SOURCE-SINK RELATIONS IN COTTON: GENETIC AND ENVIRONMENTAL AFFECTERS

by

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A THESIS

IN

CROP SCIENCE

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

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August, 2005

ACKNOWLEDGMENTS

Several people have been instrumental in aiding me throughout this project. First and foremost, Dr. Krieg has been more than patient while guiding me through my research. It has been my honor and pleasure to work so closely with such a renowned scientist and researcher. A debt of gratitude is also in order for my committee members for their time, guidance, expertise, and patience.

Furthermore, there were the friends in and around the lab without whom I could not have completed this endeavor. Without Joel's computer assistance and guidance, this project would not have gotten very far. I am very appreciative for the time and effort Trent, Jerry, Dale, and Kelly offered with data collection, as well as the computer entry and analysis.

A very special thanks goes out to my wife, Cynthia, for being patient with me for the past several years while I was pursuing a personal goal. To my mother, Kathleen, and my brother Shawn, a very deserved thank you goes out for their moral support and their belief in me.

I also wish to thank Cotton Incorporated through the Texas State Support Committee for their belief in this project and for their financial support.

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ABBREVIATIONS

ETp	Potential Evapotranspiration
mm	millimeter
C	Degrees Centigrade
DPA	Days post anthesis
M	meter
cm^2	square centimeters
m^2	square meter
LA	Leaf area
LA/Boll	Leaf area per boll
Mod Indet	Moderately Ineterminant
Indet	Indeterminant

CHAPTER 1

INTRODUCTION

Cotton (*Gossypium hirsutum)* production represents the largest crop enterprise in Texas with over 60% of the state’s cotton acreage on the High Plains around Lubbock. Large year-to-year and field-to-field variation exists in lint yield across this vast area under both irrigated and dryland conditions. Both environment and genetics contribute to yield variation with the environmental complex being the primary yield affector. Lack of an adequate water supply throughout the growing season represents the single greatest limitation to cotton productivity in this semi-arid region. Approximately 70% of the regions annual rain (450 mm) does occur during the cotton growing season but potential evaporation exceeds precipitation by a factor of over 3 times. Approximately 50% of the cotton acreage in this area has supplemental irrigation capability; however, the application volumes are highly variable from system to system and rarely adequate to provide all the water the cotton crop needs each year. Irrigated cotton yields on the Southern High Plains are highly correlated with water supply; however, dryland yields are more closely related to when the summer rains occur with July being most important.

Lint yield can be assessed in terms of the respective yield components: boll number and boll size. Regression analyses indicate that boll number accounts for over 80% of the yield variation and is largely influenced by the growing environment, including management. Boll number is determined by the production of fruiting sites and retention and final size of fruit. Water stress has a major impact on the production of mainstem nodes and thus the number of fruiting branches and fruiting sites. Fruit retention is strongly related to the supply of reduced carbon and nitrogen from the subtending leaf associated with each fruit form. Many factors influence average boll size, seed weight and lint turnout, with genetics being the major factor and water and nutrient supplies being secondary.

The total water available, or degree of irrigation (percent of ETp replaced), has a direct effect on yield and yield components Considerable evidence exists to say that as water supply increases, the number of fruiting sites and the number of harvestable fruit produced per plant increases, but the retention of fruit per plant decreased. Guinn and Mauney (1984) determined that cotton yields are proportional to the number of bolls produced. Grimes *et. al.*(1969) found final yield to be most highly correlated with the number of fruiting sites produced, and determined that boll retention decreased as irrigation rates increased, but that the total number of fruiting sites per plant actually increased, and offset the decreased retention effects resulting in more bolls per plant. Previous research shows that the final number of fruiting sites is most affected by water supply (Morrow and Krieg, 1987).

On the Texas Southern High Plains, water supply (or the lack of) is the single most limiting factor to the cotton producer. Water supply is also the single most important factor determining the production of fruiting sites. The water supply from the 6 leaf stage through the first week of flowering produces all the fruiting sites that have a chance to produce a mature fruit on the Texas High Plains. Average irrigated yields, are approximately two times dryland yields across the Southern High Plains; however, with adequate water the physical environment can support yields of greater than 5 times the dryland yields.

The cotton plant normally produces several times more fruiting sites than it retains and matures fruit. Numerous hypotheses and observations have been proposed for fruit abortion of the cotton crop. The “Nutritional” and “Hormonal” hypotheses have the most credibility. The Nutritional Hypothesis states that fruit abortion during the first 10 days of the embryo life results from inadequate supplies of reduced carbon and nitrogen products arriving from the leaf factory. The Hormonal Hypothesis states that fruit abortion during the early life of the embryo results from an increase in abscissic acid and a reduction in auxin flow to the developing fruit. Both hypotheses have convincing evidence for support. Fruit shedding is increased by high temperatures common to the cotton belt in the summer months. Sarvella (1966) observed pollen sterility at high day and night temperatures (above 28/20 degrees C, respectively) in the field, concluding that this might be a factor in poor boll set. Mauney et. al.(1978) and Guinn and Mauney (1984) showed that at high temperatures, nutritional and water shortages were responsible for fruit loss. Ehlig and LeMert (1973) conducted a trial in which daily temperatures remained above 40 C throughout the flowering period under different boll load scenarios, concluding that abscission rates are determined by boll loads, even at high temperatures. Baker (1994) concludes that even though boll shedding at high temperatures is not well understood, source-sink imbalances account for the “vast majority of fruit loss in cotton”. Overall, boll shedding at or above 40 C can be attributed to source-sink imbalances.

Baker et. al.(1983) also showed that temperature also plays a role in fruit development. He determined that when the day/night temperatures are 30/20 C (respectively), maximum boll growth rates were obtained. He concludes that although data strongly supports there being a temperature optimum, that it cannot be used as a basis for calculating sink strengths. He also notes that there is very little information available that establishes the effects of temperature on sink strength in whole bolls, and practically no information that breaks this down into boll components.

Krieg (1973) noted that the greatest rate of dry matter accumulation was strongly affected by night-time low temperatures, with 20 C being the optimum, with a great decrease at 15 C, coupled with very slow rates of oil and nitrogen accumulation (nitrogen starting to decrease at 25 C). As maximum daily temperature reached 40 C, he determined that, due to increased respiration, after the maximum weight was reached (40 DPA) there was an appreciable decrease in dry matter. Maximum seed size (length and volume) was achieved 20 days post anthesis, but maximum weight is not reached until just before the boll opens.

Fruit retention is highly variable and is largely dependent upon the supply of reduced C and N to the young, developing fruit. Competition for reduced C and N by the vegetative growth is one of the explanations for fruit abortion. If the plants partition less photosynthate into vegetative growth, then a higher portion of the photosynthate would be available for developing the fruit load of the plant. In this aspect, the opportunity exists to alter the source-sink relations of the plant and increase fruiting site production and retention, resulting in more bolls per acre and bolls per plant.

Reducing the distance between planted rows has been evaluated for numerous years in cotton producing areas. Row spacings less than the traditional 40” (1.0m) are commonly referred to as narrow rows. According to the current literature, narrower row spacings provide substantial yield increases, due primarily to the earlier onset of fruiting (Buxton et al 1979, and Constable 1977). The literature shows a strong relationship between boll size and moisture stress, with severely water stressed cropping systems having smaller bolls with somewhat shorter fibers. Marani and Ephrath (1985) determined that with boll loading in cotton, plant height/width ratios change and a canopy which is not closed prior to boll loading will close at that time without further growth in height. This parameter has been shown to be affected by plant spacing and is manageable to some extent

Hopkins (1990) showed that when comparing conventional 40 inch rows to narrow or ultra-narrow rows under the same planting density (plants per hectare) that under narrower row spacings, the plants were provided with greater spatial distribution (ground area per plant) and had greater light interception and light penetration into the canopy. The yield averages he noted were between 20% and 40% higher than the conventional 40” rows under the same environmental conditions, and the same row spacing management strategy provided 10-20% yield increases under dryland conditions. Increased yields due to narrow row spacing practices have been attributed to increased early season reproductive growth (in response to reduced competition and increased light interception) and increased fruit retention. Hopkins also concludes that the combination of shorter plant heights and narrow row systems produced less vegetative branches under narrow row conditions, suggesting that the vegetative to reproductive tissue ratios can be altered in favor of reproductive biomass being produced.

Variety selection(growth habit), plant densities and row spacings have been shown to have a direct effect on boll numbers/plant as well as boll size. The denser the populations, the fewer bolls/acre produced and the smaller the boll size, but the higher the rate of boll retention (Staggenborg, 1993). Hopkins (1990) showed that as row spacings went from 40 inches to 18 inches but plants/acre remained constant, bolls per plant almost doubled (increasing bolls per acre), and the crop had the ground covered 2 to 3 weeks earlier, which provides maximum light interception. Narrow rows have the potential to increase yield through the increased production and retention of fruiting sites as well as boll size by increasing seed per boll and fibers per seed.

Annual type plants typically go through definite growth stages. They begin with a period of vegetative growth, followed by a period of fruit growth, and then maturation and senescence, followed by death. Cotton (*Gossypium hirsutum),* on the other hand, is a woody perennial with an indeterminant growth habit. Cotton's leaves and fruit behave as annuals, but it has stems and rootstock "programmed to live indefinitely" which is a perennial characteristic (Baker et. al., 1978). Upland cotton displays differences in the degree of indeterminacy exhibited within current cotton varieties. Maturity differences exist not only in the amount of heat units required to mature a given fruit load, but in vegetative and fruit development as well. Cultivar selection, based mainly on available water supply, is one of the main tools a producer has available in trying to maximize the natural resources for maximum productivity and profit on the Southern High Plains of

Texas. Therefore, to optimize the efficiency of a given cotton production system, a thorough understanding of the interaction between cotton’s growth habits and the environment under which it will develop must be clear.

CHAPTER 2

OBJECTIVE AND HYPOTHESIS

Hypothesis

The cotton plant is an ultra conservative woody perennial that produces and maintains excess leaf area than required to develop its fruit load. Water use is physically related to leaf area. If we are to increase water use efficiency, we must first determine whether leaf area produced per harvestable boll can be altered and second, can we use genetic and/or management strategies to modify the ratios.

Objectives

This project was initiated with two primary objectives: (1) to determine the relationship between source activity (leaf area produced and maintained on a per harvested boll basis), and (2) to determine if this relationship can be altered through management of row spacing, plant densities, growth habits, and environmental resources (water).

CHAPTER 3

MATERIALS AND METHODS

The data used to develop the leaf area/boll relationships in cotton have been generated for 20 plus years on the Plains of Texas by a large number of previous graduate students in the Crop Physiology Program. Cotton varieties exhibiting moderately indeterminant and indeterminant growth habits have been evaluated across numerous water supplies, row spacings, and plant densities over a period of years at several locations (Appendix A). This data was pooled across years and analyzed using regression analysis.

Plant maps and growth and development data were collected several times during the growing season each year. Plants were mapped to determine final number of bolls per plant. Leaf areas were measured using a LI-COR 3100 leaf area meter. Leaf area per boll was determined by using the maximum leaf area at cutout, approximately 100 d.a.p., divided by the number of bolls per plant at final harvest. Leaf area per boll, represented in cm^2/boll, was calculated as a function of main effects consisting of total water supply (mm), plant density (plants/m^2), growth habit (mod-indeterminant and indeterminant), and row spacing (meters). The interactions were then evaluated using regression analyses.

CHAPTER 4

RESULTS AND DISCUSSION

Main Effects: Water Supply, Growth Habit, Row Spacing and Plant Density

Total leaf area per plant was divided by the total number of bolls per plant to determine cm^2 leaf area/boll. Across all treatment variables and years the average leaf area/boll=277.09 cm^2, with a std. dev.= 74.53. (Radin has reported 250 cm^2/boll for Arizona) This was done across all growth habits, plant densities, and row spacings. Water supply had a significant impact on leaf area required to support a fruit as expected. Regression analyses of leaf area/boll against water supply across all other variables resulted in a curvilinear relationship. A polynomial equation resulted in the "Best Fit" with an r^2 of 0.61 (Fig 1). As water supply increased, the amount of leaf area/boll decreased reaching a minimum value of approximately 182 cm^2/boll.

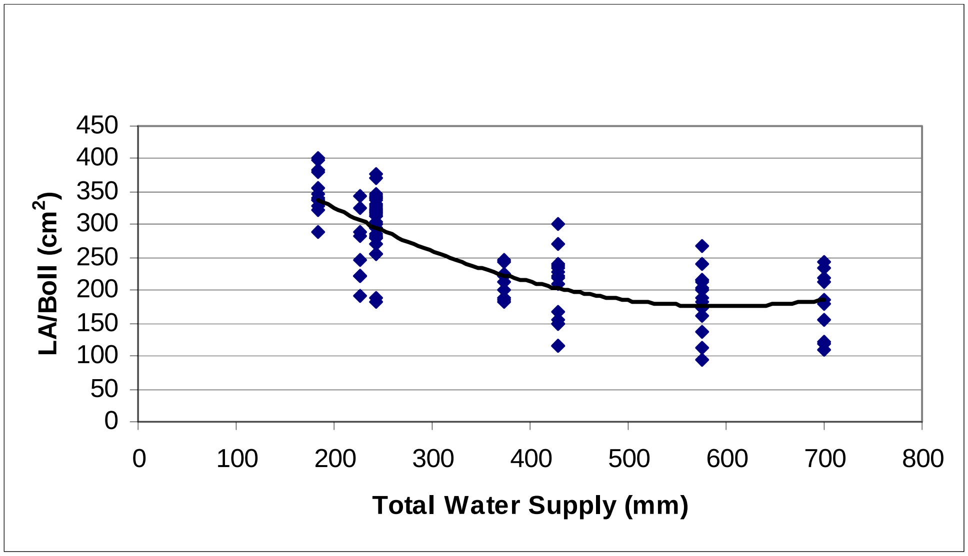

Figure 1. LA/Boll as affected by total water supply across all variables.

$y = 0.0009x^2-1.1347x+514.67, r^2=.6154$

Growth habit effects were also evaluated and shown to be significant at the p=.05 level (Table 1).

Table 1. LA/Boll means and standard deviations for moderately indeterminant and indeterminant growth habit effects.

Growth Habit	LA/Boll (cm^2)	Std Dev
Indeterminant	249.99	53.27
Mod-indeterminant	292.28	74.07

Row Spacing effects were not significant at the p=.05 level. (Table 2) Although not significant, the 1.0 meter row spacings did produce on average 18-20% more leaf area/boll than the narrower rows.

Table 2. LA/Boll means and standard deviations for row spacing effects.

Row Spacing (m)	LA/Boll (cm2)	Std. Dev.
0.25	295.19	38.72
0.5	257	54.89
0.76	262.1	61.79
0.81	251.93	84.85
1	323.52	57.42

Plant density effects (Table 3) were significant at the p=.01 level. Means and standard deviations are shown below.

Table 3. LA/Boll means and standard deviations for plant density effects.

Plants/m2	LA/Boll (cm2)	Std. Dev.
<15	238.99	76.27
>15	322.84	41.01

As plants/m^2 increased, so did the leaf area/boll that the plants maintained. Water use efficiency is directly related to leaf area, so as excess leaf area is produced and maintained per harvestable boll, water use efficiency decreases with increasing plant densities. The affects of plant density on leaf area/boll is shown below (Fig 2).

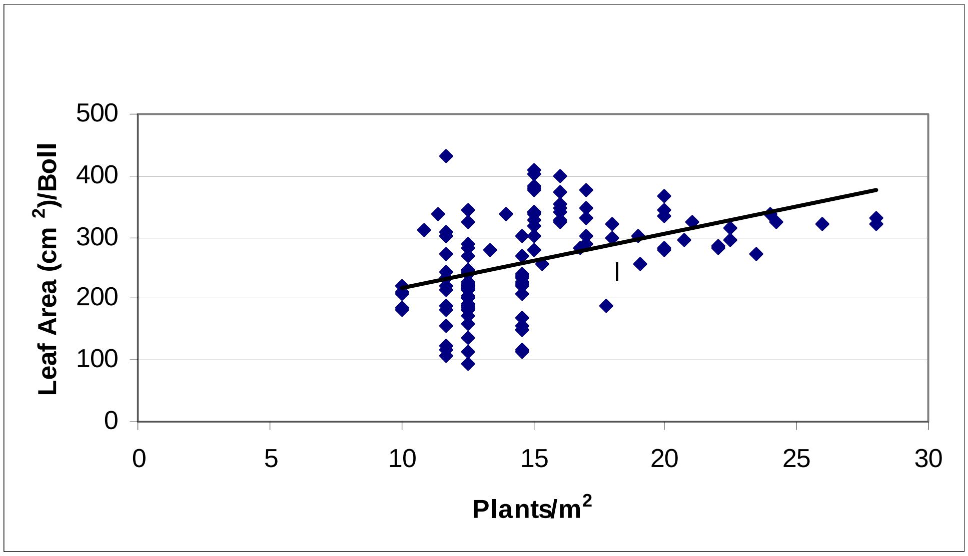

Figure 2. LA/Boll as affected by plant density across all variables.

y=8.7683x+130.44, r^2=.1902

Interactions

The LA/Boll affected by the total water supply x growth habit interaction was significant (Fig. 3) for the determinant growth habit (r^2=.195) at the p=.01 level, but not for the mod-indeterminate growth habit (r^2=.016). The mean LA/Boll for mod. indeterminant growth habits was 249.99cm^2, std. dev.=53.27, and 292.28cm^2, std. dev.=74.07 for the indeterminant growth habits. As water supply increased, the slightly negative slope would indicate the mod. indeterminant growth habits became more efficient. The higher r^2 indicates that mod. indeterminate growth habits closely follow this trend. The lower, non-significant ^{r2} for indeterminate growth habits indicates that these growth habits quit producing leaves in lower water situations, but have the potential to respond to higher water situations by producing leaf area at a higher rate.

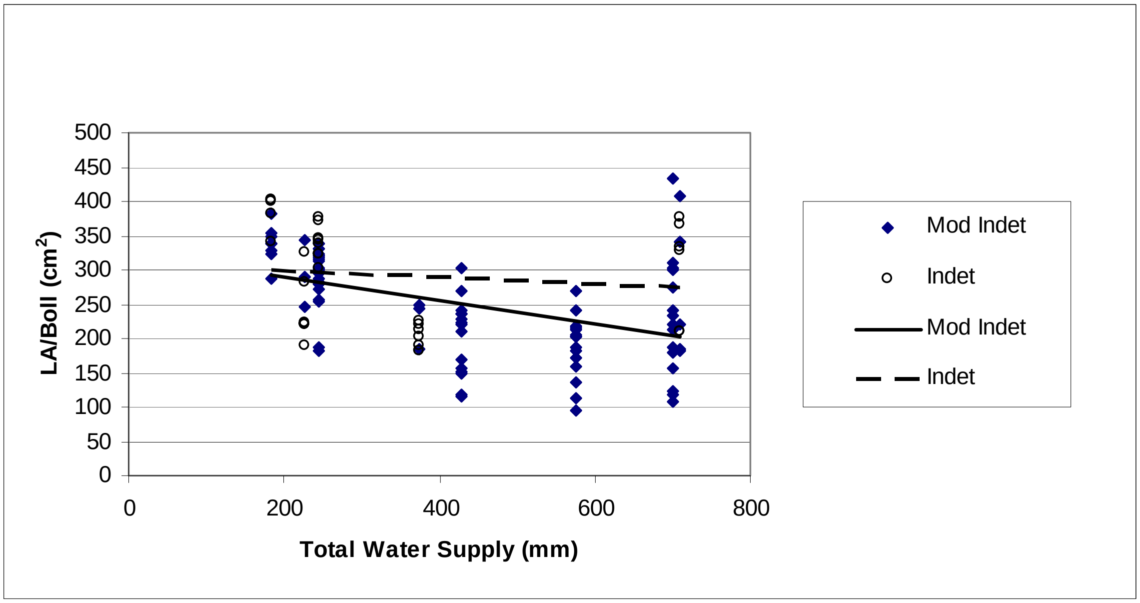

Figure 3. LA/Boll as affected by the total water supply by growth habit interaction.

Mod Indet y=-.01694x+323.38, r^2=0.1950

Indet y=-0.0483+309.22, r^2=0.0156

The total water supply x row spacing interaction was not significant.

The total water supply x plant density interaction was evaluated using two ranges of plants/m^2: <15and >15 (Figure 4). LA/boll was not significantly altered by total water supply for plant densities <15 plants/m^2. LA/Boll was significant at the p=.05 level for the >15 plants/m^2 range. The cotton plant requires a minimum amount of leaf area to produce fruit, and as the number of plants increases this amount of minimum leaf area also increases per m^2. Water use is directly related to leaf area. As plants densities increased, so did the amount of leaf area/boll. LA/boll was 238.99cm^2 for plant densities in the <15 plants/m^2 range. It increased to 322.84 cm^2 for the >15 plants/m^2 range. Plant densities in excess of 15 plants/m^2 caused the cotton plant to produce excess leaf area than that determined to be the optimum leaf area/boll, and since water use is directly related to leaf area, less efficient.

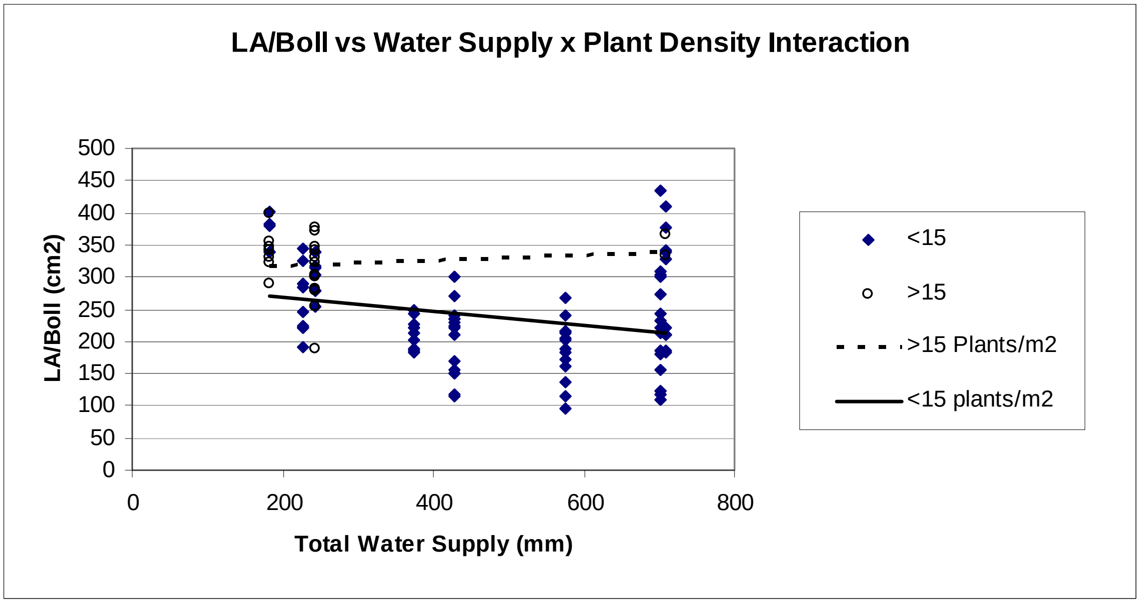

Figure 4. LA/Boll as affected by the total water supply by plant density interaction.

<15 plants/m^2 $y = 0.0417x + 308.96$, $r^2 = 0.0167$

>15 plants/m^2 $y = -0.1091x + 290.93$, $r^2 = 0.0722$

The growth habit x row spacing interaction was not significant.

Growth habit x plant density interaction effects were significant for both growth habits (figure 5). Mod. Indeterminant growth habits at the p=.05 level, and indeterminant growth habits at the p=.01 level. Mod. Indeterminant growth habits increased LA/boll with increasing plant densities at a minimal rate, while LA/boll for indeterminant growth habits increased at a faster rate with increasing plant densities.

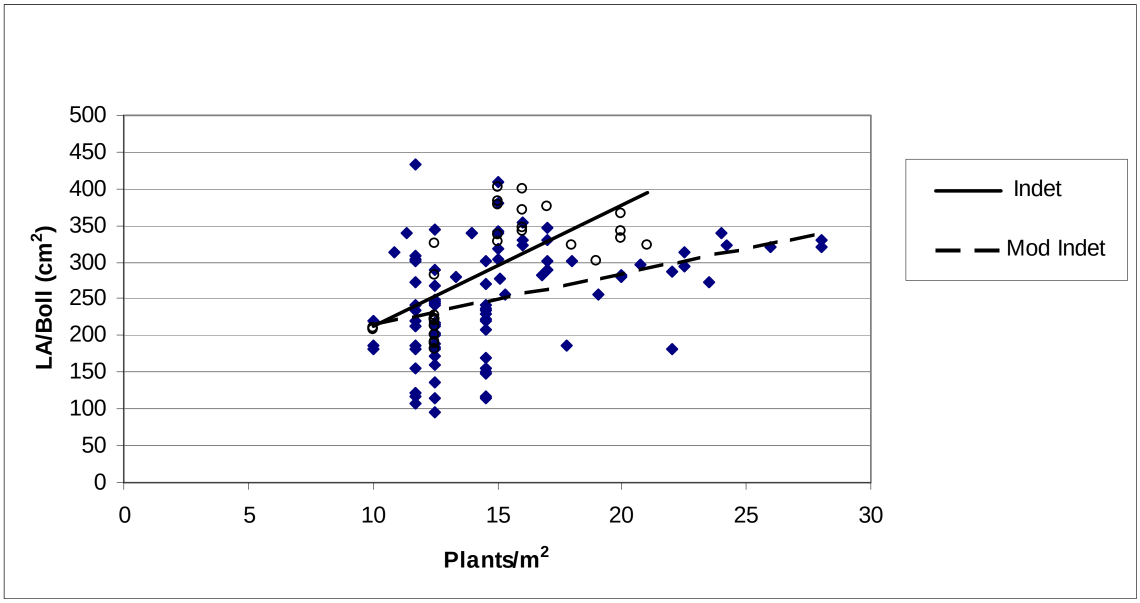

Figure 5. LA/Boll as affected by the growth habit (moderately indeterminant and indeterminant) by plant density interaction.

Indet y=6.9484x+146.01, r^2=0.1398

Mod Indet y=16.602x+46.566, r^2=0.4638

Row spacing x plant density interaction effects were also significant at the p=.05 level (figure 6). The narrower the rows, the flatter the slope. Increased plant densities produced more leaf area/boll at higher rates as row spacings became larger. At the 1 meter row spacings, some plant densities in the 10-15 plants/m^2 range were producing LA/boll numbers averaging 323.52 cm^2

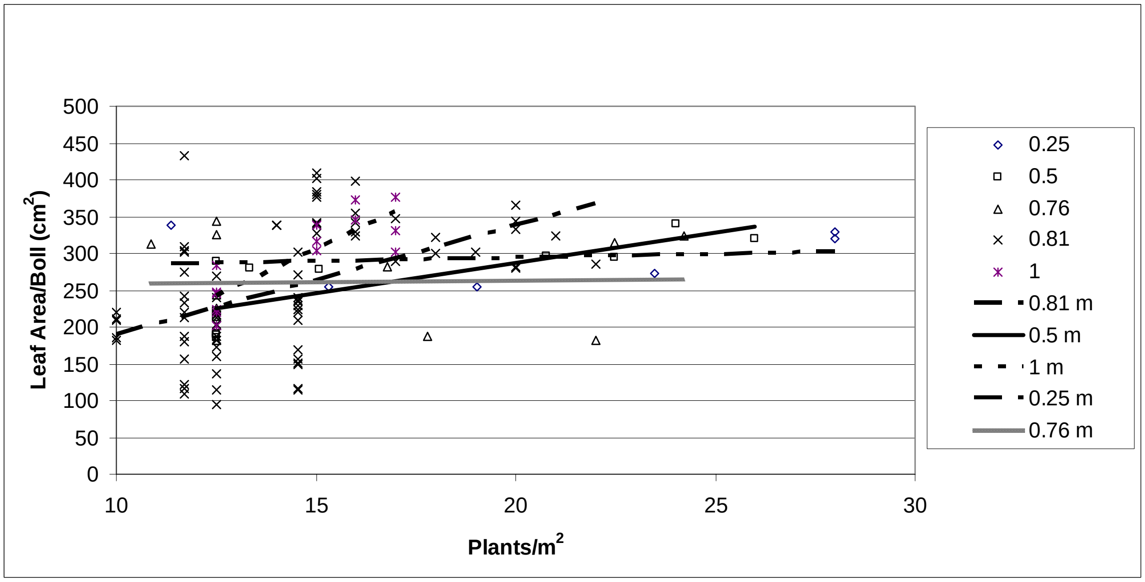

Figure 6. LA/Boll as affected by the row spacing by plant density interaction.

1m $y=25.615x-78.179$, $r^2=0.7347$

0.81m $y=14.856x+41.308$, $r^2=0.230$

0.76m $y=0.383x+256.06$, $r^2=0.0009$

0.5m $y=8.1963x+123.6$, $r^2=0.6248$

0.25m $y=1.0441x+273.41$, $r^2=0.0339$

CHAPTER 5

GENERAL SUMMARY AND CONCLUSIONS

The cotton plant is a woody perennial, with an indeterminate growth habit that we manage as an annual for maximum yield of fruit. Each fruiting site is associated with a subtending leaf that provides the majority of the organic nutrition to the developing fruit. Daily water use is directly related to leaf area within a given evaporative demand. My hypothesis was that the cotton plant produces and maintains more leaf area than it needs to develop its boll load and therefore is not optimizing water use efficiency. I first determined if the leaf area produced and maintained per harvestable boll was a constant or did it have considerable variation. Secondly, I determined the source of the variation as to genetic and environmental, including management causes. The data used to make this analysis consisted of field research I conducted and historical data generated by previous graduate students in the Crop Physiology Program.

The mean leaf area/boll across all treatments was 277 cm^2/boll, with a standard deviation of 75 cm^2/boll. Total water supply available to the crop had the major effect. As total water supply increased, the LA/Boll responded in a curvilinear manner, initially decreasing, then flatting out. This curvilinear response across all variables indicated that the most efficient LA/Boll (172.19 cm^2).was reached at a total water supply of 575mm. Moderately indeterminant growth habits were more efficient producing 249.99 cm^2 LA/Boll compared with the 292.28 cm^2 LA/Boll for the indeterminant growth habits. Row spacing effects were not significant. Plant density effects, however, were. When plant densities exceeded 15 plants/m^2, the amount of leaf area produced and maintained per harvestable boll began increasing. This rate of increase was even greater as plant densities increased with increasing row width. Plant densities <15 also became more efficient with increasing water supplies while plant densities >15 became less efficient. Growth habits were also affected by plant densities. LA/Boll for indeterminant growth habits increased at a higher rate with increasing plants/m^2 than did moderately indeterminant habits.

In summary, leaf area/boll is not constant, but can be managed for greater efficiency. There are several tools at our disposal for maximizing the amount of leaf area produced and maintained per harvestable boll, and thus maximizing our water use efficiency. Row spacing, plant density, and growth habit selection are all management tools we can use to alter the LA/Boll ratios and water use efficiency of the plants.

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