TRENDS IN COTTON YIELDS AND YIELD VARIABILITY IN THE TEXAS HIGH PLAINS: AN IRRIGATED VERSUS DRYLAND COMPARISON

David B. Willis and Octavio A. Ramirez
Department of Agricultural and Applied Economics
Texas Tech University
Lubbock, TX

Abstract

This paper investigates the 30 year trends in cotton yield and yield variability for three crop reporting districts in the Texas High Plains. Irrigated and dryland yield comparisons are made between the three crop reporting districts. Cotton yields significantly increased on both irrigated and dryland acreage in two of the three districts. In all districts, irrigated yield variability increased over time but dryland yield variability has remained constant.

Introduction

Recent cotton price decreases have significantly reduced cotton profitability and focused research efforts on reducing production cost. In addition to cotton price, yield trends and yield variability also influence profitability. Increasing yield variability translates into higher grower risk even if output price and production cost remain stable. One characteristic of the yield distribution that has implications on management decisions is the skewness of the distribution. For example, if a yield distribution is skewed to the right, the average yield will be achieved less than 50 percent of the time, and a farmer who budgets for an average yield will end up short more often than not. Given the severe economic stress confronting cotton producers in the Texas High Plains, knowledge of yield and yield variability trends is critical to sound long-run planning. This paper represents a preliminary attempt to gain insight into the trends in yield growth and yield variability, and the shape of the yield distribution in this region.

Analytical Method

Study Area

The three northern-most crop reporting districts in Texas serve as the study area for examining the temporal trend in cotton yield and yield variability. These districts consist of the Northern High Plains district (District 1-N) located in the Northwestern section of the Texas panhandle, the Southern High Plains district (District 1-S) located just south of District 1-N, and the Northern Low Plains district (District 2-N) which is adjacent and east of Districts 1-N and 2-N. Twenty-nine years of annual county level data on irrigated and dryland cotton yields were compiled for each cotton producing county in the three crop reporting districts for the period 1969-1997 (Texas Agricultural Statistics Service).

Eleven counties in District 1-N produced both irrigated and dryland cotton over the twenty-nine year period. Annual harvested cotton acreage averaged 503,640 acres within the district, with 83 % of the acres being irrigated. District 1-N is generally cooler and has the shortest growing season of the three districts. Districts 1-S and 2-N each contain 16 counties which produce either irrigated and/or dryland cotton. Average harvested acreage in District 1-S is 2,208,000 acres, with only 47 % of the acreage irrigated. District 1-S groundwater supplies are considerably scarcer than District 1-N supplies. Ninety percent of the 514,800 harvested acres in District 2-N are dryland. Heavier annual precipitation levels in District 2-N partially compensates for a paucity of groundwater supplies which makes cotton production in this district less dependent on irrigation.

Statistical Procedure

Per acre yield trends and yield variability trends were estimated for each irrigated and dryland yield distribution in each district using Ramirez's (1997) multivariate parametric modeling approach. Conceptually, Ramirez's approach is a pooled cross-sectional time series technique for estimating parameters of random processes which may not be normally distributed. In this particular application the technique improves statistical efficiency by systematically and simultaneously using time series information on yield covariances between regions, and between dryland and irrigated yields, to estimate time dependent expected yield and variance parameter values for each distribution. In addition to providing yield mean and variance estimates for each yield distribution, the technique also provides skewness and kurtosis estimates which are used to test if the data generating process is normally distributed.

A variety of functional forms and explanatory variables were used to estimate the parameters that characterize the individual statistical distributions. Given the aggregate nature of the county yield data, only a linear time trend variable (0 for 1968, 1 for 1969, 2 for 1970 and so forth) was statistically significant in explaining district yields over time. Indicator (dummy) variables were used to link counties to the appropriate district in the estimation process. Each observed county yield in a specific year and district is treated as an experimental replication. Thus, if in a given year, average irrigated yield data is reported for 16 counties, the 16 county values are considered to be experimental replications within the district.

The statistical procedure estimates the mean yield and yield standard deviation at each point in time, for each district and distribution (irrigated and dryland). The yearly standard deviation estimate of district yield used in this study is

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calculated as the individual county deviations from the estimated trended district average yield value for all counties within the district, and not as the county deviation from the historical district average. If irrigated and non-irrigated yield standard deviations were calculated as county deviations from the historical district average, at each point in time, yield variability within a district would be understated. This is the case because the historical county yields are realized outcomes of a stochastic process and the computed historical district average can significantly differ from the expected trended level in any given year. When individuals make planting decisions they are concerned about expected yield and the variability of expected yield, and not the variability surrounding a specific outcome which is unknown when the planting decision is made. Thus, to more accurately measure the inherent variability in yields, over time, yield variability is measured as deviations from the yield trend and not the realized average outcome at each point in time.

Results

Statistical Estimates

Table 1 presents the nonlinear maximum likelihood estimates for the yield and variability trends which categorize the six crop distributions (dryland and irrigated crop distribution for each district). Twelve of the fifteen parameter estimates are statistically significant at the .01 or higher significance level (t-value equal to or greater than 2.626), two of the remaining three estimated parameters are statistically significant at the .05 or higher significance level (t-value equal to or greater than 1.960), and the remaining estimated parameter is statistically significant at the .12 significance level (t-value equal to 1.58). The high statistical significance of the estimated parameters suggest the yield and yield variability trends characterizing each distribution are adequately captured by the statistical model. The estimated parameters in Table 1 fall into one of four classifications: (1) parameters used to estimate expected 1968 yields; (2) parameters used to estimate annual increase in expected yield relative to 1968 yield; (3) parameters used to estimate 1968 yield standard deviation; and (4) parameters used to estimate the annual change in yield standard deviation relative to 1968.

The first three rows of Table 1 contain the parameters used to estimate expected 1968 irrigated yield. Expected 1968 irrigated yield for District 1-N is about 302 pounds per acre. The second and third rows, respectively, contain the yield shifting parameters for 1968 irrigated yields for districts 1-S and 2-N relative to District 1-N. The yield shift is upward in both districts relative to District 1-N. All 1968 irrigated yield parameters are significant at the .01 level.

The second set of three rows in Table 1 (rows 4 to 6) contain the parameters used to estimate the annual change in irrigated yield for each district. Expected irrigated yields have annually increased by 10.69 pounds per acre in District 1-N. Rows 5 and 6, respectively contain the slope shifting parameter values used to adjust the annual increase in irrigated crop yields for districts 1-S and 2-N relative to District 1-N. The annual yield adjustment is downward for both districts, 3.25 pounds per acre less for District 1-S and 8.72 pounds per acre less for District 2-N. Two of the three irrigated yield trend parameters are significant at the .01 level (districts 1-N and 2-N) and the remaining parameter (District 1-S) is significant at .05 level.

No significant statistical difference was detected between the 1968 standard deviation of irrigated yield in any of the three districts, thus one parameter is used to estimate the irrigated yield standard deviation for 1968. The 1968 irrigated yield standard deviation estimate is 103 pounds per acre and is statistically significant at the .01 level. Two parameters are needed to capture the temporal trend in irrigated yield variability. Since 1968, the irrigated yield standard deviation has annually increased by 2.06 pounds per acre in districts 1-N and 1-S, and is statistically significant at the .01 level (Table 1). The annual standard deviation increase is .66 pounds less in District 2-N, relative to the other two districts (Table 1).

The bottom six rows of Table 1 contain the parameter estimates used to estimate dryland yield and dryland yield variability trends. Expected 1968 District 1-N dryland yield is 204 pounds per acre. Expected 1968 dryland yield is 51 pounds higher in districts 1-S and 2-N than in District 1-N. Both expected 1968 yield parameters are significant at the .01 probability level.

Similar to the irrigated acreage situation, three parameters are needed to accurately estimate the annual dryland yield trend in each district. Expected dryland yields have annually increased by 5.31 pounds per acre in District 1-N. But, the expected annual yield increase is 2.90 pounds per acre less in District 1-S, and 4.92 pounds per acre less for District 2-N. The yield trend parameter for District 1-N, and the yield trend adjustment parameter for District 2-N (slope shifter relative to the District 1-N yield trend) are statistically significant at the .01 level. The yield trend slope shifter for District 1-S is statistically significant at the .05 level. The last row in Table 1 is the dryland yield standard deviation estimate. A variety of statistical tests failed to detect a significant difference in expected 1968 dryland yields between districts, or any trend in the magnitude of the dryland yield standard deviation over time in any district. Hence, the dryland yield standard deviation was determined to be constant across districts and over time, and has an estimated value of 106 pounds per acre which is statistically significant at the .01 probability level.

Yield Trends

Table 2 summarizes the statistical results for expected 1968 irrigated and dryland yield and annual yield trend for each district. These results are derived from the information contained in Table 1. Irrigated and dryland yields have been increasing over time, in all districts, with the magnitude of trend being greatest in District 1-N and smallest in District 2-N. Historical annual average yields for District 1-N irrigated and dryland acreage are presented in Figure 1. Despite many erratic yield swings, district yield for both irrigated and dryland acreage steadily increased over the 29 year data series. Moreover, as one would suspect, dryland and irrigated yield generally move in the same direction each year reflecting their high correlation (correlation coefficient of .63) with irrigated yield always being greater. Figure 2 illustrates the variation around the long-run irrigated yield trend for District 1-N. As noted earlier, irrigated yields in District 1-N increased at an annual rate of 10.69 pounds between 1968 and 1997. Though of smaller magnitude, an upward yield trend was found to exist in all districts for both irrigated and dryland yields. District yield trend comparisons for irrigated and dryland acreage are respectively presented in Figures 3 and 4.

Experts commonly attribute yield increases over time to improved varieties, and improved management practices, such as, advances in herbicides, growth regulators, and harvest aids. One potential explanation for the greater absolute yield increase for irrigated acreage relative to dryland acreage is the wide spread adoption of low pressure sprinkler irrigation systems which has complimented the yield gains achievable from improved seed varieties, chemical aids, and management. Advances in irrigation efficiency, timing, and delivery systems has improved the ability of irrigators to more effectively apply scarce water supplies in the most critical growth periods to enhance yields. Today, irrigated yields are highest in district 1-N because irrigation water supplies are relatively more abundant in this district and more irrigation water is applied to the crop.

Variety improvement may explain why District 1-N has the greatest annual yield increase for both irrigated and non-irrigated acreage. In 1968, District 1-N had the lowest irrigated and dryland yields primarily because available varieties were not well adapted to the shorter growing season and cooler temperatures found in District 1-N. The introduction of better adopted varieties may have enhanced the yield potential of District 1-N relative to districts 2-S and 2-N.

Variability Trends

Table 3 reports the 1968 irrigated and dryland yield standard deviation estimate and annual standard deviation yield trend for each district. The values in these tables are derived from the information contained in Table 1. Surprisingly, irrigated yield variability has been increasing while dryland variability has remained constant.

Figure 5 contains the same information as Figure 2 in that it plots annual average irrigated District 1-N yields around the long-run yield trend, but adds an additional two standard deviation upper and lower band around the long-run trend. Despite the significant deviations from the yield trend, the average yield deviations do not fully capture yield variability because the district average data masks the yearly variation in the underlying county level data. Figure 6 more fully captures the annual county level variation by plotting the yearly county data against the linear trend and the two standard deviation band for District 1-N. In some years all county yields are above the linear trend line, and in other years all yields are below the trend line. Twelve of the 237 data points are outside the two standard deviation bound. The county level variability within a district is important because it approximates the yield variability an individual farmer is subject to.

Figures 7 and 8, respectively, graph the standard deviation yield trend for irrigated and dryland cotton acreage for each district. Irrigated yield variability has increased in all districts, increasing most rapidly in districts 1-N and 1-S, and more slowly in district 2-N. The increased variability is partially attributable to the right skewness in the irrigated yield distribution. In certain irrigated situations a timely late July or early August rainfall can significantly increase yield in these districts because irrigators generally do not irrigate to full net irrigation requirement, preferring instead to partially irrigate as many acres as they can with their water supply (Krieg, 1999).

As shown in Figure 8 the variation in dryland yield around the trended mean has remained constant over time in all three districts. This is probably attributable to the fact that weather is the most important factor in explaining dryland yield variability, and the seasonal weather variability pattern has remained relatively constant over the period of analysis.

In absolute terms, irrigated yield variability has been greater than dryland yield variability since 1970 in all districts. However, in relative terms, irrigated yield variability is still less than dryland yield variability in all districts. The coefficient of variation is often used to examine relative variability when the mean and/or standard deviation of a process is changing over time and is calculated as the standard deviation divided by the average value. A decreasing coefficient of variation implies the process is becoming relatively less variable, and an increasing coefficient of variation implies the process is becoming relatively more variable. Figures 9 and 10, respectively, graph the irrigated and dryland coefficient of variation for each district over time. No consistent coefficient of variation trend exists for irrigated acreage. District 2-N reveals increasing relative variability, District 1-N exhibits decreasing relatively variability, and District 1-S relative variability has remained constant over time. In contrast to the irrigated acreage, all dryland districts reveal decreasing relative yield variability (Figure 10). Moreover, dryland relative yield variability has been decreasing at a much faster rate than irrigated yield relative variability in those irrigated districts that have experienced a decrease in relative yield variability.

Probability Distributions

Ramirez's technique was applied to the parameters reported in Table 1 to simulate 50,000 potential yields at selected points in time for each of the six production system/district combinations considered. The simulated yield values were subsequently used to develop six yield probability distributions at each selected point in time. Figures 11 and 12, respectively, report the probability distributions developed for 1998 irrigated and dryland yields in District 1-S. The interpretation of the probability distributions can best be illustrated by an example. Consider Figure 11. The probability of achieving a 1998 per acre irrigated yield between 500 and 700 pounds in District 1-S is calculated by adding the height of each histogram bar bracketed by the endpoints 500 and 700. Summing the height of each bar included in the bracketed range results in a probability value of 45.2%. Summing the height of all bars in Figure 11 yields the probability value of 100%, which implies that all 50,000 of the 1998 simulated irrigated cotton yield values are between 260 and 1040 pounds per acre.

As seen in figures 11 and 12, the irrigated yield distribution for District 1-S is slightly skewed to the right, but the dryland yield distribution in District 1-S does not significantly depart from normality. Similar results were derived for the two other districts; irrigated yield distributions are skewed to the right, and the dryland yield distributions are normally distributed.

Average irrigated yield is 577 pounds for District 1-S in 1998, but given the distribution's right-hand-side skewness, an average yield will only be exceeded 47.2 percent of the time and will be below the average 52.8 percent of the time. Hence, irrigated producers budgeting for an average yield, will realize a less than an average per acre gross revenue 52.8 percent of the time due to the right-hand-side skewness of the yield distribution. The dryland distribution for District 1-S is nearly symmetric and the average yield of 327 pounds per acre is exceeded 50.4 percent of the time.

Conclusions, Limitations and Areas of Future Research

This study supports and quantifies the general observation that cotton yields have been increasing in the Texas High Plains over the last 30 years on both irrigated and dryland acreage. In addition to documenting this trend, this study also found that irrigated yield variability has been increasing over time, but dryland yield variability have remained stable. Additional research is required to fully understand the causes of these trends. It is hypothesized that advances in production technology (chemical and mechanical), irrigation technology, water management (of both irrigated and precipitation supplies), seed varieties, and on-farm management practices account for the observed trends. Of particular importance to producers is gaining insight into the factors that explain increasing irrigated yield variability. Kreig (1999) has speculated that yields for newer seed varieties are more sensitive to the irrigation scheduling in critical crop growth stages and non-optimal water application timing may explain the increasing yield variability among producers. That is, each growth stage time window where a crop can make maximum use of applied water may he shorter for the newer varieties, and a poorly timed irrigation schedule may significantly diminish yield. Hence, an optimal irrigation scheduling regime may be increasingly important today to jointly maximize yield and minimize yield variability.

A potential limitation to the reported findings is the assumption that each county within a crop reporting district is homogenous. This assumption needs to be empirically examined in future research. One means of testing this assumption is to weight each county by the number of irrigated and dryland acres in the estimation of model parameters. If the re-estimated model parameters are consistent with the un-weighted parameter values the homogeneity assumption would be supported. Moreover, it is likely that the increase in county irrigated yield variability understates the farm level increase in irrigated yield variability. Even though irrigated yield variability has increased in all three districts, it is important to recall that relative irrigated yield variability as measured by coefficient of variation went up in one district, remained constant in a second district, and decreased in the third district. Hence, no definitive statement regarding relative irrigated yield risk can be made for all districts.

Acknowledgements

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Table 1. Maximum Likelihoood Parameter Estimates and Associated Standard Errors (N=1852)

Variable	**Estimate (Lbs/ac)**	**T- Value**
1968 Irrigated Yield (District 1-N)	301.72	18.10
1968 Irrigated Yield shifter (District 1-S relative to District 1-N)	52.80	2.69
1968 Irrigated Yield shifter (District 2-N relative to District 1-N)	109.72	5.55
District 1-N Annual Irrigated Yield Increase	10.69	8.94
District 1-S Slope Shifter for Annual Irrigated Yield Increase (relative to District 1N)	-3.25	-2.31
District 2N Slope Shifter for Annual Irrigated Yield Increase (relative to District 1N)	-8.72	-6.02
1968 Standard Deviation Irrigated Yields (Districts 1-N, 1-S, and 2-N)	103.00	9.67
Annual Increase in Standard Deviation of Irrigated Yields (Districts 1-N and 1-S)	2.06	4.98
District 2-N Slope Shifter for Annual Increase in Standard Deviation of Irrigated Yield (relative to Districts 1-N and 1-S)	-0.66	-1.58
1968 Dryland Yield (District 1-N)	204.13	12.83
1968 Dryland Yield shifter (Districts 1-S and 2-N relative to District 1-N)	50.65	2.82
Annual Dryland Yield Increase (District 1-N)	5.31	5.26
Slope Shifter for Annual Dryland Yield Increase (District 1-S relative to District 1-N)	-2.90	-2.50
Slope Shifter for Annual Dryland Yield Increase (District 2-N relative to District 1-N)	-4.92	-4.16
Standard Deviation for Dryland Yields (all years and Districts)	106.27	43.98

Table 2. Estimated Yield Trends by Crop Reporting District: Irrigated Versus Dryland Cotton (lbs/Acre)

	District		
Yield Parameters	**1-N**	**1-S**	**2-N**
Irrigated			
1968 Base Yield	301.72	354.52	411.45
Annual Yield Increase	10.69	7.44	1.97
Dryland			
1968 Base Yield	204.13	254.78	254.78
Annual Yield Increase	5.31	2.41	0.39

Table 3. Estimated Standard Deviation Trends by Crop Reporting District: Irrigated Versus Dryland Cotton (Lbs/Acre)

	District		
Yield Parameters	**1-N**	**1-S**	**2-N**
Irrigated			
1968 Base Std. Dev.	103.00	103.00	103.00
Annual Change in Standard Deviation	2.06	2.06	1.41
Dryland			
1968 Base Std. Dev.	106.27	106.27	106.27
Annual Change in Standard Deviation	0.00	0.00	0.00

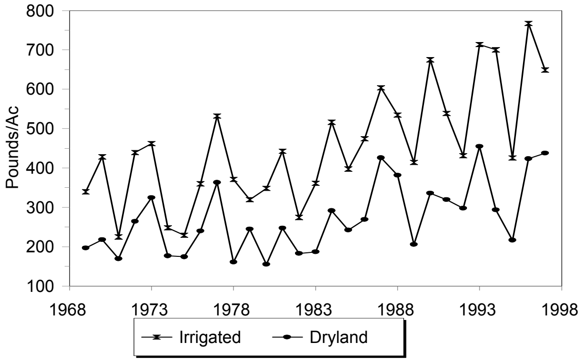

Figure 1. Irrigated and Dryland Crop Yields: District 1-N

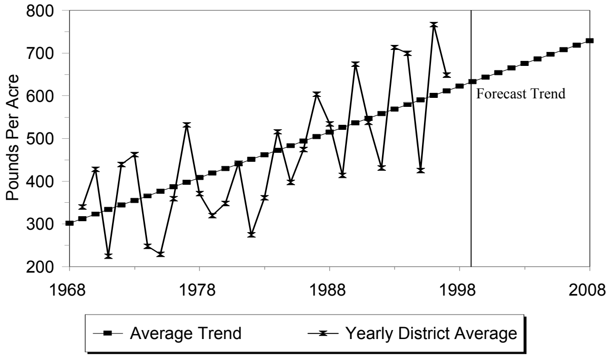

Figure 2. Annual Average Irrigated Yields and Statistical Yield Trend: District 1-N

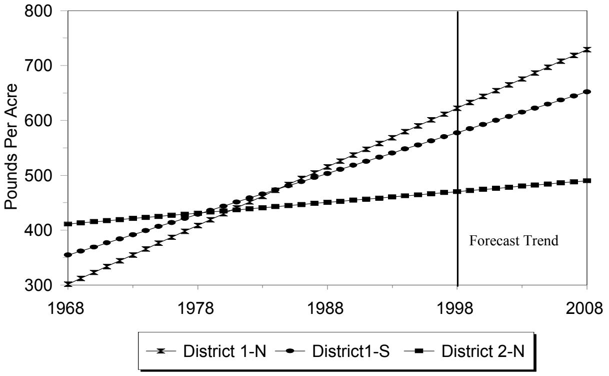

Figure 3. Comparison of Irrigated Yield Trends by Crop District

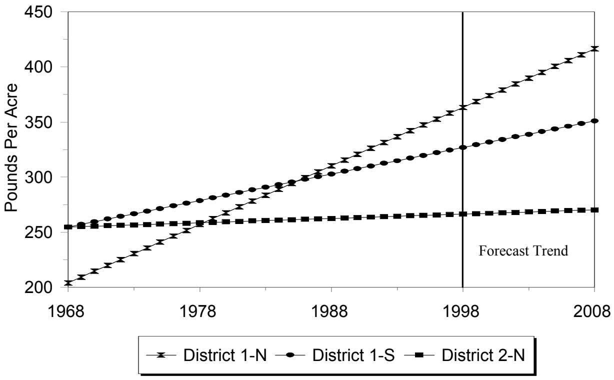

Figure 4. Comparison of Dryland Yield Trends by District

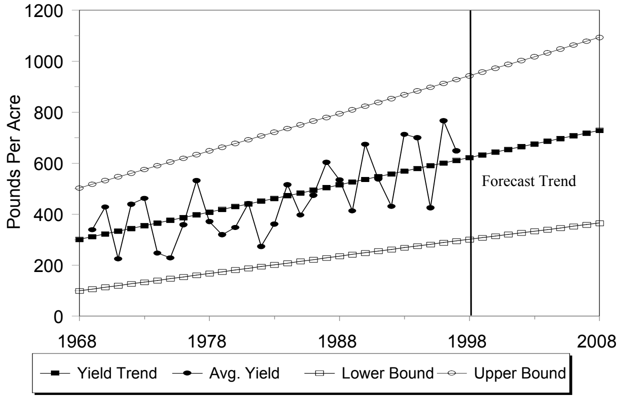

Figure 5. Two Standard Deviation Bound (for <u>individual</u> county yields in District 1-N) Relative to Annual Average District Yield and District Yield Trend: Irrigated Yield District 1-N

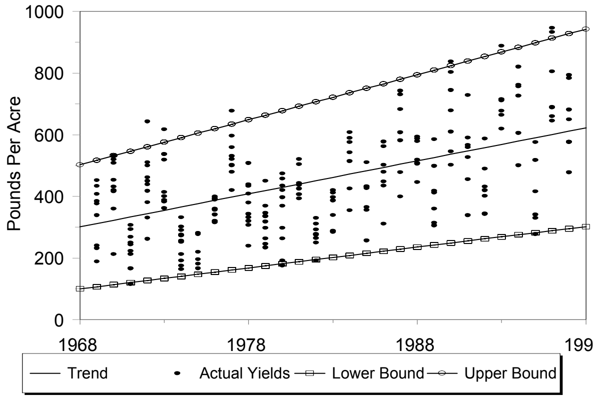

Figure 6. Two Standard Deviation Bound, Individual County Yields, and District Yield Trend Through Time: Irrigated Yield District 1-N

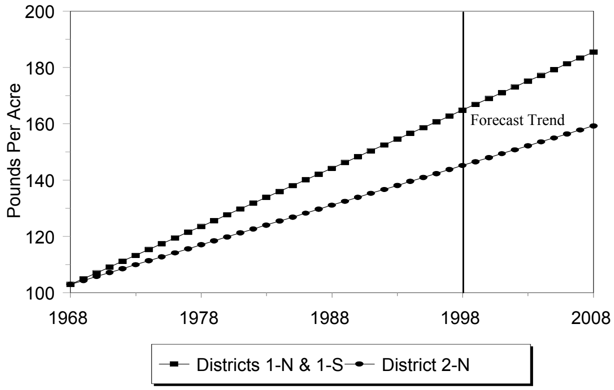

Figure 7. Regional Comparison of the Trend in District Standard Deviation Values for Irrigated Cotton Yields

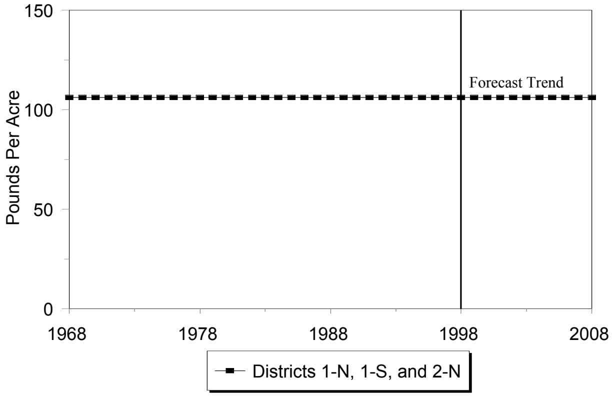

Figure 8. Regional Comparison of the Trend in District Standard Deviation Values for Dryland Cotton Yields

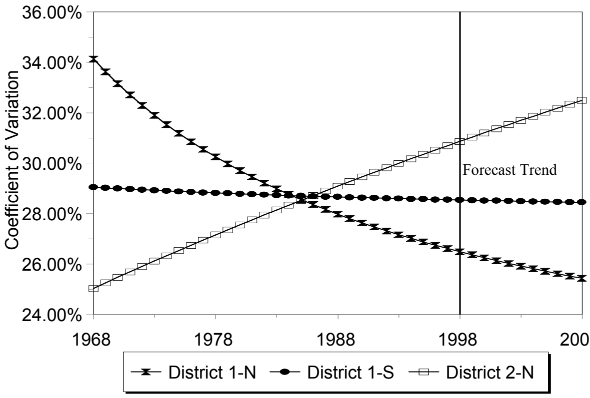

Figure 9. Regional Comparison of the Trend in District Coefficient of Variation Value for Irrigated Cotton Yields

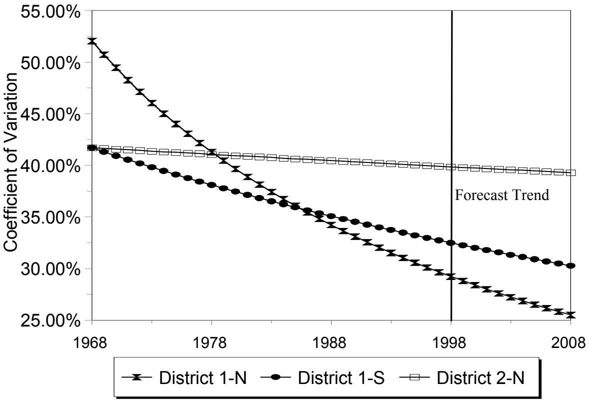

Figure 10. Regional Comparison of the Trend in District Coefficient of Variation Value for Dryland Cotton Yields

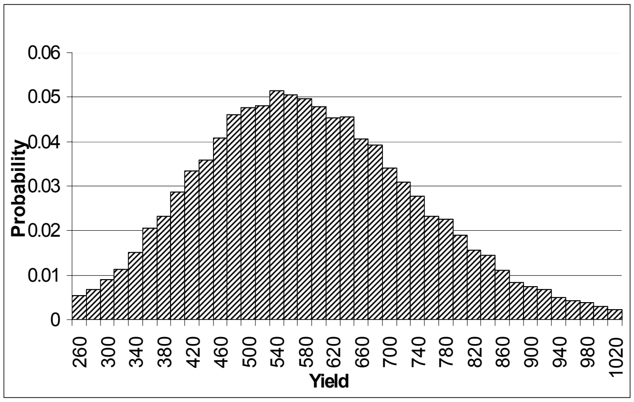

Figure 11. 1998 Simulated Probability Distribution for Irrigated Yields: District 1-S

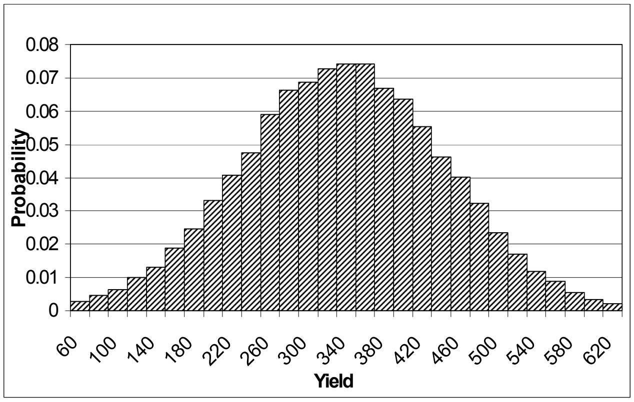

Figure 12. 1998 Simulated Probability Distribution for Dryland Yields: District 1-S