b$	82.3(0.9)$_{ns}$	277(9.2)$_{ns}$	4.55(0.3)$_a$	1.17(0.05)$_a$	1244(476)$_a$	1464(586)$_a$
					irrigated					
1	18(3.3)$_c$	326(49.4)$_b$	3.40(0.4)$_{ns}$	28.6(1.3)$_a$	81.2(0.6)$_a$	265(22)$_a$	4.43(0.1)$_{ns}$	1.13(0.04)$_b$	1054(267)$_b$	1201(353)$_b$
2	27(3.5)$_b$	410(41.6)$_{ab}$	4.00(0.4)$_{ns}$	30.1(0.3)$_b$	82.3(0.5)$_b$	287(13)$_b$	4.43(0.1)$_{ns}$	1.19(0.01)$_a$	1564(263)$_a$	1866(324)$_a$
3	43(7.0)$_a$	487(42.3)$_a$	3.87(0.4)$_{ns}$	30.6(0.3)$_b$	82.6(0.6)$_b$	292(8.9)$_b$	4.40(0.1)$_{ns}$	1.18(0.04)$_{ab}$	1413(133)$_{ab}$	1665(201)$_{ab}$

$_{a, b,}$ and $_c$ indicate significant differences between EC_a categories within each irrigation treatment (p-value <0.05).
$_{ns}$ indicates no significant difference (p-value <0.05).

Table 2. Average (standard deviation) soil and cotton properties measured for 2007 dryland and irrigated fields divided into three EC_a (apparent electrical conductivity) categories.

ECa category	Clay content	Water holding capacity	Micronaire	Length	Uniformity	Strength	Elongation	Loan value	Lint yield	Lint value
	----%----	----mm----	---value---	----mm----	-----%-----	kN m kg^{-1}	-----%-----	---$ kg^{-1}---	--kg ha^{-1}--	---$ ha^{-1}---
					dryland					
1	16(4.0)$_{c}$	243(12.8)$_{c}$	3.60(0.6)$_{b}$	29.2(0.1)$_{ns}$	83.5(0.4)$_{ns}$	281(16)$_{ns}$	4.93(0.1)$_{ns}$	1.16(0.08)$_{ns}$	767(385)$_{ns}$	905(485)$_{ns}$
2	28(3.8)$_{b}$	320(32.8)$_{b}$	3.95(0.2)$_{ab}$	29.7(0.3)$_{ns}$	83.4(0.9)$_{ns}$	289(7.7)$_{ns}$	4.83(0.1)$_{ns}$	1.20(0.00)$_{ns}$	1151(376)$_{ns}$	1383(451)$_{ns}$
3	47(7.3)$_{a}$	482(51.4)$_{a}$	4.05(0.1)$_{a}$	29.5(0.8)$_{ns}$	83.7(0.6)$_{ns}$	294(16)$_{ns}$	4.88(0.2)$_{ns}$	1.20(0.01)$_{ns}$	905(520)$_{ns}$	1089(629)$_{ns}$
					irrigated					
1	19(1.5)$_{c}$	262(12.3)$_{c}$	3.88(0.4)$_{ns}$	28.9(0.4)$_{b}$	82.9(1.3)$_{ns}$	272(5.0)$_{a}$	4.85(0.1)$_{ns}$	1.18(0.03)$_{ns}$	653(82)$_{b}$	771(102)$_{b}$
2	35(3.7)$_{b}$	368(31.7)$_{b}$	3.90(0.1)$_{ns}$	29.9(0.0)$_{a}$	83.8(0.3)$_{ns}$	291(14)$_{b}$	4.98(0.1)$_{ns}$	1.20(0.01)$_{ns}$	1138(178)$_{a}$	1368(209)$_{a}$
3	45(6.3)$_{a}$	484(59.5)$_{a}$	4.13(0.4)$_{ns}$	28.7(0.6)$_{b}$	82.5(1.0)$_{ns}$	289(5.9)$_{b}$	4.93(0.2)$_{ns}$	1.19(0.01)$_{ns}$	1001(326)$_{b}$	1194(329)$_{ab}$

$_{a, b,}$ and $_{c}$ indicate significant differences between EC_a categories within each irrigation treatment (p-value <0.05).
$_{ns}$ indicates no significant difference (p-value <0.05).

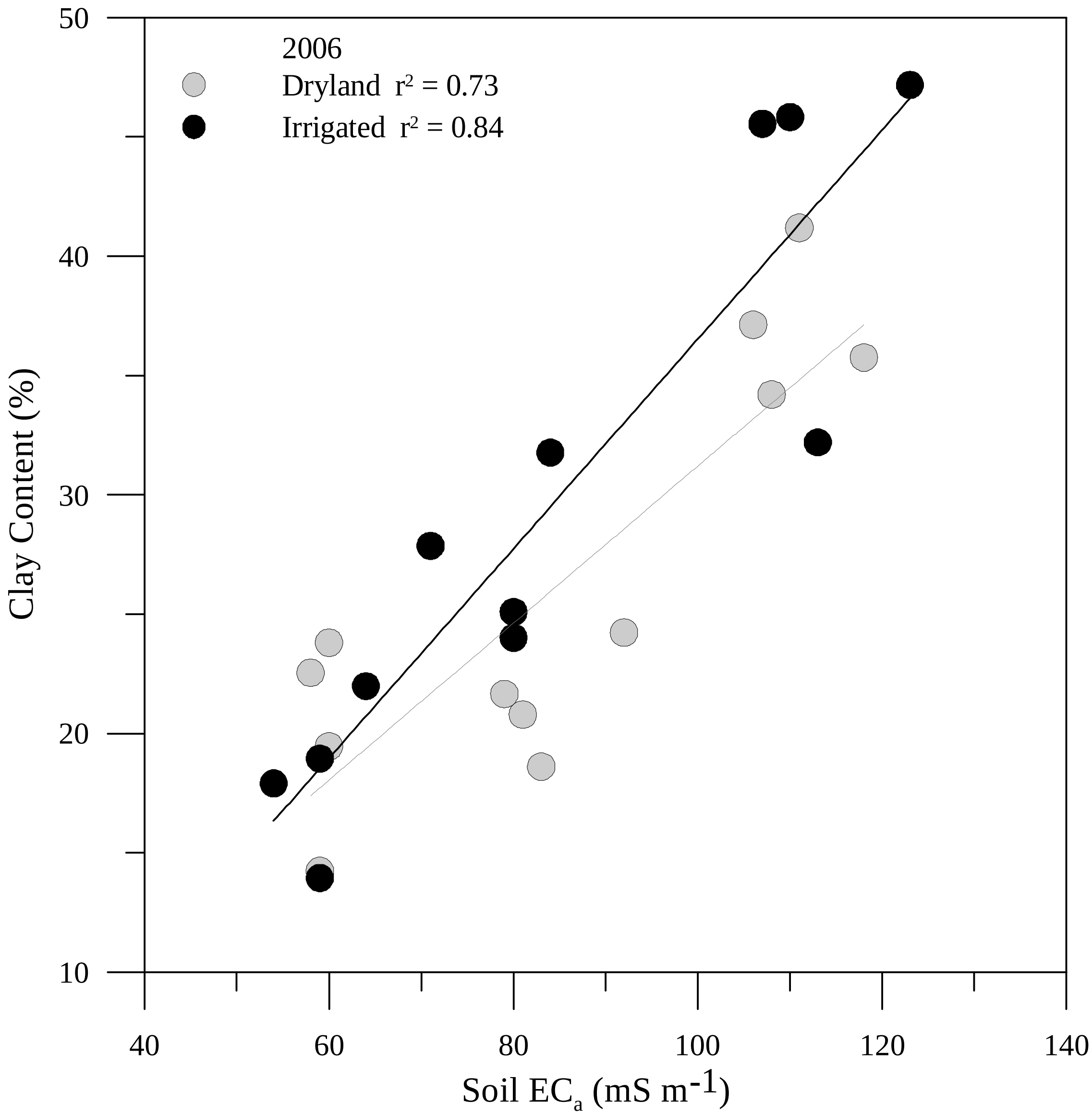

Fig. 5. Average clay percentage as a function of soil apparent electrical conductivity (EC_a) for 2006.

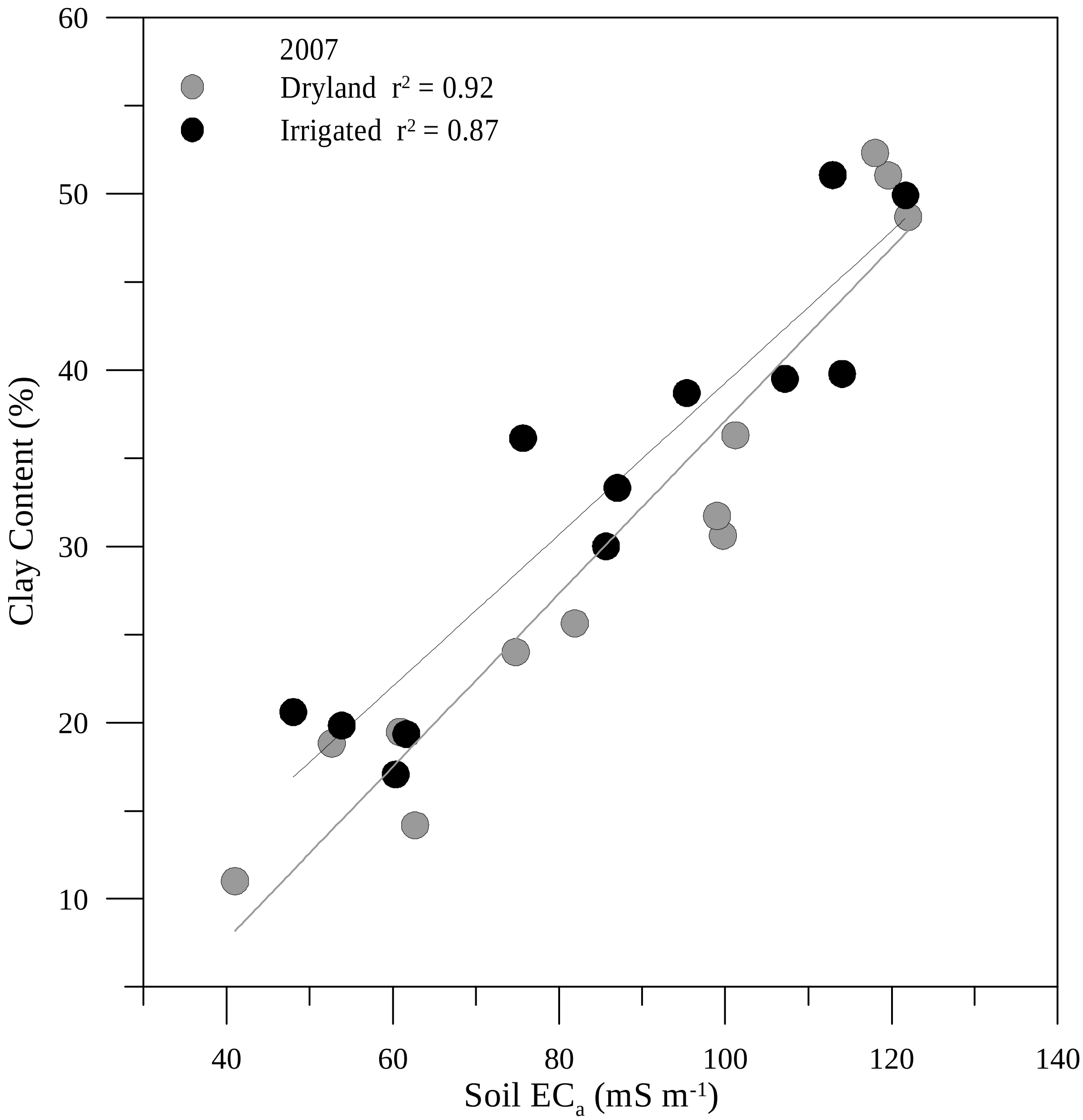

Fig. 6. Average clay percentage as a function of soil apparent electrical conductivity (EC_a) for 2007.

In 2006 the estimated water holding capacity in the dryland field was 307, 258 and 422 mm in EC_a categories 1, 2, and 3, respectively. The water holding capacity of EC_a category 3 was significantly different from categories 1 and 2 (p-value < 0.05, Table 1). The water holding capacity for the EC_a categories of the irrigated field ranged from 326 to 487 mm with the lowest and highest value in categories 1 and 3, respectively. Water holding capacity in the irrigated field was significantly different between EC_a category 1 and 3, but not category 2 (Table 1). For the 2006 dryland field we were surprised that EC_a category 2 had the lowest water holding capacity; however, we could not find a reason for the medium-valued EC_a readings and low-valued water holding capacity, even after two EM38 surveys. In 2007, all water holding capacities increased with EC_a category. The ranges for the dryland and irrigated fields were similar at, 243 to 482 mm and 262 to 484 mm, respectively (Table 2).

The relationship between soil EC_a and water holding capacity during the 2006 growing season is represented by Fig.7. The relationship between soil EC_a and water holding capacity was stronger in the irrigated field when compared to the dryland field, r^2 values were 0.67 and 0.26 respectively. In 2007, r^2 values of the dryland and irrigated fields were similar, 0.89 and 0.88, when compared to 2006 (Fig. 8). Differences in the relationship between soil EC_a and water holding capacity in 2006 and 2007, and the r^2 values between the two seasons can be accounted for by error in the neutron probe calibrations that occurred in 2006.

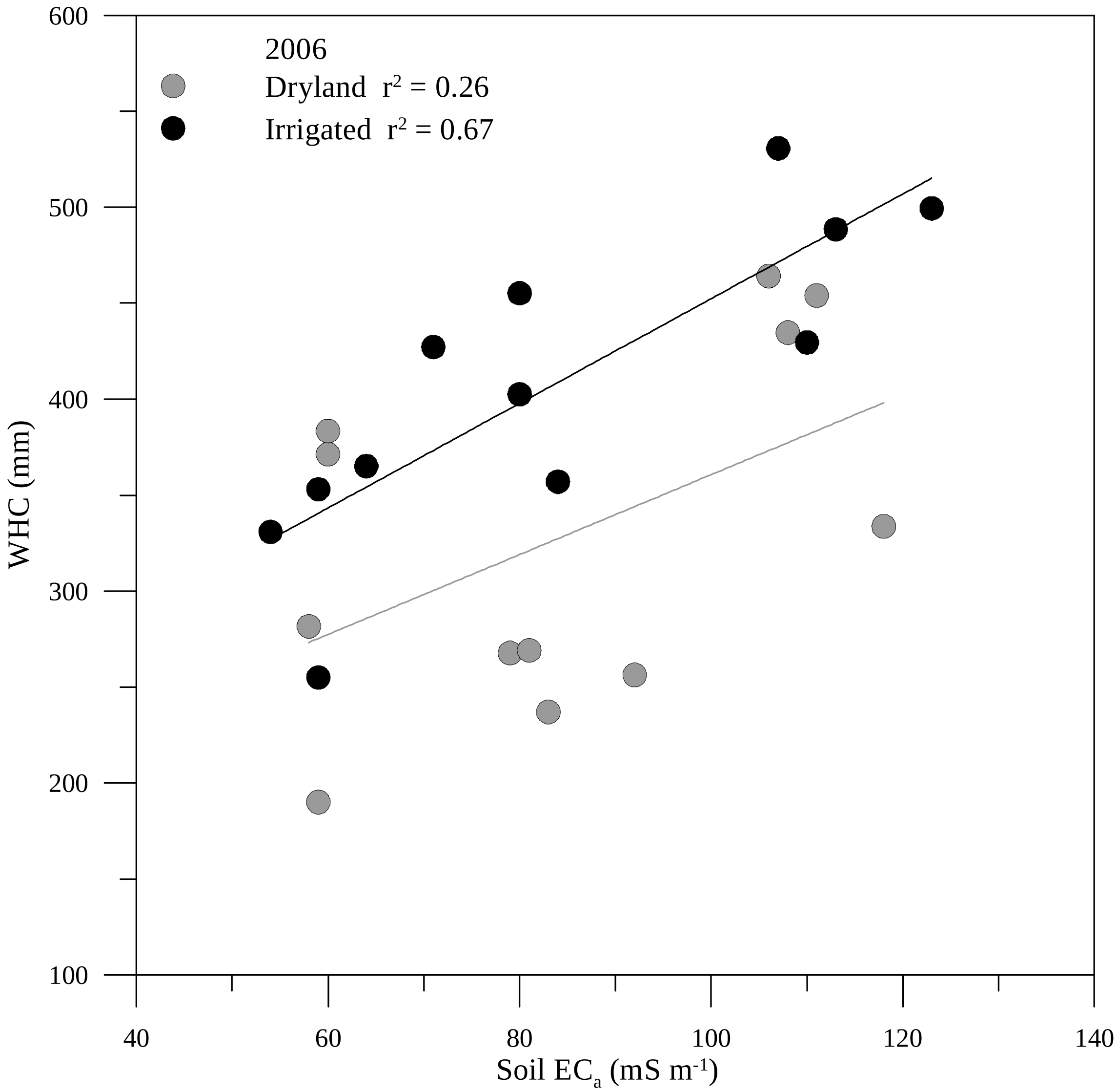

Fig. 7. Water holding capacity (WHC) as a function of soil apparent electrical conductivity (EC_a) for 2006.

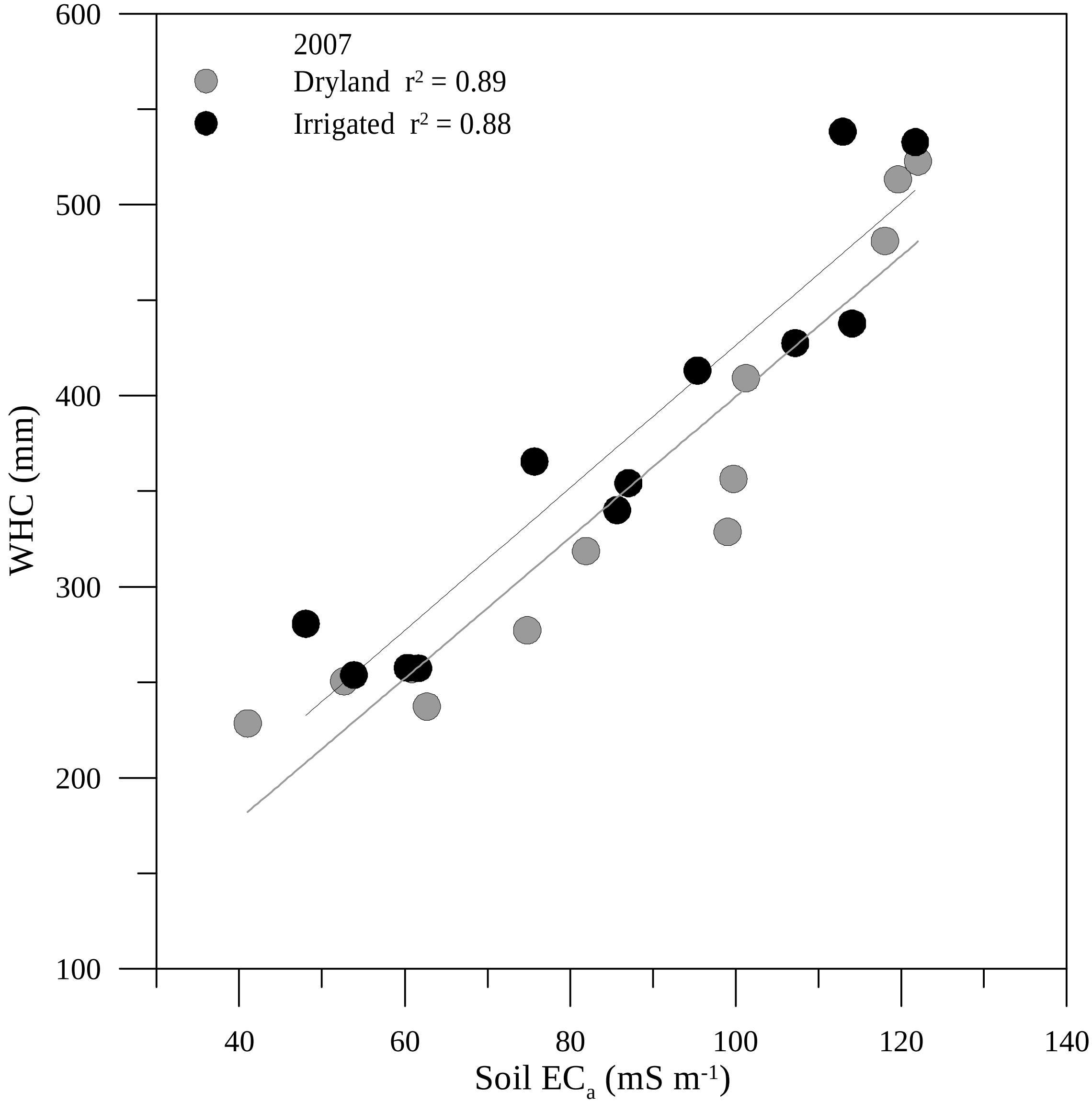

Fig. 8. Water holding capacity (WHC) as a function of soil apparent electrical conductivity (EC_a) for 2007.

The standard deviation for estimated volumetric water content calculations were higher than later, 2007 calibrations.

Cotton lint yield, loan value, and lint value

The 2006 growing season received 168 mm less rainfall compared to 2007. The difference in precipitation between the two years resulted in differences in overall cotton lint yield, loan value, and lint value between the two years (Tables 1 & 2). As a result, 2006 had large variation in lint yield and value within the dryland and irrigated fields, while both 2007 fields were somewhat uniform.

In 2006, lint yield varied highly across the three EC_a categories. The poorest producing EC_a category was category 2. This category produced 471 kg ha^{-1} of cotton lint, while EC_a categories 1 and 3 produced 847 and 1244 kg ha^{-1} of cotton lint. In the dryland field EC_a categories 3 and 2 were significantly different, but EC_a category 1 was not significantly different from 2 or 3 (Table 1). The irrigated field produced the opposite trend in that the highest lint yield was in EC_a category 2, 1564 kg ha^{-1} .Only EC_a categories 1 and 2 were significantly different (Table 1).

In 2007, cotton lint yield in the dryland field ranged from 767 kg ha^{-1} in EC_a category 1 to 1151 kg ha^{-1} in EC_a category 2. The irrigated field lint yield ranged from 653 kg ha^{-1} in EC_a category 1 to 1138 kg ha^{-1} in category 2. For both the dryland and irrigated fields, EC_a category 2 yielded the highest, while category 1 yielded the least. Although

EC_a category 2 yielded the most and category 1 the least in both fields, significant differences were only observed in the irrigated field between category 1 and the other categories (Table 2).

The correlation between water holding capacity and lint yield during the 2006 growing season produced r^2 values of 0.74 and 0.17 in dryland and irrigated settings, respectively (Fig. 9). In 2007, the correlation between water holding capacity and lint yield produced different results because of the excessive rainfall during the growing season. The dryland and irrigated fields produced a polynomial relationship between water holding capacity and yield, R^2 = 0.43, and 0.84, respectively (Fig. 10). The polynomial relationship occurred because of excessive soil wetness in clayey soils with higher water holding capacities. The continued wetness between rainfalls had a negative impact on cotton lint yield.

The base price for a kilogram of cotton lint in 2006 and 2007 was 1.16 and 1.19 ($\$ kg^{-1}$), respectively. In 2006, the loan value by EC_a zone ranged 0.07 $\$ kg^{-1}$ from 1.10 to 1.17 $\$ kg^{-1}$ in the dry land, with poorest quality lint in EC_a zone 2. The irrigated loan value also had a 0.07 $\$ kg^{-1}$ range from 1.13 to 1.19 $\$ kg^{-1}$ (Table 1). Significant differences in loan value existed in EC_a category 3 for dryland and between EC_a categories 2 and 1 in the irrigated field. Overall, the loan values followed the 2006 yield trends in both fields. Although average yield was lower in 2007, loan values were higher because of a

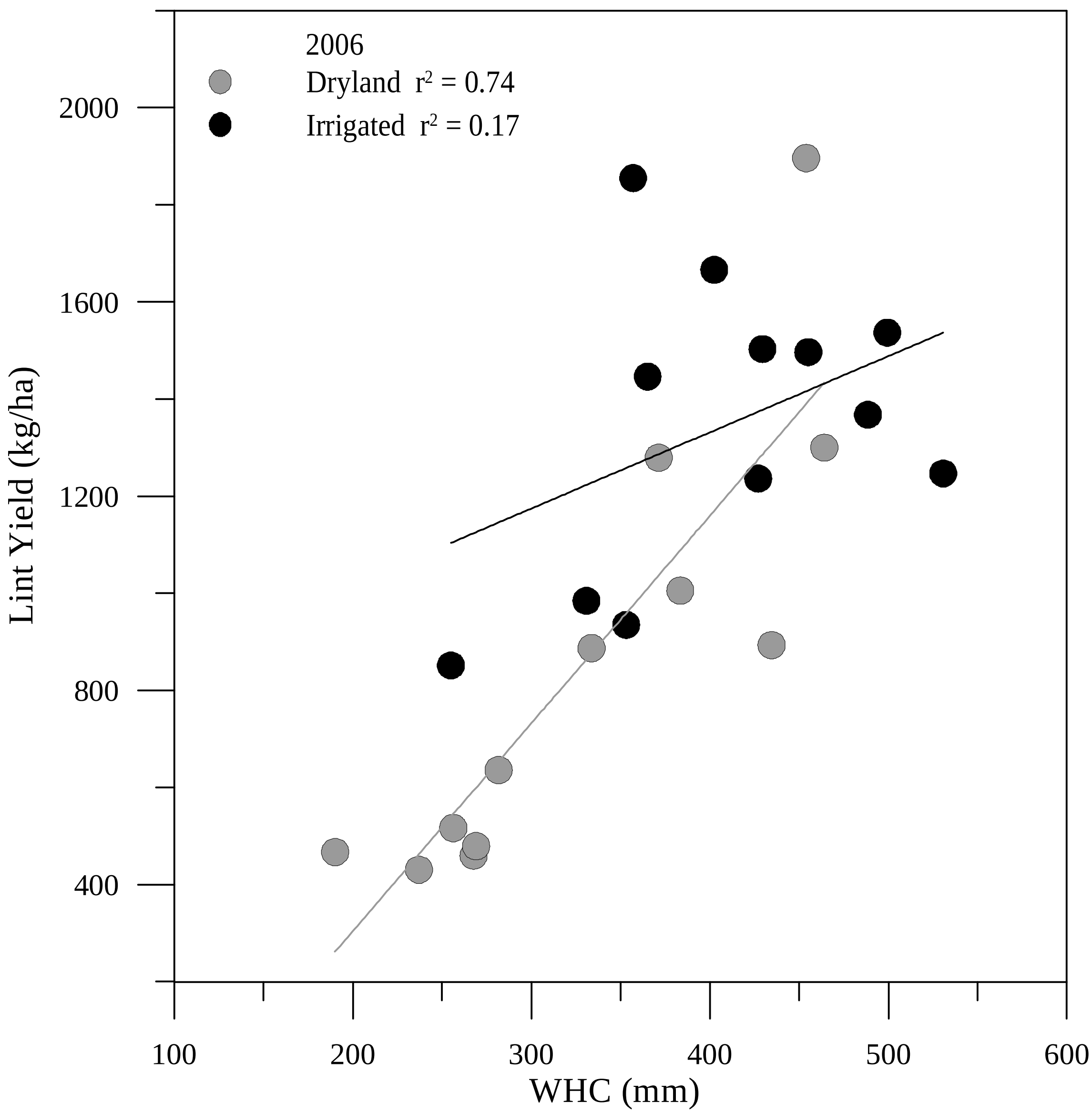

Fig. 9. Lint yield as a function of water holding capacity (WHC) for 2006.

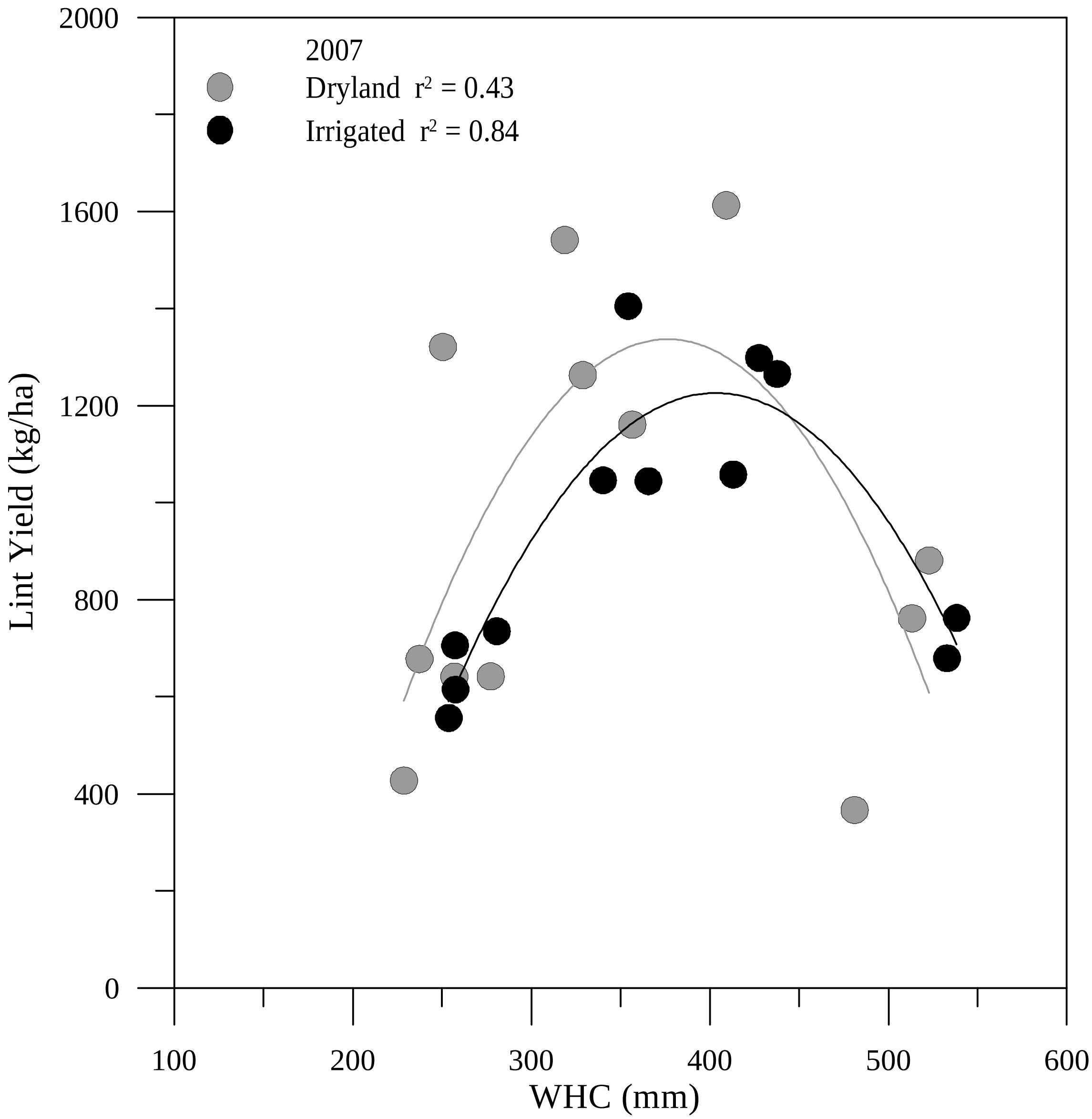

Fig. 10. Lint yield as a function of water holding capacity (WHC) for 2007.

0.03 \$ kg^{-1} increase in base loan value. If the increase on value were standardized for the two years, the actual value of the 2007 lint was lower. For 2007 loan values in both fields were relatively uniform, ranging from 1.16 to 1.20 and 1.18 \$ kg^{-1} to 1.20 \$ kg^{-1}, respectively (Table 2). Because of the relative uniformity in 2007, there were no significant differences in loan value.

The relationship between soil water holding capacity and loan value in 2006 was linear in the dryland field, $r^2 = 0.39$, and polynomial in the irrigated field, $R^2 = 0.33$ (Fig. 11). The polynomial is a result of one point showing a reduction in lint quality at some soil moisture threshold. This location was probably just too wet; the whole field was irrigated to optimize yield in the drier soils. In 2007, correlation between water holding capacity and loan value was weak and insignificant (Fig. 12). Loan values were relatively uniform because 2007 was wet and soil moisture storage for plant use was irrelevant to lint quality.

Lint value integrates both lint quality and quantity, giving an overall picture of potential profitability, in \$ ha^{-1} by EC_a zone. In 2006, lint values obtained for the dryland field ranged from 531 to 1464 \$ ha^{-1} in EC_a categories 2 and 3, respectively. The irrigated field followed the opposite trend of the dryland field for lint value. EC_a category 1 had a lint value of 1201 \$ ha^{-1}, and lint value peaked at 1866 \$ ha^{-1} in category 2 (Table 1). Significant differences in lint value for the 2006 dryland field were seen between EC_a category 2 and 3. The irrigated field showed significant differences between EC_a

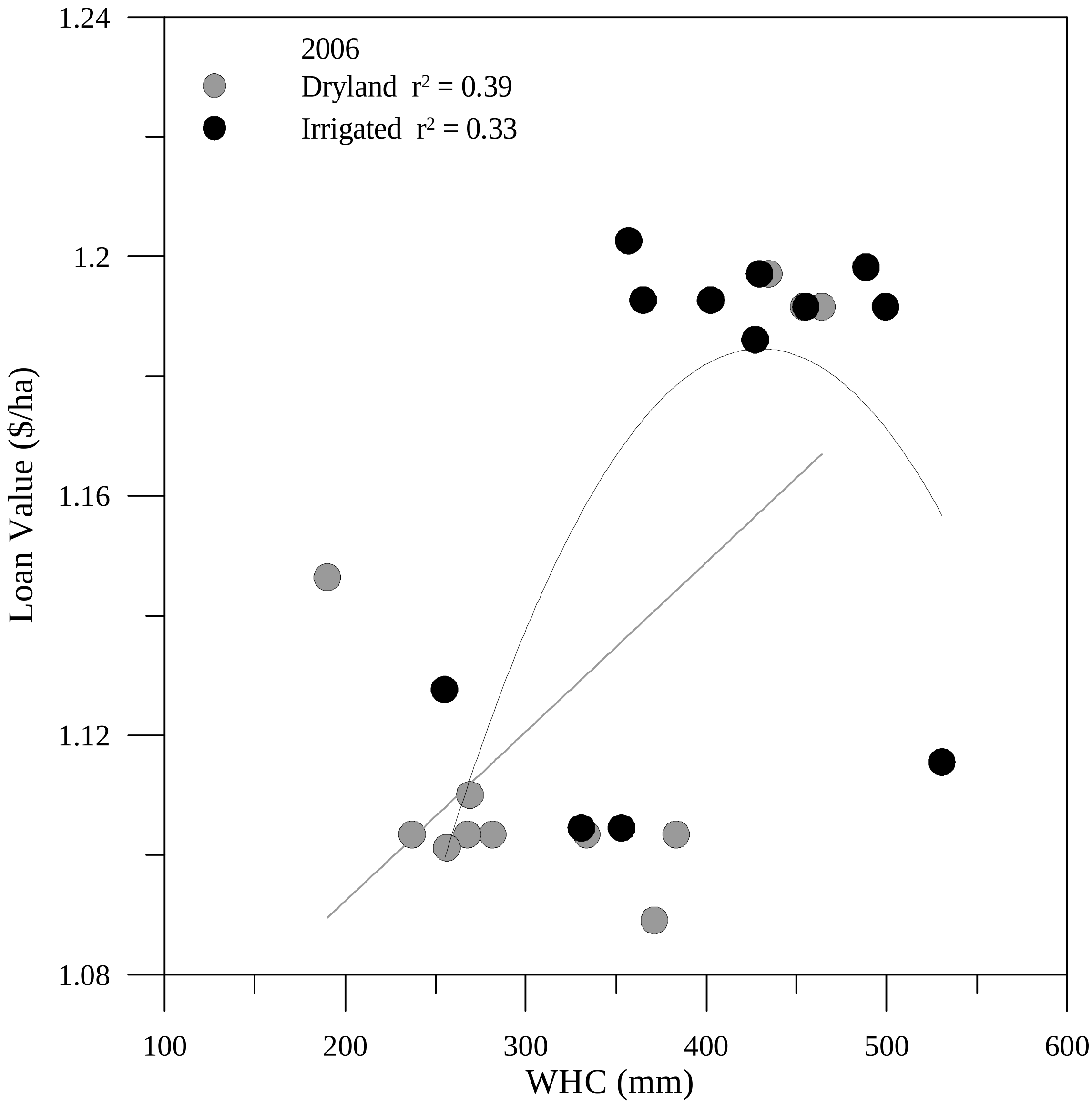

Fig. 11. Loan value as a function of water holding capacity (WHC) for 2006.

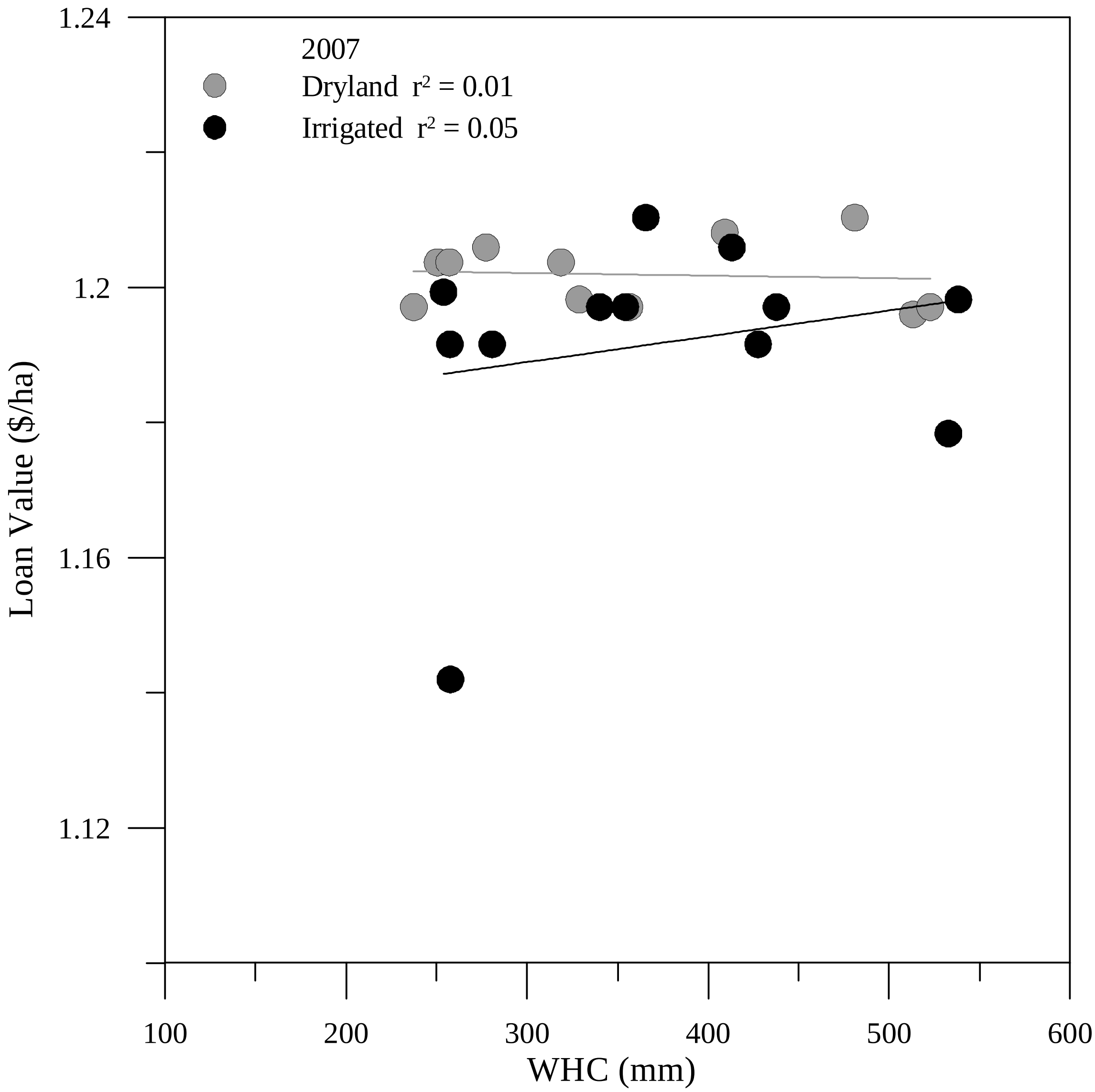

Fig. 12. Loan value as a function of water holding capacity (WHC) for 2007.

categories 1 and 2. In 2007, the two fields were about the same (because no irrigation was needed). In both fields, EC_a category 1 was the lowest at 838 \$ ha^{-1} on average and in EC_a category 1, and category 2 was the highest at 1376 \$ ha^{-1} on average (Table 2). For 2007, the dryland field produced no significant differences between the three EC_a categories. The irrigated field produced significant differences between EC_a category 2 and 1.

Cotton fiber quality

Cotton fiber quality parameters affect not only the price of the cotton lint, but it also determines the uses for the lint. High Volume Instrument (HVI) testing tests cotton lint for micronaire value, fiber length, fiber uniformity, fiber strength, and fiber elongation. Micronaire value is the main factor in establishing a price for cotton lint. Micronaire is a degree of fiber maturity that can affect how clothing dye will adhere to fabric. The micronaire range that is considered premium and receives the highest price is from 3.7-4.2. Length also plays an important role in determining the price and use of the cotton fiber. Shorter cotton fibers are in less demand in the world market.

During this two year study, a wide range of micronaire values were observed, some falling within the premium range and some being below or above the premium range (Table 1 & 2). In 2006, micronaire averages were premium in EC_a category 3 of the dryland field and EC_a categories 2 and 3 in the irrigated field. (Table 1). EC_a category 3 in the dryland field was significantly different. In 2007, all micronaire averages were premium except EC_a category 1 in dryland field (Table 2). The dryland field had significant differences between EC_a category 3 and 1.

The relationship between water holding capacity and micronaire in 2006 is not well defined by regression; however there is an overall positive linear trend (Fig. 13). For 2007, water holding capacity and micronaire were more strongly correlated (Fig. 14). The relationship between soil water holding capacity and micronaire seemed to be the same in dryland and irrigated fields, with yearly weather conditions driving the association.

During the 2006 growing season the length quality parameter, of the HVI tests, followed the trend of shorter cotton fibers in EC_a category 1, with the longest fibers being in category 3. During 2007 the precipitation amounts caused fiber lengths to be relatively uniform. In 2006 dryland, cotton fiber lengths ranged from 26.9 to 29.9 mm, with EC_a category 3 having significantly higher lengths. In the irrigated field, cotton fiber lengths ranged from 28.6 to 30.6 mm, with EC_a category 1 having significantly lower length (Table 1). In 2007, dryland cotton fiber lengths were uniform at 29.7 mm; in the irrigated field, fiber lengths ranged from 28.7 to 29.9 mm (Table 2). In the 2007 irrigated field, EC_a category 2 had significantly longer cotton fiber. In the drier year, 2006, fiber length was longer in the higher EC_a zones, and irrigating the cotton significantly improved length in the middle zone.

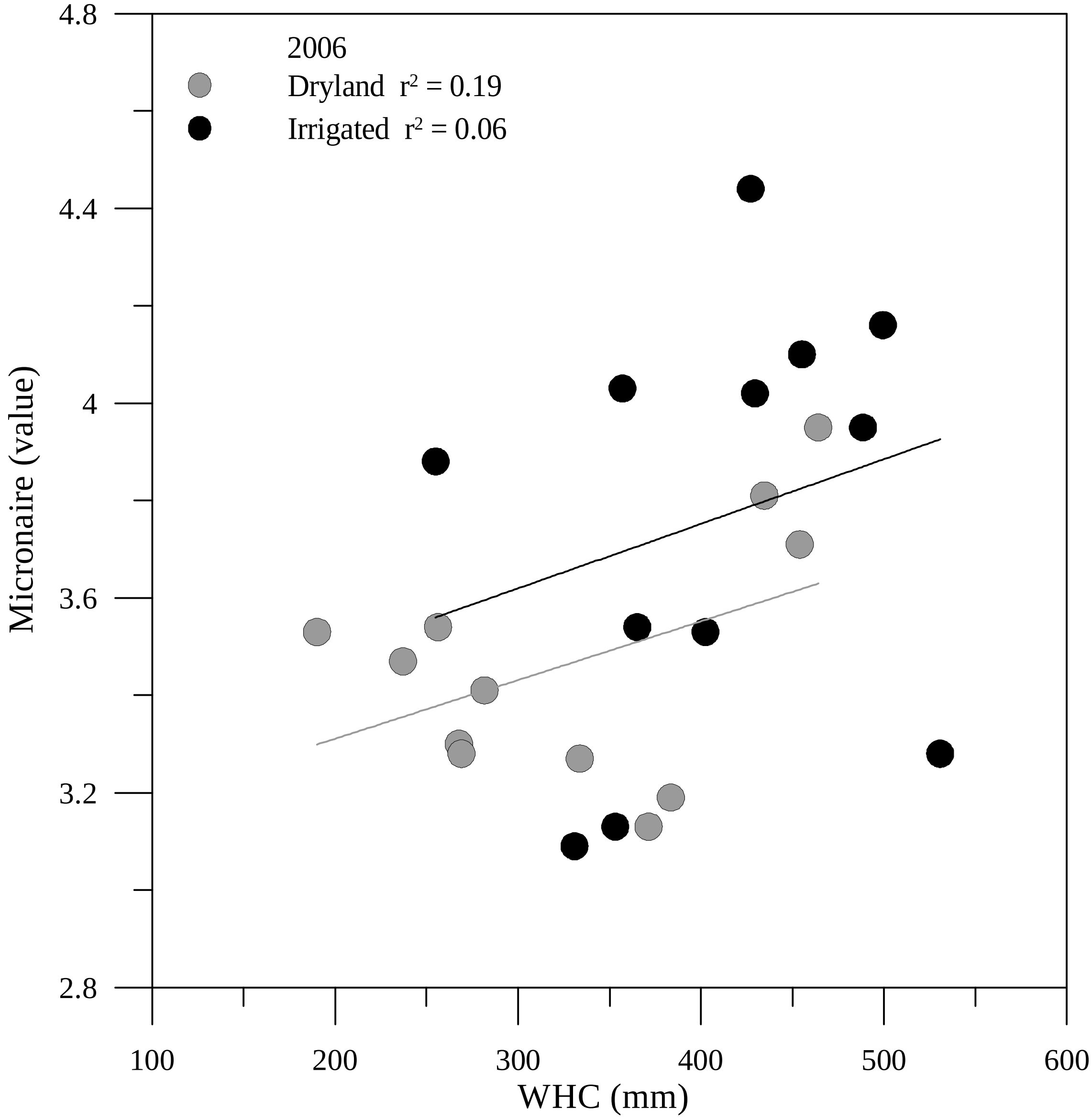

Fig. 13. Micronaire as a function of water holding capacity (WHC) for 2006.

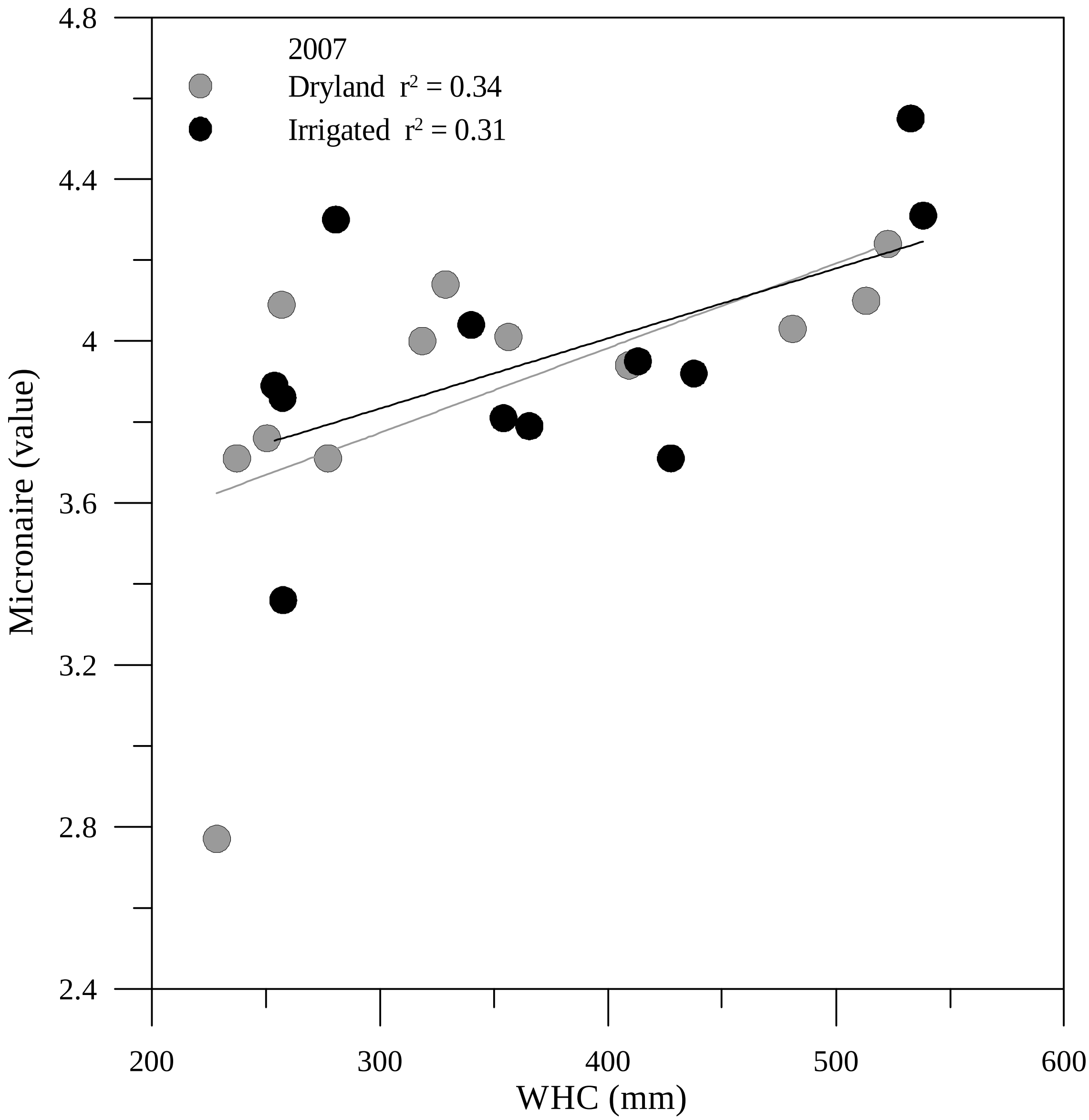

Fig. 14. Micronaire as a function of water holding capacity (WHC) for 2007.

In the wetter year, fiber length was fairly uniform. In the irrigated field there is evidence that category 2 had longer fiber, but the reason is unknown.

The relationship between water holding capacity and fiber length were correlated to each other in the 2006 year, but not in the 2007. In 2006 the relationship between water holding capacity and fiber length produced r^2 values in the dryland and irrigated fields of 0.74 and 0.60, respectively (Fig. 15). In 2007 the relationship between water holding capacity and fiber length produced a polynomial trend, with r^2 values of the dryland and irrigated fields being 0.45 and 0.46 (Fig. 16). Again the trend seems to be unaffected by irrigation and highly affected by yearly weather variation. In 2006, higher water holding capacity categories produced longer fiber, while in 2007; excessive precipitation was detrimental to fiber length in high water holding capacity soils.

Cotton fiber length uniformity is the percentage of the fibers that are a uniform length. Higher length uniformity values are more desirable. During the 2006 season, dryland length uniformities were the same, average 81.6 %. Irrigated length uniformities ranged from 81.2 % to 82.6 %; essentially EC_a category 1 had significantly lower length uniformity (Table 1). The 2007 length uniformities were similar in both the dryland and irrigated studies, 83.3 % (Table 2).

The relationship between water holding capacity and length uniformity in 2006 showed

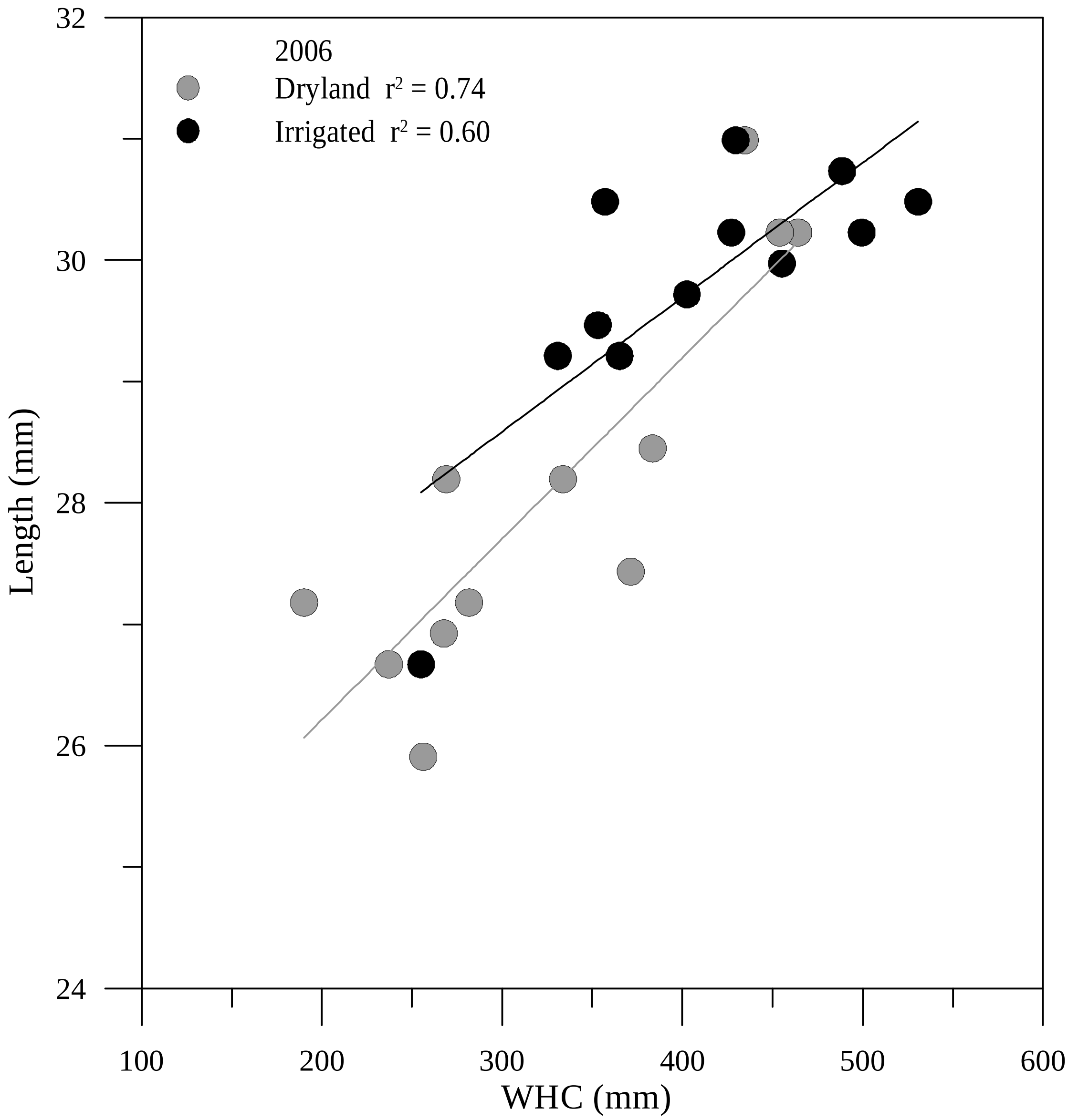

Fig. 15. Fiber length as a function of water holding capacity (WHC) for 2006.

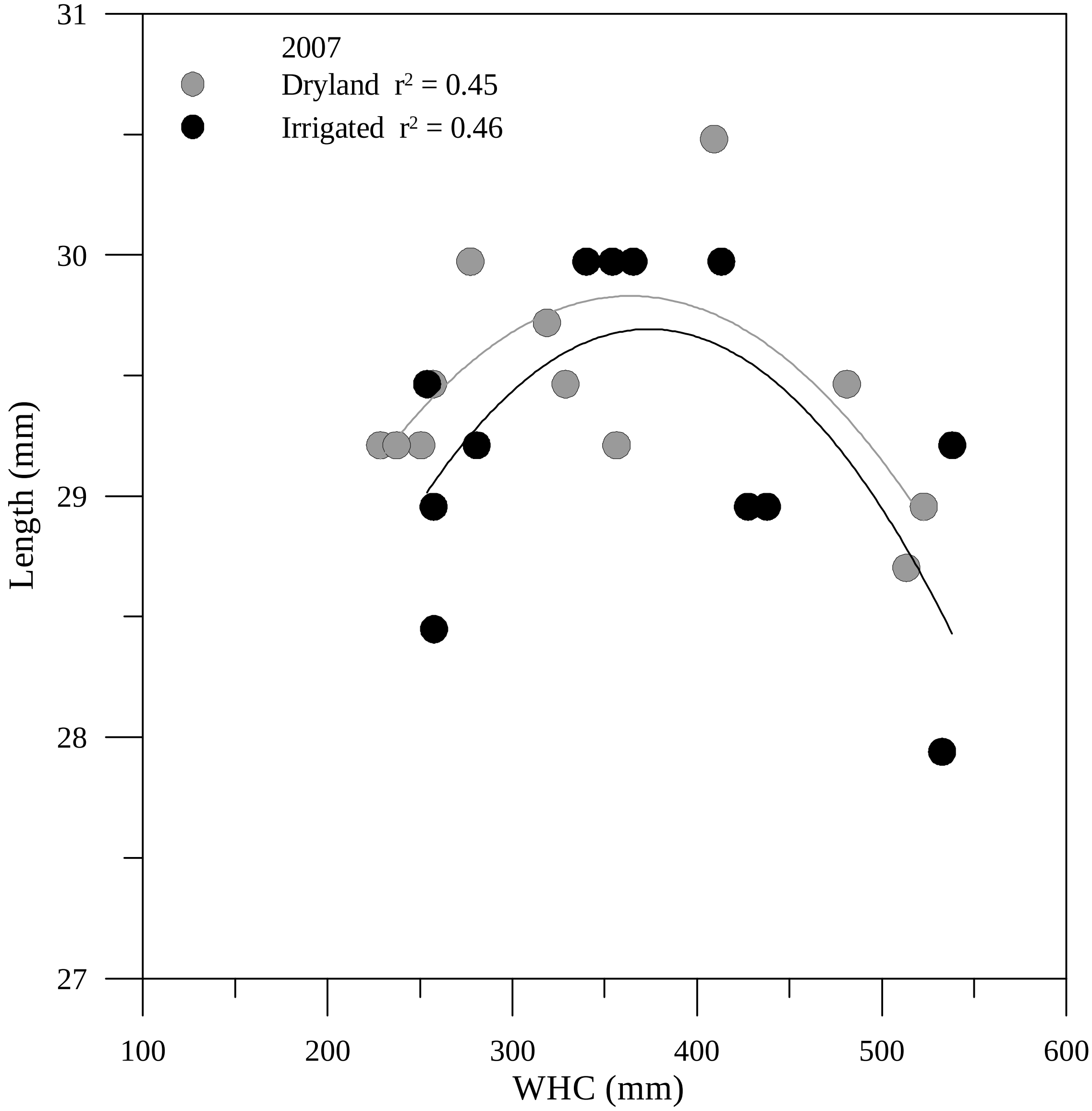

Fig. 16. Fiber length as a function of water holding capacity (WHC) for 2007.

a slight positive correlation. Both fields had similar slopes and intercepts; the dryland regression coefficient (r^2= 0.16) was affected by one location; and the r^2 value for the irrigated field was 0.41 (Fig. 17). The 2007 data showed no correlation in either fields (Fig. 18). In 2007, excessive rainfall meant that the cotton in the lower water holding capacity soils was not stressed as in 2006. In 2007 more uniform fibers were produced.

Cotton fiber strength is a measure of how far the cotton fibers can be stressed without breaking. The stronger the fibers the better price received for the overall lint.

In 2006 cotton fiber strength was insignificantly different across EC_a categories in the dryland field; however strength values ranged from 265 kN to 277 kN m kg^{-1} from EC_a category 1 to 3, respectively. The irrigated field showed fiber strengths ranging from 265 to 292 kN m kg^{-1} from EC_a category 1 to 3, respectively (Table 1). The EC_a category was significantly different in the irrigated field. In 2007, cotton fiber strength ranged from 281 to 294 kN m kg^{-1} and 272 to 291 kN m kg^{-1} in the dryland and irrigated fields, respectively (Table 2). No significant differences were observed in the dryland field; however EC_a category 1 was significantly different in the irrigated field (Table 2).

The relationship between water holding capacity and cotton fiber strength during 2006 is linear and much stronger in the irrigated field (Fig. 19). The r^2 values for the dryland and irrigated fields are 0.13 and 0.46, respectively. In 2007, the relationship between water holding capacity and fiber strength followed the a similar trend as 2006 (Fig. 20).

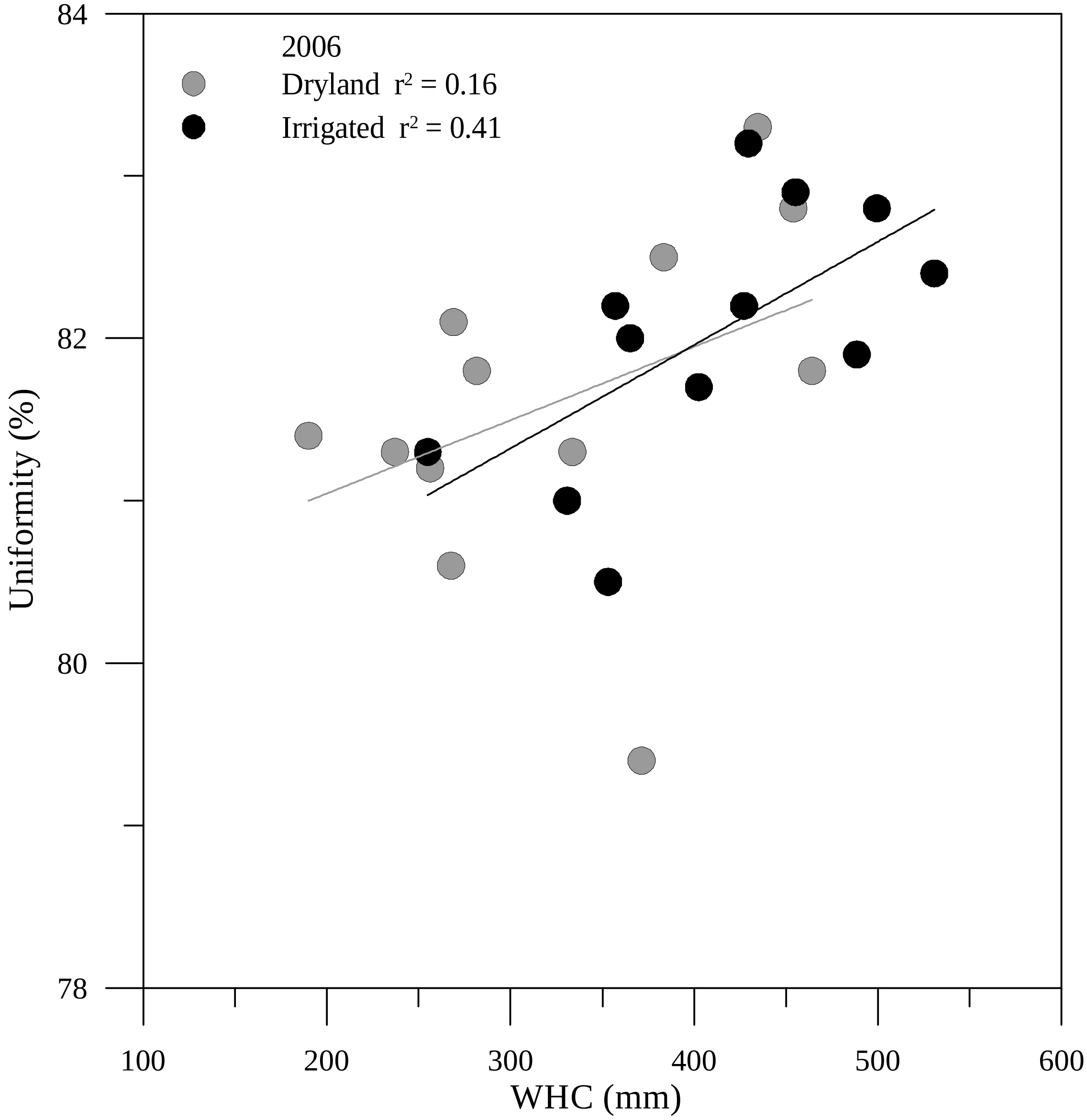

Fig. 17. Fiber uniformity as a function of water holding capacity (WHC) for 2006.

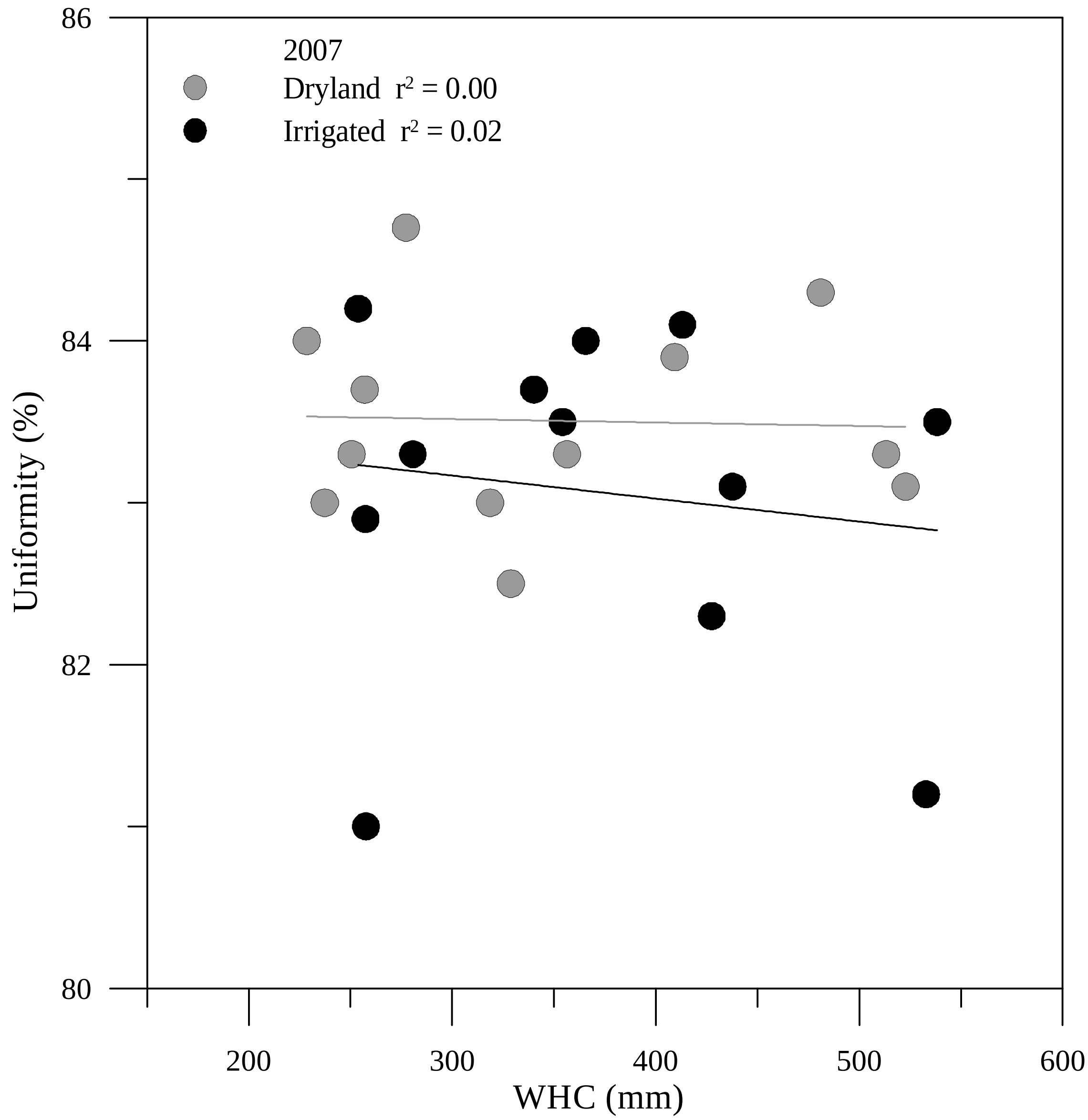

Fig. 18. Fiber uniformity as a function of water holding capacity (WHC) for 2007.

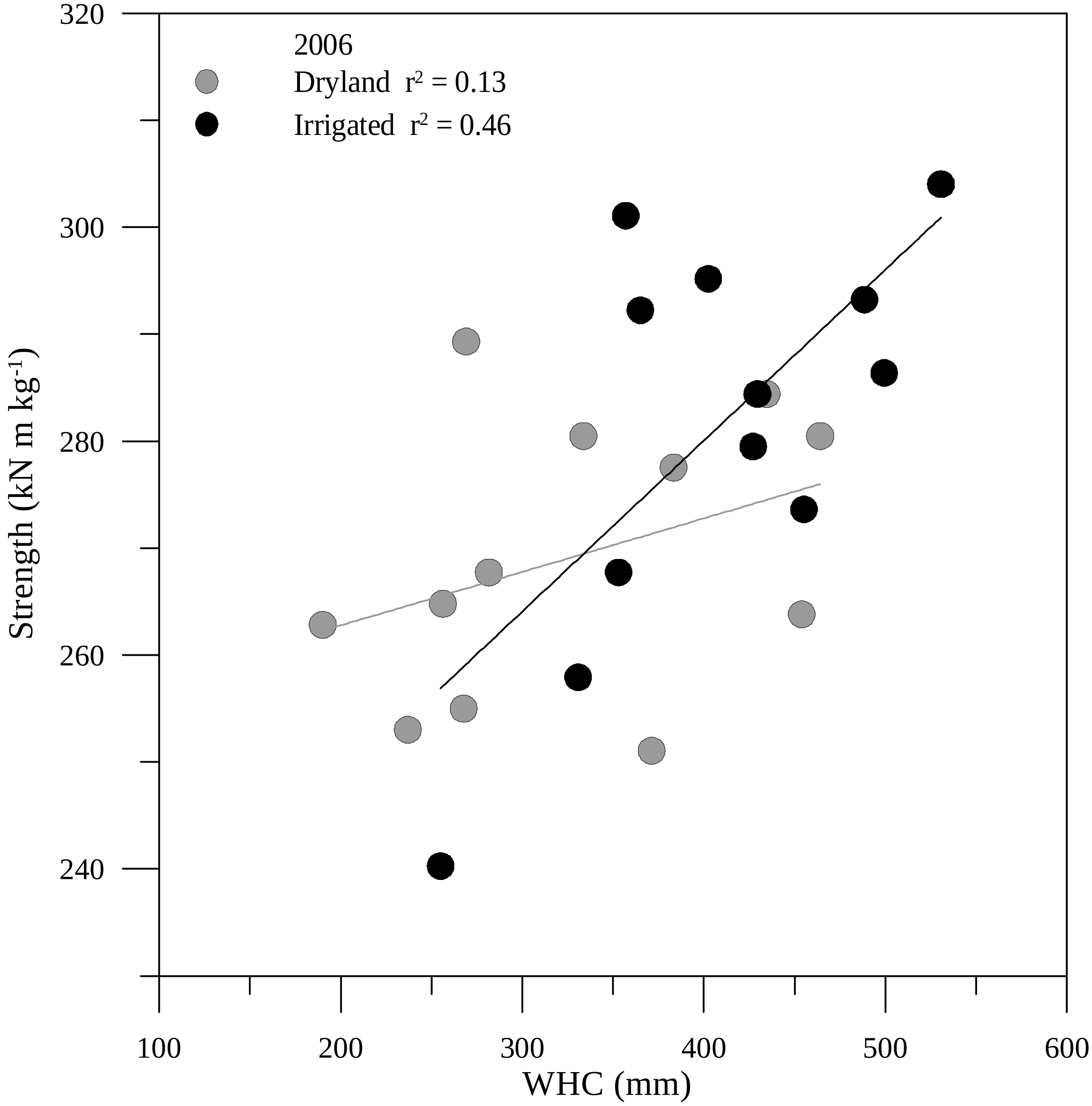

Fig. 19. Fiber strength as a function of water holding capacity (WHC) for 2006.

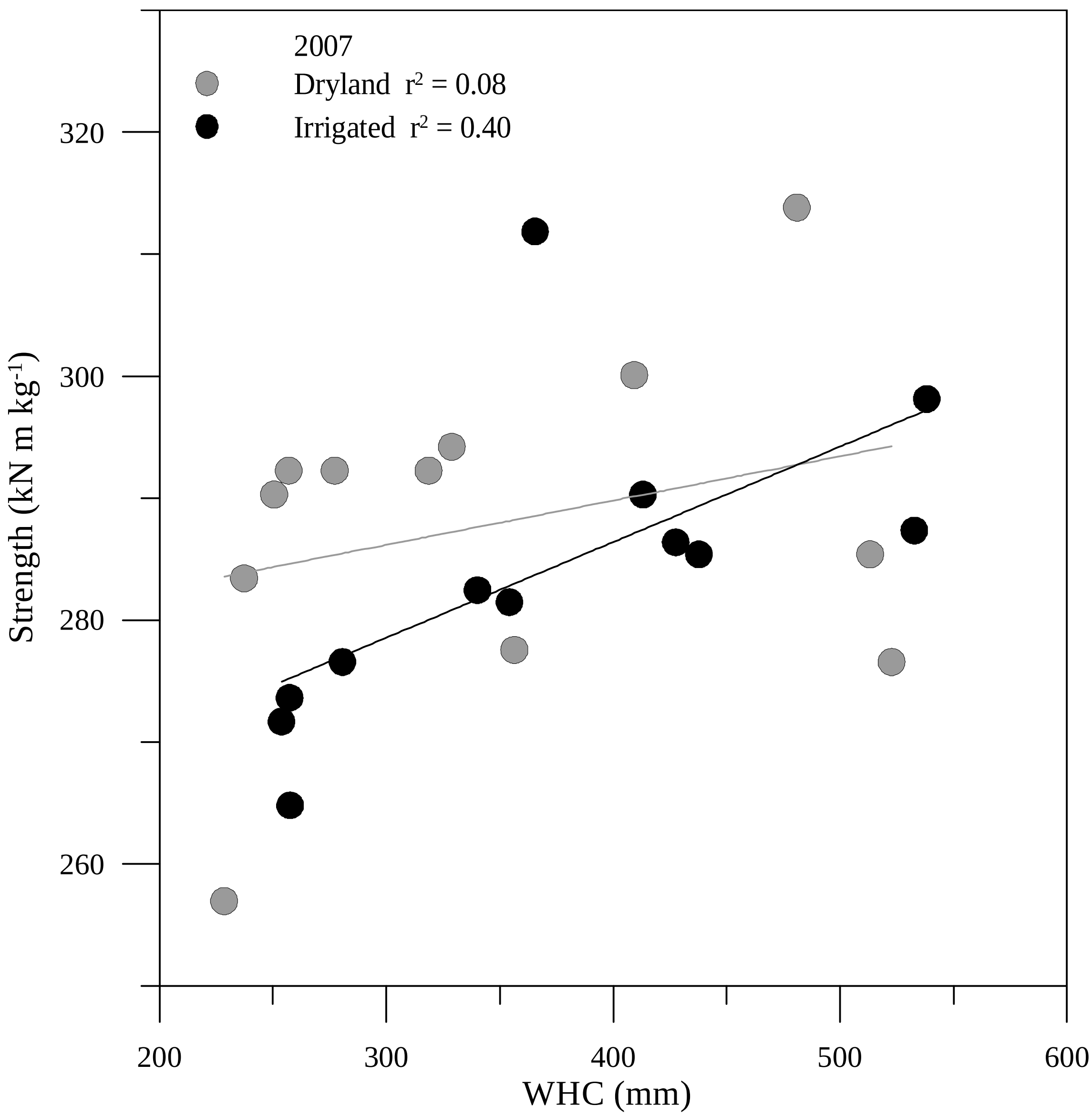

Fig. 20. Fiber strength as a function of water holding capacity (WHC) for 2007.

Cotton fiber elongation is a factor of strength indicating what percentage of the fibers stretch to the point prior to breaking. The higher the percentage of elongation, the higher quality the cotton fiber is. In 2006, fiber elongation in the dryland field ranged from 4.55 % in EC_a category 3 to 5.10 % in category 2. The irrigated field was uniform, at 4.42 % (Table 1). In 2007, fiber elongation values were similar in both the dryland and irrigation fields, averaging 4.90% (Table 2). The only significant difference in elongation occurred in the extreme drying condition of the dryland field in 2006; EC_a categories 1 and 2 were significantly higher. Essentially, elongation seemed to respond to extreme stress conditions that were not optimal for cotton yield and other quality parameters.

The relationship between extreme water stress and fiber elongation is also vary apparent in the plots of elongation and water holding capacity. In 2006, the dryland field had a strong negative correlation, $r^2 = 0.84$ (Fig. 21). In 2007 there appeared to be weak polynomial relationships; however, the trends contradicted each other and we would not expect this because there was very little difference in the irrigation treatments (Fig. 22).

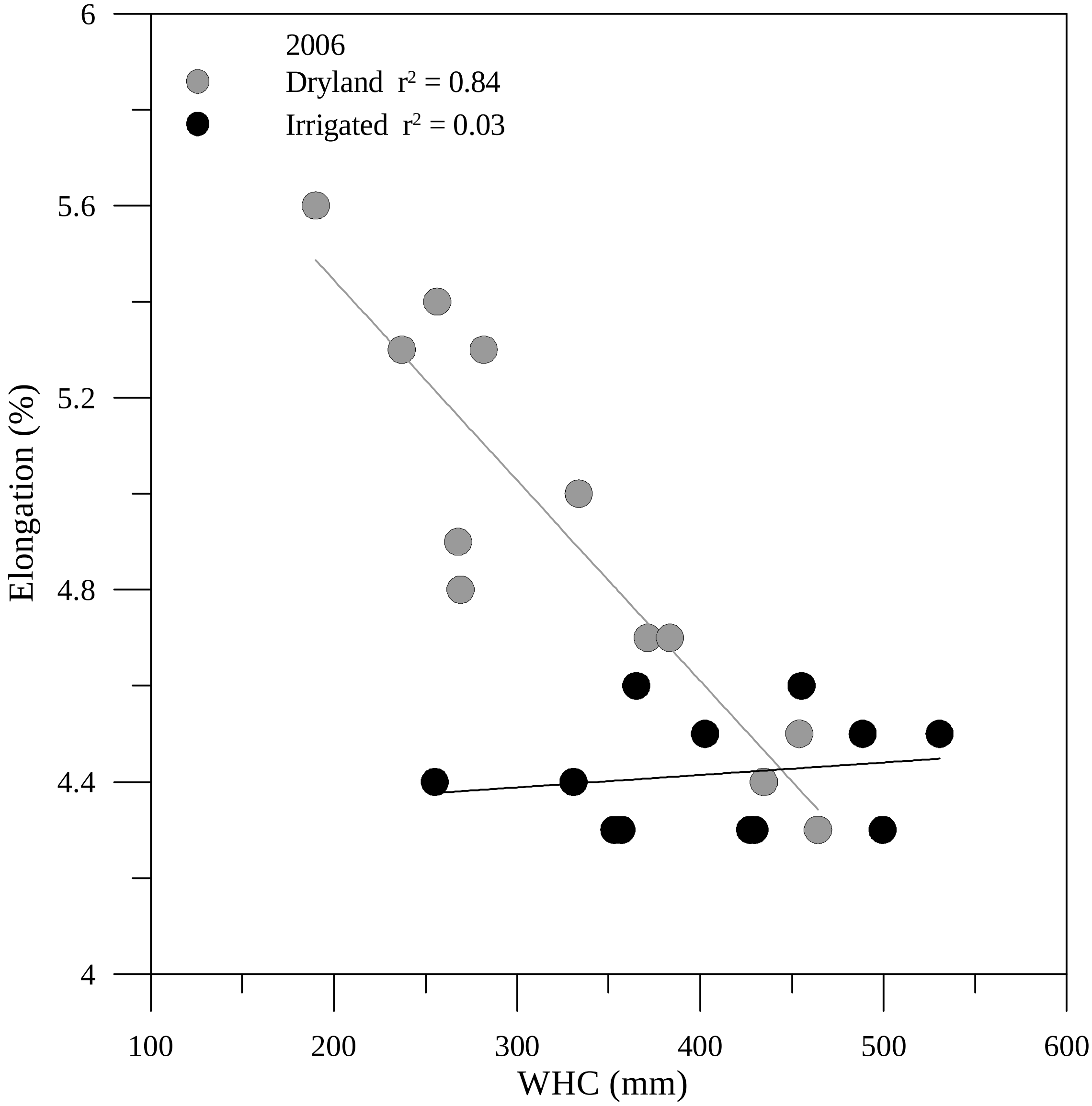

Fig. 21. Fiber elongation as a function of water holding capacity (WHC) for 2006.

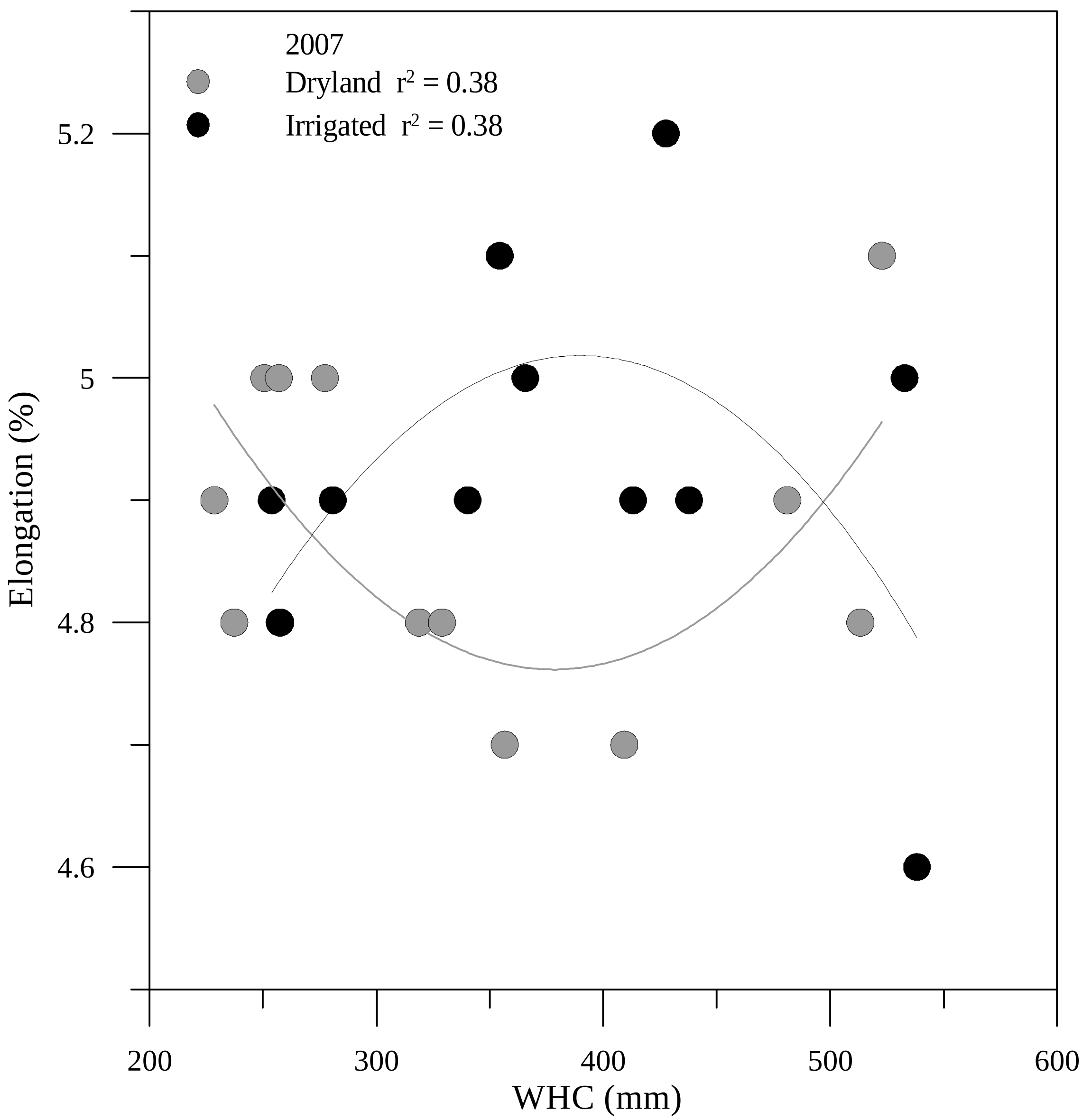

Fig. 22. Fiber elongation as a function of water holding capacity (WHC) for 2007.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Clay content and water holding capacity of the soil was successfully mapped in 2006 and 2007. Using the EM38DD and subsequent EC_a map, management zones were correctly identified, based on soil variability and resulting cotton yield and quality for one dry and one wet year. Clay contents and water holding capacities increased as EC_a values increased, with the exception of EC_a category 2 in the dryland field during the 2006 season. This trend may be because of error in the EC_a map, or factors resulting from growing cotton four consecutive years in the dryland field used for the 2006 study.

The EC_a categories were successful in identifying significant differences in lint yield, lint quality, and loan values. In the 2006 dryland field, lint yield, loan value, and lint value were lowest in EC_a category 2, while these parameters were the highest in EC_a category 2 in the irrigated field. In the dryland field, lint quality, loan value and total yield followed the trend of plant available water except in EC_a category 2. This oddity is probably because of the four consecutive years prior to the study that the field was in continuous cotton. It is possible that EC_a category 2 had a pest problem. In the 2006 irrigated field, weather, soil, and management affected the yield and yield quality responses. The season was dry, requiring irrigation. The field was irrigated uniformly which resulted in over watering in EC_a category 3. However not enough irrigation could compensate EC_a category 1 to produce similar yields as category 2, because the soils in category 1 were so sandy. This is a typical problem in a dry year under irrigation with variable soils.

Nonetheless, year 2007 resulted in a different story. Water availability was not a factor for lint yield or quality. In this situation, the soil was the primary factor for field heterogeneity. The cotton yield still responded to soil variability. In category 3, the reduced drainage capacity of the soil reduced yield. And in EC_a category 1 the yield was still not as high as EC_a category 2. However the interesting result is that overall lint quality and loan value was uniform. The uniformity of lint quality and non-uniformity of lint quantity leads to the conclusion that these soils have individual yield thresholds, but without water stress the quality threshold is uniform. This conclusion illuminates opportunities for precision management strategies. A producer may choose to minimize inputs on a drought-prone area of a field and can still reach full yield potential, while possibly increasing inputs in highly productive portions of the field for maximized profits. If irrigation is available it can be used to maximize yield, but if too much irrigation is applied detrimental effects can follow. Another management strategy may be to reduce seeding rates in lower production areas of the field, if the plants will compensate for yield to still reach the soil's yield potential, perhaps less competition for water would improve lint quality.

The HVI fiber quality test data revealed in a dry year when the plant is water-stressed and under irrigation, lint micronaire, length, and uniformity all responded positively and linearly to soils with higher water holding capacities. Elongation was unusual in that it was uniform in the irrigated field and had a strong negative correlation to soil water holding capacity in dryland. Stressed-out cotton has more fiber elongation but overall undesirable lint quality. In 2007, with little to no water stress, fiber micronaire and length responded positively to higher water holding capacities, but all soils had premium quality values. Uniformity and elongation did not respond to soil variability in 2007.

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