Optimal Production Inputs with Varying Quality and Yield Components:

Irrigation Termination of Upland

by

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Abstract

We utilize Classification and Regression Tree analysis to categorize the return of extending the season for upland. High, medium, and low values for cost of water, lint prices, and quality discount/premiums were applied to the lint yield and quality differentials realized from 198 irrigation termination experiments conducted in central Arizona for the crop years of 1991, 1992, 1994, 1996, 1996, 1997, and 2000. The progression of each crop was analyzed using heat units (86/55 F). The relative ranking results of CART, where the most important variable is normalized on 100, were: variety (100), additional heat units after IT-1 (94), yield of IT-1 (93), crop year (83), micronaire associated with IT-1 (68), HUAP for IT-1 (67), lint price (5), water cost (2), and the quality discount/premium year (.09). Significant yield variation from extending the season was found. In addition, agronomic signals for predicting micronaire changes were very important for determining profitability since quality is impacted for both base and any additional yields attained. These are the primary reasons why agronomic factors were found to be more influential than the economic factors considered for explaining the profitability of extending the season for upland.

Key words: CART, micronaire, irrigation termination, relative ranking

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A profit function for the producer of an agricultural commodity is commonly derived assuming that the level of factor inputs applied does not impact the output price received (e.g., Bontems and Thomas; Dai, Fletcher, and Lee; Isik, Khanna, Moffitt et al.; and Winter-Nelson, Kumbhakar). While this assumption may be reasonable for feed grain production, this framework has serious limitations for looking at the irrigation termination of upland cotton. Cotton is priced according to the High Volume Instrument (HVI) measured attributes of fiber length, strength, micronaire, uniformity, trash, and color. Of particular interest for the irrigation termination decision is the HVI property of micronaire or fiber diameter which is also related to fiber maturity. Variety, environment, and management practices, like the timing associated with the irrigation termination decision, impacts fiber micronaire. Extending the season to produce a "top crop" has the potential to lower the overall micronaire average of a plant since these top bolls will be relatively fine or low in micronaire compared to the more mature bottom bolls. However, extending the season can also exacerbate the problem of high micronaire if significant losses in fruit retention occur late in the season. Unless plants gain a significant boll load, carbohydrates are loaded into existing bolls and increase the crop's micronaire level. Prior irrigation termination studies (Moffitt et al., Silvertooth et al., Unruh and Silvertooth) have not accounted for lint quality effects in analyzing the profitability of the irrigation termination decision for upland.

Lint quality changes from extending the season can have a dramatic impact on profit since both the "base yield" and any additional yield are affected. For example, if the initial per acre base yield is 1,200 lbs. and 50 lbs. of additional lint are obtained from extending the season, a 4¢/lb. quality enhancement would increase revenues by $50/acre. This is more than double the $25/acre that would be received from the extra 50 lbs. of lint from extending the season, assuming a base price near the loan rate at 50¢/lb. The objective of this paper is to identify agronomic and economic combinations that are profitable or not conducive for extending the season for upland cotton, considering both yield and quality components.

Overview of Situation

Average micronaire has been increasing for the U.S. cotton belt over the last 25 years, as illustrated in figure 1. Given that breeders and producers continue to select for higher yields, it is not surprising that micronaire has increased. That is, one way to obtain higher yields is to produce a fiber with a thicker cell wall thickness which weighs more. From 1975 to 1999, average micronaire trended upward by .0092 and .0102 each year, for the U.S. and Arizona respectively. Note also that the average micronaire level for a production regime like Arizona is much higher than for the U.S. High day and night temperatures are conducive for producing high micronaire cotton. As shown in figure 2, 38.6% of Arizona crop in 1999 was discounted due to high micronaire. In 1991, about half of this percentage or 19.4% of Arizona's crop was discounted from having undesirably high micronaire readings. Subsequently, the general upward trend in micronaire has had a much more adverse impact for regions like Arizona that are more conducive to producing high micronaire than California and Texas.

Table 1 describes the discount/premium schedule that has been received for different micronaire readings in the last week of November from 1990 to 2000. Micronaire readings of 5.0 to 5.2 received just a 1¢ to 3¢ discount prior to 1999. But since then the discount associated with 5.0 to 5.2 micronaire has increased to around 8¢/lb. or about four-fold increase for Desert SouthWest (DSW) cotton. This 8¢ discount reduces the net price received by over 15 percent of the value of current low spot prices. Micronaire readings of 5.3 or greater accounted for 11.6% of Arizona's crop in 1999. The 9¢ to 10¢ per pound discount associated with this high level of micronaire reduces the current net price received by the producer by almost 20 percent compared to the more desirable micronaire readings in the 3.5 to 4.9 range. Some cotton marketing professionals in Arizona believe that high micronaire has cost Arizona producers $20 to $25 million per year (Silvertooth, et al.) in recent years.

Data and Methods

Irrigation termination studies conducted in central Arizona by Jeff Silvertooth and Steve Husman for the years of 1991, 1992, 1994, 1995, 1996, 1997, and 2000 are the basis for this analysis. To quantify the progression of each crop among different years on a relatively equal basis, Heat Units After Planting (HUAP) accumulated by the irrigation termination date of each study were obtained from the nearest AZMet weather station. A total of 198 irrigation termination experiments were available with lint quality measures that included at least micronaire. These 198 observations are comprised of 67 experiments that are used to determine the baseline irrigation termination treatment or IT-1. Another 67 experiments comprise the 2nd irrigation termination treatment or IT-2. 64 experiments had a 3rd irrigation termination treatment or IT-3. The deviations in lint yield, quality, and production costs for IT-2 and IT-3 as compared to IT-1 are the basis for this analysis.

In evaluating the timing of irrigation termination and shutting down other crop inputs, both agronomic and economic factors need to be considered. Crop maturity, variety, existing boll load, and micronaire readings of base cotton bolls can provide signals as to what the additional yield potential and change in micronaire will be for extending the season. Genetics, environment, and management all influence fiber properties like micronaire. Economic factors like the price of lint, micronaire discount/premium schedule, harvest and interest costs, plus the cost of crop inputs like water, insecticides, fertilizer, labor, and defoliants will also impact the profitability of extending the season.

To help quantify the impact of key economic factors like the base lint price, discount/premium for micronaire, and cost of water, the profitability of each experiment was made assuming a low, medium, and high value scenario. That is, the profitability for extending the season on each of the 131 experiments was solved for using all of the following possible combinations: 1) a base lint price of 50, 60, or 70 cents per pound, 2) a discount/premium schedule for micronaire and lint quality that existed in November of 1994, 1996, or 1999, and 3) a water cost of either $10, $35, or $60 per acre foot. Applying these 27 different possible price and cost combinations to the 131 termination experiments results in 3,537 return observations. Other assumptions used to calculate the return for each possible combination were: additional harvest and ginning costs at $.10/lb., cottonseed priced at 6.5¢/lb. and equal to 175% of lint weight (turnout of 36.36%), each irrigation requires .3 hrs. of labor per acre at a wage of $5.75/hr., opportunity cost of funds associated with the first irrigation termination date was added at .1/365 per day, and insecticide, fertilizer, defoliation, and any other remaining costs were added at $.75 per day. This value of $.75 per day is on the lower end of what was actually experienced for most of the crop years considered, to reflect the recent widespread adoption of Bt cotton and the accompanying reduced insecticide spray requirements for pink boll worm late in the season.

Profitable agronomic and economic combinations for extending the season were identified using the non-parametric procedure of Classification and Regression Trees (CART).

CART is a computationally intensive statistical algorithm that was also used to determine the relative importance of factors for influencing profitability, the dependent variable. Independent variables used to explain the profitability of irrigation termination were: 12 different lint varieties, HUAP for the first irrigation termination date (IT-1), additional heat units accumulated for subsequent irrigation termination dates, crop year, yield and micronaire of IT-1 experiments, base lint price, price year (last week in November for 1994, 1996, or 1999) for quality discounts/premiums, and water cost.

To better understand the CART algorithm, envision a jar full of marbles where each marble is identified with a return from irrigation termination. Each marble or return is also labeled with the value of each independent variable. The first question CART addresses is what variable and accompanying magnitude can be used to divide the marbles into two jars so that the returns in each jar are as close to one another as possible. For this analysis, closeness refers to the total sum of squared errors for all marbles and the predictor value for each jar is simply the average of all marbles in the jar. Then, subsequent divisions occur until all returns are placed into terminal categories or noes of the same value of less than a minimum number of observations (5 for our analysis). Although a variable may not give the best split for a node, it may give the second or third best split. CART utilizes this concept of surrogate splits to determine the relative importance of different variables. A surrogate split is essentially how well each variable predicts the action of the best linear split. CART keeps track of the performance of each variable for all splits and normalizes all variables so that the most important variable has a ranking of 100. This procedure was used to quantify the relative importance of agronomic and economic factors for the irrigation termination decision.

A tree with one node for every observation would have no node impurity but would likely produce spurious results from a test sample. Whereas, a very small sized tree will inadequately represent the relationships embodied in the data. To determine the trade-off between tree complexity and accuracy, optimal tree size was determined using the *v*-fold (*v* equal to 10 for our results) Cross-Validation (CV) procedure. The CV procedure has been referred to as the "leave-one-out" estimate. First, the entire data is randomly divided into *v* different subsets, $L_1, \ldots, L_v$, that are equal or nearly equal in size. A classification tree with a specified number of terminal nodes is computed *V* times, each time leaving out one of the L_v subsamples out to serve as a test sample. Misclassification costs for each L_v test sample are then averaged over each of the different sized trees to determine their respective CV error.

As described by Sorensen, Miller, and Ooi, advantages associated with CART include: 1) intuition provided by the hierarchy provided in the estimated binary tree -- CART is not a black box, 2) accounting for non-linearities in the data, and 3) accounting for dependencies among variables. They successfully used CART to predict stocks that would underperform or outperform their industry on a short-term basis. The average rate of return for their outperform stocks was 34.06% or almost double the 18.33% obtained from their underperform stocks. Additional information regarding the procedures and properties of estimates obtained from CART are discussed in Breiman et al., Efron and Tibshirani, Horowitz and Carson, Lim, Loh, and Shih, and Tronstad.

Results

Applying CART to the 3,537 return observations revealed that agronomic factors were more important signals for predicting the profitability of extending the season than the economic factors of lint prices, quality discounts/premiums, and water costs. The relative ranking criteria of CART were as follows: variety (100), additional heat units after IT-1 (94), yield of IT-1 (93), crop year (83), micronaire associated with IT-1 (68), HUAP for IT-1 (67), lint price (5), water cost (2), and the quality discount/premium year (.09). Variety influences both the yield potential of a top crop and how prone the crop's genetics are for producing high micronaire cotton. Both base yield and micronaire associated with the first irrigation termination date (IT-1) provide signals as to whether a crop has the potential for producing a significant top crop and whether micronaire has room to increase without moving into the discount range. HUAP for IT-1 provides a signal as to where the crop is in relation to its fruiting cycle.

While economic factors of lint price and water cost influence profitability, their impact is relatively small compared to agronomic factors. For example, as described in figure 3, extending the season from the first to second termination date (anywhere from 247 to 840 heat units) resulted in a per acre yield change that ranged anywhere from -343 lbs. to 999 lbs. and averaged 171 lbs. Extending the season for studies with three termination dates (anywhere from 478 to 1432 heat units) also had significant variation in yield. Per acre yield changes for these experiments averaged 345 lbs. and ranged from -252 lbs. to 1029 lbs. Given the range in yields associated with these experiments, it is not surprising that lint price is a relatively small component. That is, the maximum range in lint price is only 20¢ per lb. (50¢ to 70¢ per lb.) or

33% of the value of its average. Whereas, yield changes range from -343 to 1029 lbs. per acre or by 536% of the average yield change associated with all field plots. Given that the additional water applied ranged from .31 to 2.0 acre feet and water costs varied from $10 to $60 per acre foot, the range in cost associated with water and irrigation labor was anywhere from $4.83 to $126.90 per acre. While this range of $122.07 per acre is quite large, it is relatively small compared to the $686.00 range in lint revenues realized from different yield changes with only 50¢/lb. lint prices.

The market discount/premium associated with lint quality was also relatively small compared to agronomic factors for explaining profitability. Figure 4 illustrates the change in micronaire realized for the experiments from their respective IT-1 values. Due to the discrete nature associated with quality discounts as described in table 1, an increase in micronaire is not necessarily an issue until it exceeds a threshold value. Thus, being able to predict whether a crop will exceed a threshold micronaire level appears to be more important for explaining profitability than knowing whether the discount associated with high micronaire is relatively low or high (i.e., 1994 versus 1999 prices). Because the production from several experiments with replications were weighed separately in trailers, but combined into a module from which samples were taken to determine lint quality, the number of individual data points are less for quality than quantity.

Figure 5 presents a CART generated decision tree which describes the profitability of "extending the season" using 50¢ lint prices and quality discount/premium rates of November 1999. Even though current DSW 31-3/35 prices (August 10, 2001) are less than 35.70¢/lb., the loan deficiency payment is such that growers should exceed 50¢ for 2001. To illustrate the results, consider a situation where the variety planted is SG747, your IT-1 yield is estimated at

1,300 to 1350 lbs, and IT-1 micronaire is expected to be 5.0 to 5.1. Yield is less than 1368 lbs. so proceed left down the decision tree. Then, if the crop year is like 1995 or 1996 the decision tree categorizes the return from extending the season at -$50.28/acre. If the crop year is like 5 out of the 7 years considered (i.e., not 1995 or 1996), move right below the crop year node, then right at the subsequent variety node, IT-1 yield of 934 lbs./acre, and IT-1 micronaire of 4.95. Extending the season less than 644 heat units after the initial IT-1 termination date results in an expected profit of $83.47. But extending the season beyond 644 heat units yields a category with twice this level of return at $196.74/acre. On average, 644 heat units equaled 24 days for all the experiments considered. Excluding observations for 2000, the average HUAP for IT-1 was 3278 or roughly equal to the 3200 HUAP recommended by University of Arizona Cooperative Extension for the optimal timing for irrigation termination of a mid-season variety. The range in HUAP for all IT-1 plots is from 2305 to 3494, and averages 2863. Several plots in 2000 were targeted for one irrigation prior to the recommended 3,200 HUAP and were terminated at 2561 HUAP. Irrespective of this somewhat earlier IT-1 termination date for 2000, this element did not rise to the forefront as a significant item for categorizing the data by CART.

Note in figure 1 that when IT-1 micronaire is relatively high (i.e., greater than 4.95 or 5.17), extending the season at least 644 heat units pays a dividend. If IT-1 micronaire is real low, less than 4.05, extending the season is also likely to be profitable since higher micronaire is not likely to occur. However, if IT-1 micronaire is less than 4.35 with an IT-1 yield less than 1368 lbs./acre and a variety type of ST474 or DP388, extending the season results in a negative return of -$137.60/acre. In addition, extending the season is generally unprofitable when IT-1 yields are greater than 1368 lbs./acre and IT-1 micronaire is less than 5.17. If a crop has already attained a good load of bolls and micronaire is not real high, the potential to add profit through extending the season appears limited. However, if micronaire is above 5.17 with a high boll load, extending the season at least 644 heat units pays a dividend. This result supports the notion that a top crop can enhance returns through improving the quality of the base yield and providing addition yield.

Conclusions

The return associated with "extending the season" in a heat unit framework (86/55F) for upland was analyzed considering both quality and yield factors. In general, results indicated that agronomic factors relating to variety, additional heat units, and yield associated with IT-1 experiments were more important signals than economic factors of water cost, base lint price, and quality discount/premium year. In addition, crop year was near the top of importance for determining whether extending the season was profitable or not, suggesting that each year is different and risks are involved with producing a top crop.

Significant yield variation from extending the season was found. In addition, agronomic signals for predicting micronaire changes were very important for determining profitability since quality is impacted for both base and any additional yields attained. Because many inputs are already sunk in getting the crop to the first irrigation termination date or IT-1, the marginal cost associated with extending the season is relatively small in relation to the yield and quality changes associated with extending the season. These are the primary reasons why agronomic factors were found to be more influential than the economic factors considered for explaining the profitability of extending the season for upland.

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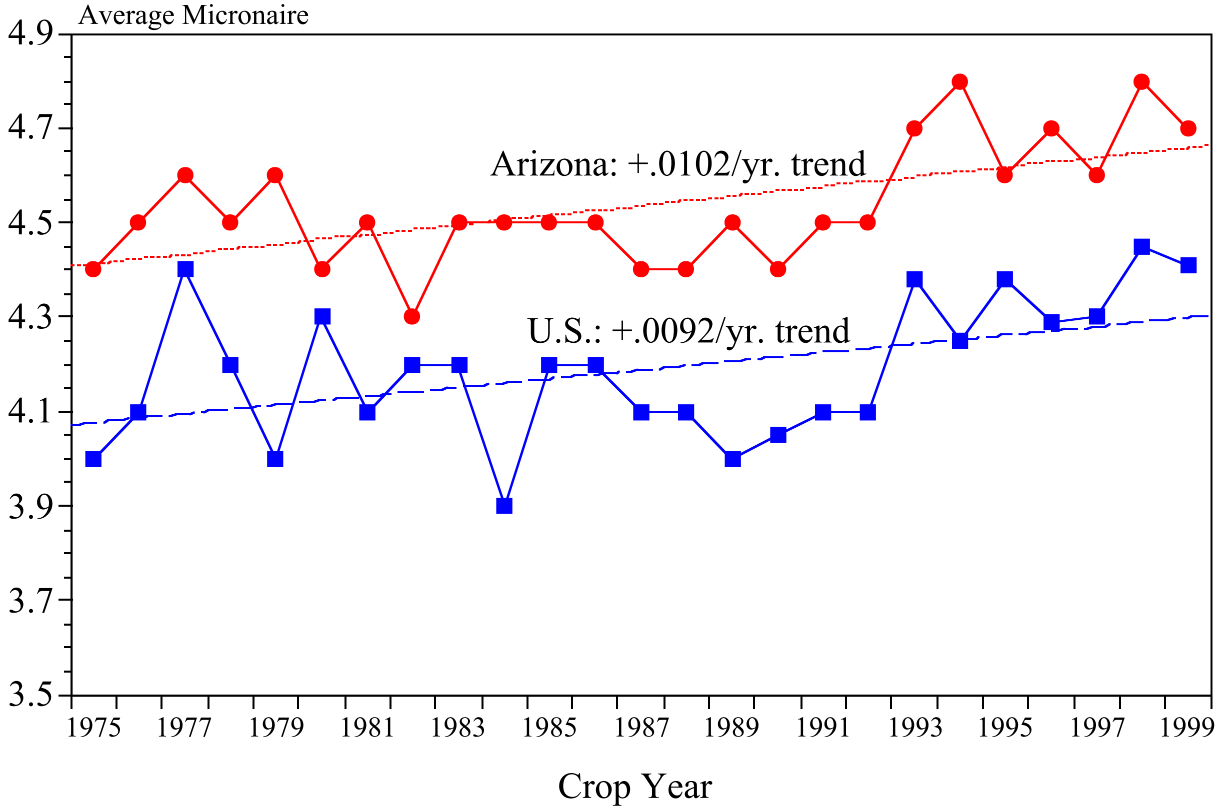
Table 1. Prices and the accompanying micronaire discount/premium schedule, 1990-2000.[a]

	DSW	Discount/Premium for Micronaire Ranges									
Year	31-3/35	< 2.4	2.5-2.6	2.7-2.9	3.0-3.2	3.3-3.4	3.5-3.6	3.7-4.2	4.3-4.9	5.0-5.2	> 5.3
1990	76.03		-21.0	-14.0	-8.0	-3.5	0.0	0.0	0.0	-1.0	-1.5
1991	56.58	-17.0	-14.0	-10.0	-4.5	-2.0	0.0	0.25	0.0	-1.0	-2.0
1992	51.30	-16.0	-13.0	-11.0	-5.0	-2.5	0.0	0.25	0.0	-2.0	-3.0
1993	55.68	-14.0	-11.0	-9.0	-4.0	-1.5	0.0	0.25	0.0	-3.5	-4.5
1994	75.03	-14.0	-11.0	-9.0	-4.0	-1.5	0.0	0.25	0.0	-1.5	-2.25
1995	85.34	-14.0	-11.0	-9.0	-4.0	-1.5	0.0	0.25	0.0	-3.5	-5.0
1996	72.32	-16.0	-14.0	-12.5	-7.0	-1.5	0.0	0.25	0.0	-3.5	-7.0
1997	69.48	-16.0	-14.0	-12.5	-7.0	-1.5	0.0	0.25	0.0	-2.0	-4.0
1998	64.00	-16.0	-14.0	-12.5	-7.0	-1.5	0.0	0.25	0.0	-2.0	-4.0
1999	47.51	-16.0	-14.0	-12.5	-7.0	-1.5	0.0	0.25	0.0	-8.0	-10.0
2000	58.07	-16.0	-14.0	-12.5	-7.0	-1.5	0.0	0.25	0.0	-7.0	-9.0

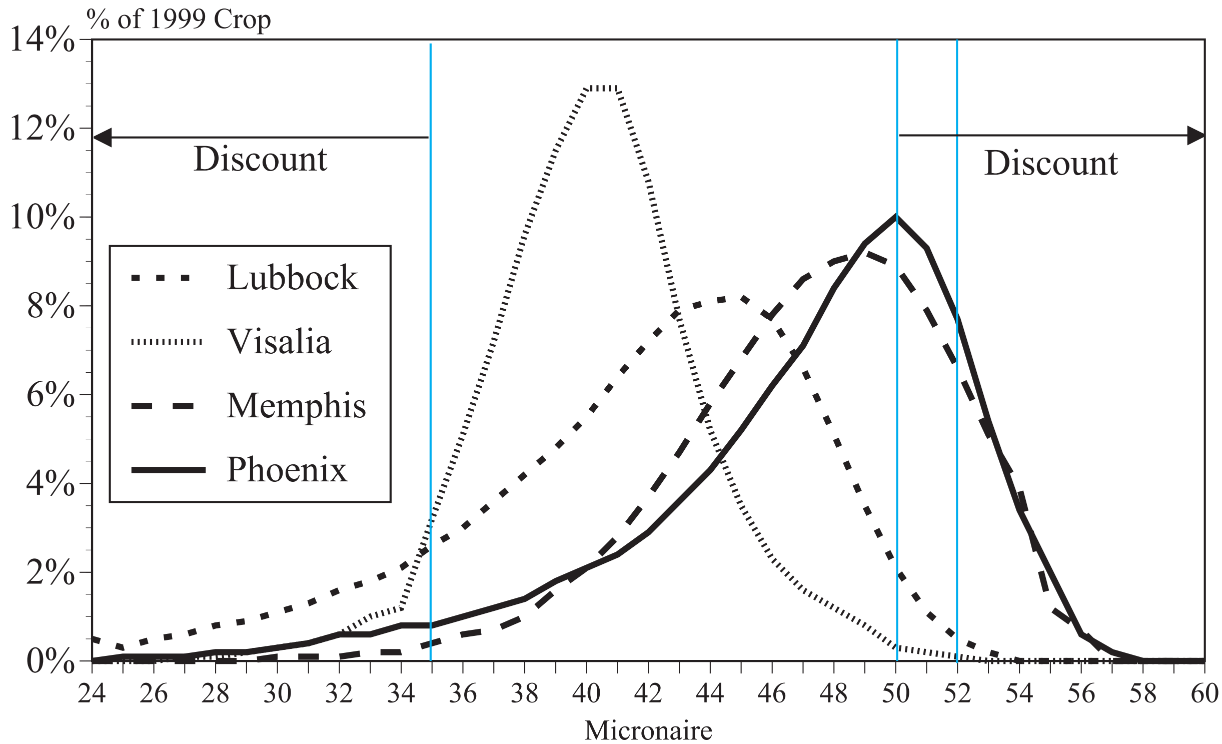
[a] Desert SouthWest (DSW) 31/3-35 prices for the last week in November, uncompressed bales.

Figure 1. Average micronaire for the U.S. and Arizona, 1975-1999



Source: AMS/USDA Classing Offices

Figure 2. Micronaire distribution for the 1999 upland crop from selected classing offices



Source: AMS/USDA Classing Offices

Figure 3. Change in lint yield from extending the season beyond the first irrigation termination date, 86/55F heat units

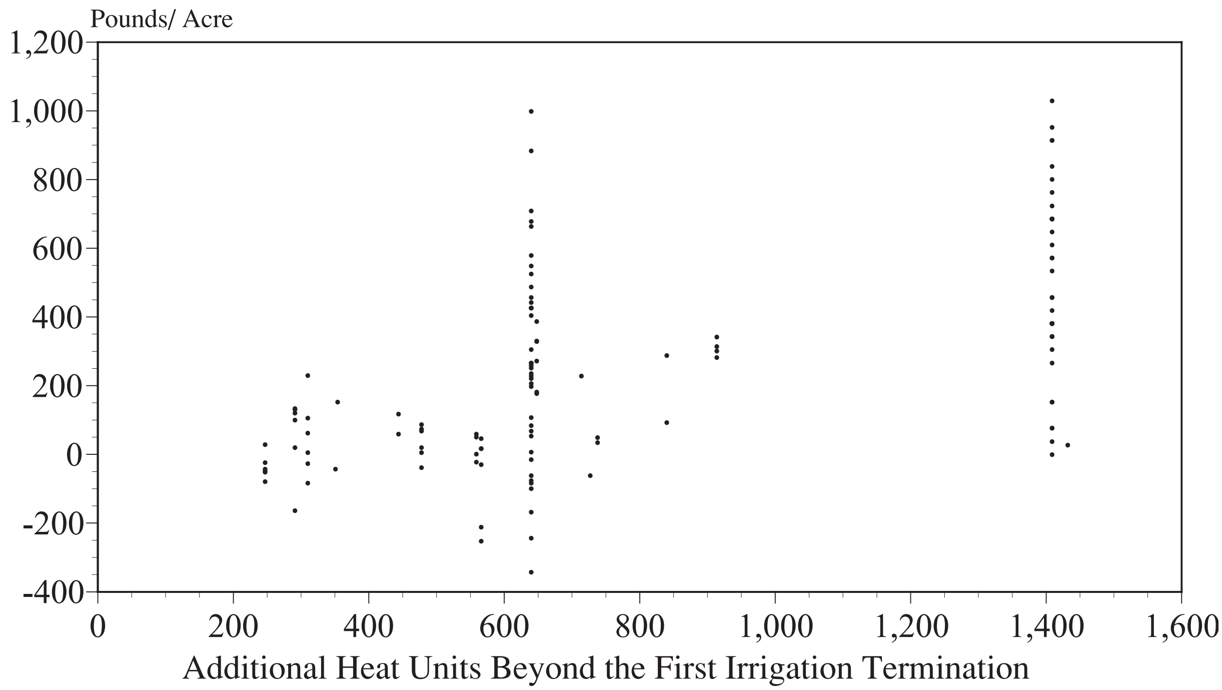


Figure 4. Change in micronaire from extending the season beyond the first irrigation termination date, 86/55F heat units

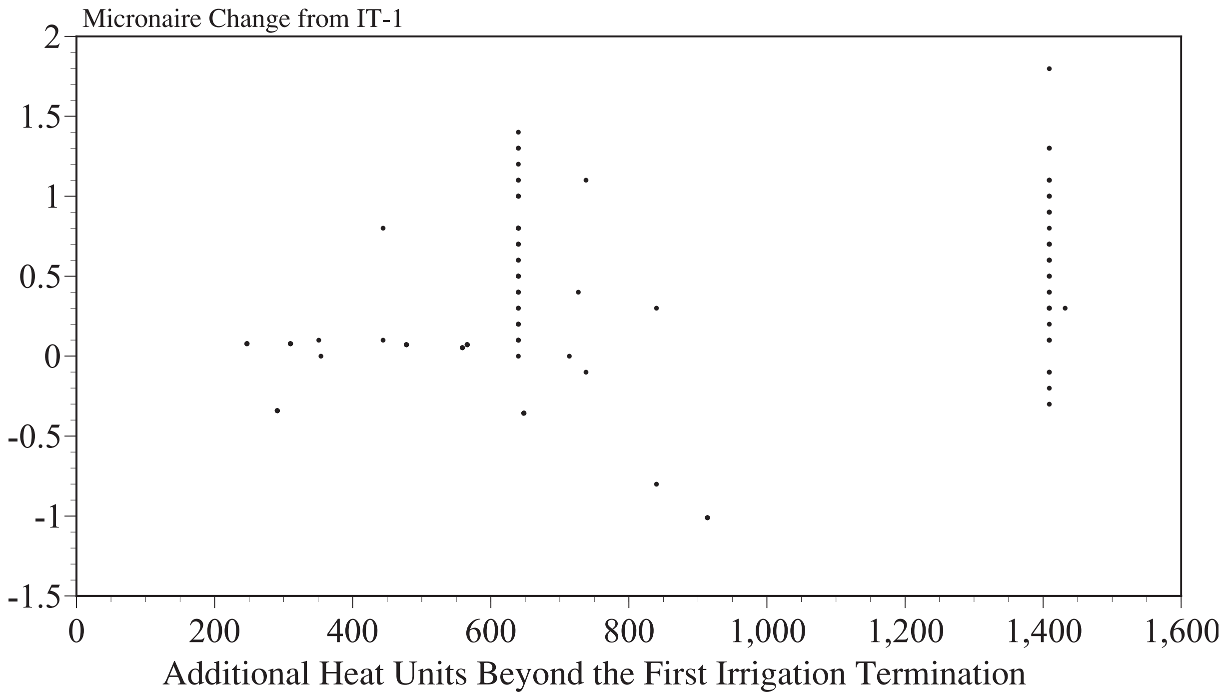
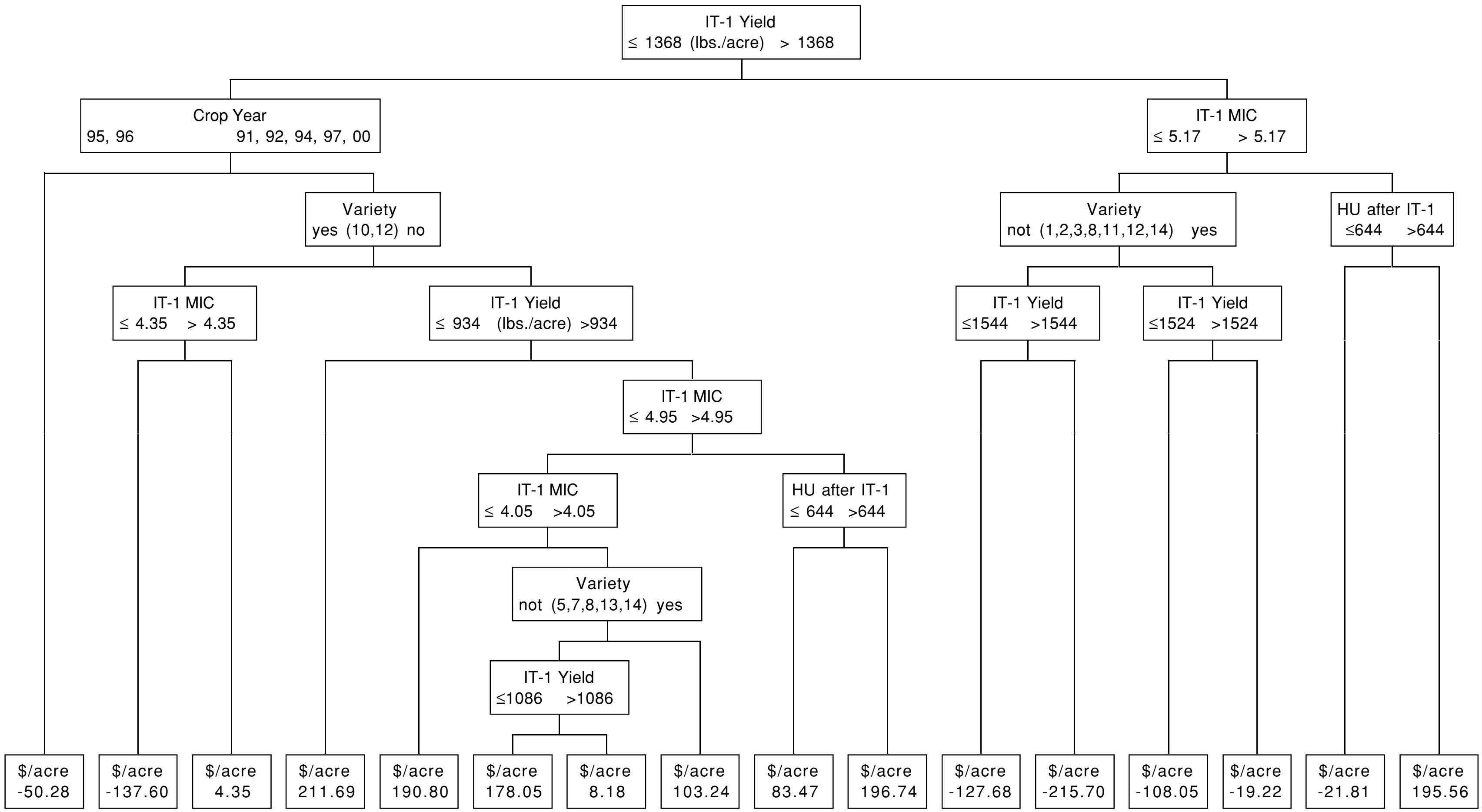


Figure 5. Irrigation termination guidelines: 1999 micronaire schedule and 31-3/35 lint price of 50¢/lb.



Variety Legend: 1=DP90 2=DP5415 3=DP33B 4=SG747 5=DP451BR 6=BXN47 7=ST4691B
8=DP20B 9=DP422BR 10=ST474 11=DP428B 12=DP388 13=SG125BR 14=DP655BR