Journal of Agricultural and Resource Economics 32(2):383–401

Herbicide-Resistant Technology Price Effects on the Plant Density Decision for Ultra-Narrow-Row Cotton

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Farmers are concerned about the high cost of planting herbicide-resistant cotton with the high plant densities recommended for ultra-narrow-row cotton. This study evaluates the effects on net revenues of four herbicide-resistant technology fee policies used since 1996 by Monsanto, the technology license holder. Results indicate that changes in the technology fee policy by Monsanto have raised the cost of planting herbicide-resistant cotton. As a consequence, farmers may have an incentive to switch from ultra-narrow-row cotton to wide-row cotton and to use a lower plant density when the technology fee is tied to the seeding rate.

Key words: profit, seed cost, technology fee, transgenic cotton

Introduction

Upland cotton traditionally has been produced in 38- or 40-inch rows. Cotton farmers have shown increasing interest in an alternative cotton production system commonly referred to as ultra-narrow-row cotton (UNRC). UNRC is defined as having a row spacing of between 7.5 and 15 inches (Parvin, Cooke, and Martin, 2002). With UNRC, a finger-type stripper rather than a spindle picker is commonly used to harvest the crop. Spindle picking is the most common method of machine harvesting cotton and uses rotating spindles on each row to grab the lint from the plants. By comparison, a finger stripper literally strips off most of the parts of the plant and uses one or more cleaners to separate the lint from the other plant parts. Although production statistics are lacking, UNRC appears to occupy a small but stable percentage of cotton area in the United States. Early attempts to develop the UNRC production system in the 1950s and again in the 1970s were stymied by weed control and other production problems (Gwathmey and Hayes, 1996). UNRC became more feasible with the availability of herbicide-resistant cotton, which facilitated weed control in solid planted cotton and has been an important factor in renewed farmer interest in UNRC (Jost and Cothren, 2000).

Another characteristic of UNRC is the use of very high plant densities, relative to wide-row cotton. Recommended plant densities for UNRC range from 80,000 to 200,000 plants/acre (Delaney et al., 2002). By comparison, typical plant densities for wide-row cotton vary from 30,000 to 60,000 plants/acre. High plant densities are often used in

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Review coordinated by T. F. Glover and David K. Lambert; publication decision made by David K. Lambert.

UNRC production to compensate for imprecise seed placement at planting with a drill and to facilitate efficient machine harvesting with a finger stripper.

Reported advantages of UNRC include lower machinery and labor costs and higher yields (Parvin, Cooke, and Martin, 2002; Jost and Cothren, 2000). Brown, Cole, and Alphin (1998) evaluated costs for UNRC and wide-row cotton on five farms participating in industry field tests in 1996. They found fixed costs for UNRC were lower than for picker cotton. An important factor in the lower fixed costs for UNRC is the lower ownership cost for a finger stripper compared with a spindle picker (Larson et al., 1997). UNRC has been advocated as a way to bring marginal land into cotton production while minimizing equipment costs (Brown and Reeves, 2002). Reduced soil erosion and runoff are other potential advantages of the UNRC system (Gwathmey and Hayes, 1996).

Impeding the potential profitability of UNRC are the substantially higher seeding costs associated with the higher plant densities relative to wide-row cotton (Parvin, Cooke, and Martin, 2002). Brown, Cole, and Alphin (1998) found that variable costs of production averaged $17/acre higher for UNRC cotton, with seed costs accounting for $16/acre of this total. High seed costs, especially with the use of more expensive herbicide-resistant varieties, have hindered the adoption of UNRC. Another potential drawback of UNRC is finger stripping cotton may result in more leaf and bark content in the lint than with spindle picking (Valco, Anthony, and McAlister, 2001). More of these plant parts are harvested by the finger stripper and they are not completely removed during lint cleaning. Higher leaf grades and bark in lint may result in larger price discounts for UNRC relative to spindle-picked cotton. The John Deere Company recently introduced a 15-inch, narrow-row spindle picker that may overcome the problem of higher leaf and bark in UNRC (Robinson, 2004). However, the ownership and operating costs for a spindle picker are higher than those for a finger stripper (Larson et al., 1997).

Notwithstanding the positive effects of herbicide-resistant cotton on the viability of UNRC through better weed control, cotton farmers are concerned about the profitability of UNRC because of high planting costs associated with high seeding rates and transgenic varieties. Our objective was to evaluate the effects of herbicide-resistant technology pricing on the plant density decision for UNRC production. Results from our analysis also provide insight into the effects of herbicide-resistant technology pricing on planting decisions for wide-row cotton.

Analytical Framework

The pricing of cotton seed changed with the introduction of herbicide-resistant BXN (Buctril-resistant) cotton by the Stoneville Pedigreed Seed Company in 1995 (Ward et al., 1995). About 79% of U.S. cotton acreage in 2004 was planted using herbicide-resistant technologies (Doane Agricultural Services, 2005). Monsanto, which licenses glyphosate-resistant (Roundup Ready and Roundup Ready Flex) and Bt (Bollgard and Bollgard II) technologies through various seed companies, is the dominant provider of transgenic characteristics in U.S. cotton production with a 98% market share (Doane Agricultural Services, 2005).

The primary benefit of Roundup Ready technology in cotton production is in early-season weed control. The technology allows Roundup herbicide to be applied over the top of the crop up to the four-leaf stage of cotton plant growth and development. Any

Roundup applications after the four-leaf stage and before canopy closure must be post-directed using a hooded sprayer so the herbicide does not contact cotton plants and cause injury. Consequently, the post-directed application of Roundup is potentially feasible in wide-row cotton but not in UNRC because of its narrow row spacing. Farmers growing UNRC must use other over-the-top herbicides such as Staple (prythiobac sodium) for weed control after the four-leaf stage. Staple is another technology that has made weed control more feasible in UNRC. The new Roundup Ready Flex technology allows for over-the-top application of Roundup herbicide until about one week before harvest, and thus could be used for a much longer period in UNRC production (Monsanto Company, 2005).

Since 1996, Monsanto has billed cotton farmers a technology fee in addition to the transgenic seed cost charged by the seed company. This practice contrasts with corn and soybeans where, in 2002, Monsanto started charging a royalty to seed companies rather than assessing a separate technology fee to farmers (Monsanto Company, 2001). Monsanto's practice of charging technology fees for cotton has changed several times since 1996 when it first introduced Roundup Ready cotton (Johnson, 1996). These alternative technology fee structures have impacted seed costs and profitability for both wide-row cotton and UNRC. The alternative fee regimes described below are representative of the methods used by Monsanto to sell transgenic cotton to farmers and were used to analyze the plant density decision for UNRC.

Pre-transgenic UNRC Seed Pricing Policy

Before the introduction of transgenic cotton in 1995, the target UNRC plant population density (*PPD*) for a profit-maximizing farmer could be characterized as:

$$\text{(1)} \qquad \text{Max } NR(PPD) = \left[BLP + LPD(PPD)\right] \times LY(PPD) - SC(PPD),$$

where *NR* is net revenue ($/acre), *BLP* is base quality lint price ($/lb.), *LPD* is expected lint price difference for fiber quality ($/lb.), *LY* is expected lint yield (lbs./acre), and *SC* is seed cost ($/acre). Functional notation in equation (1) indicates that *NR*, *LPD*, *LY*, and *SC* are functions of *PPD* (1,000s plants/acre).

The theory of plant population where crop yield is a product of growth in the reproductive phase indicates that the relationship between lint yield and *PPD* is approximately parabolic (Bridge, Meredith, and Chism, 1973; Holliday, 1960). In addition, research has shown that higher *PPD*s in UNRC may result in larger price discounts for fiber quality (Valco, Anthony, and McAlister, 2001; Larson et al., 2004). Thus, the price difference term *LPD*(*PPD*) in equation (1) also was assumed to be a function of *PPD*. Because less than 100% of the seeds dropped from a planter germinate and produce harvestable plants, the seeding rate chosen by the farmer also was assumed to be a function of *PPD*. Therefore, the seed cost (*SC*) based on a farmer's expectation of plant survival can be modeled using:

$$\text{(2)} \qquad SC(PPD) = (PPD \div PSR \div SEED) \times SPLB,$$

where *PSR* is the expected plant survival ratio (plants/seed), *SEED* is number of seeds per pound (seeds/lb.) for the variety planted, and *SPLB* is price of seed for the variety ($/lb.). *PSR* represents a farmer's expectation of plant survival used to determine seeding rate.

Monsanto's 1996–1997 UNRC Pricing Policy

With the introduction of glyphosate-resistant cotton in 1996, Monsanto initially charged a per acre technology fee ($/acre) for both wide-row cotton and UNRC in addition to the seed price ($/lb.) charged by the seed company. For example, the glyphosate-resistant cultivar, PM 1220 RR, had a suggested retail price of $43.95/bag (or $0.88/lb.) that was charged by the Delta and Pine Land Company (Jenkins, 2002) and a $9/acre technology fee (*TFA*) assessed by Monsanto (Montgomery, 2002). Farmers provided documentation of area planted for the purpose of billing technology fees. A key assumption for this analysis is that the benefits of glyphosate-resistant cotton in weed control are the same regardless of the *PPD* chosen. As noted previously, the primary benefit is in early-season over-the-top weed control. We are not aware of any research indicating that herbicide or other production practices would change with *PPD* in UNRC.

The *PPD* decision for a profit-maximizing UNRC farmer who used transgenic seed under this pricing regime could be characterized as:

$$(3) \qquad \text{Max}\, NR(PPD) = \left[BLP + LPD(PPD)\right] \times LY(PPD) - SC(PPD) - TFA.$$

Under the initial technology fee policy established by Monsanto, the farmer's choice of *PPD* was not influenced by the technology fee (*TFA*) because the fee was not tied to seed planted.

Monsanto's 1998–2003 Seed Pricing Policy

Starting in 1998, Monsanto modified its technology fee policy for wide-row cotton and developed a separate policy for UNRC cotton (Monsanto Company, 1998), but the two policies were related as will be seen later. In general, this schedule was used by Monsanto from 1998 through 2003. First, for wide-row cotton, the technology fee was calculated using the seed drop rate (*SDR*) and the seed variety category (*SVC*). Monsanto defined the *SDR* as the number of seeds dropped from the planter to achieve a final *PPD*. The *SDR* varied by production region.

For example, the *SDR* was 76,000 seeds/acre for middle Tennessee and northern Alabama compared with 52,000 seeds/acre for Georgia, Florida, and southern Alabama (Virginia Cooperative Extension Service, 1998). The *SDR* assumes that, within each *SVC*, one 50-lb. bag of seed would cover a predetermined acreage in a particular region. According to Monsanto, the *SDR* was based on seeding rate and *PPD* data compiled from state universities, crop consultants, seed companies, and others, and was intended to represent common planting practices for different production areas across the U.S. Cotton Belt (Monsanto Company, 1998). Seed variety category (*SVC*) was the mean number of seeds per pound (seeds/lb.) for a variety that was used by Monsanto for the purpose of calculating the technology fee.

The UNRC *PPD* decision using the wide-row policy can be modeled as:

$$(4) \qquad FEE(PPD) = (SVC \div SDR \times TFA) \times (PPD \div PSR \div SEED),$$

and

$$(5) \qquad \text{Max}\, NR(PPD) = \left[BLP + LPD(PPD)\right] \times LY(PPD) - SC(PPD) - FEE(PPD).$$

The revised technology fee policy given by equation (4) converted the per acre technology fee to a per pound basis. For example, the technology fee for a farmer in northern Alabama who planted a Roundup Ready variety with an *SVC* of 4,200 seeds/lb. and an *SDR* of 76,000 seeds/acre was calculated as: 4,200 ÷ 76,000 × $9 = $0.50/lb. By comparison, a farmer in Georgia paid a technology fee of $0.73/lb. (4,200 ÷ 52,000 × $9 = $0.73/lb.). A farmer who used a seeding rate exactly equal to the *SDR* paid a technology fee of $9/acre, while a farmer who used a seeding rate less than the *SDR* paid a technology fee that was less than $9/acre. The cotton plant can compensate for fewer plants per acre by producing more bolls per plant, suggesting a favorable cost-return tradeoff between lower *PPD*, lint yields, seed costs, and technology fees may be possible (Larson et al., 2004). Hence, farmers had an incentive to reduce technology fees by using a seeding rate that was less than the *SDR* with the 1998–2003 wide-row policy.

Under Monsanto's 1998–2003 UNRC exception policy, farmers were exempted from paying the per pound technology fee on a portion of the seed that was planted in UNRC, and instead paid the per acre fee (*TFA*). To be eligible for the exception, farmers were required to grow at least 50 acres of UNRC. The *SDR* for UNRC was determined by estimating *PPD* in the field after planting and dividing that population by a *PSR* of 0.80 (Monsanto Company, 1998). The farmer and a representative from Monsanto determined *PPD* after planting. The estimated *SDR* was used to calculate the amount of seed excluded from the wide-row per pound technology fee. Any seed used beyond the amount excluded was priced using the wide-row pricing policy modeled in equation (4). The technology fee for UNRC can be represented as:

$$(6) \qquad \begin{aligned} FEE(PPD) &= TFA + \big((PPD \div PSR \div SEED) - (PPD \div 0.80 \div SVC)\big) \\ &\quad \times (SVC \div SDR \times TFA);\ \text{else} \\ FEE(PPD) &= TFA \text{ for } FEE(PPD) < TFA. \end{aligned}$$

Under the UNRC exception policy, the minimum fee paid by farmers was the *TFA* of $9/acre. Farmers who used a lower *PSR* to determine their seeding rate rather than the 0.80 assumed by Monsanto paid an additional technology fee above the base per acre rate of $9/acre. Low plant stand establishment rates are not uncommon in cotton production, so farmers may use a *PSR* lower than 0.80 to determine their seeding rate. For example, Larson et al. (2004) reported UNRC stand establishment rates using a precision planter that averaged 64% but varied from 43% to 81% in a four-year UNRC experiment. Soil temperature and moisture conditions after planting influence the *PSR* (Kerby et al., 1996).

In addition, the difference in the actual seed count (*SEED*) versus the seed count assumed by Monsanto to calculate the technology fee (*SVC*) also influences the technology fee paid. Prior to 2004, cotton seed was typically sold in 50-lb. bags. Seed size for a variety can vary by 10% or more above or below the average value (Robinson, 2003a). A high seed count (small seed size) reduces seed cost and technology fee, while a low seed count (large seed size) increases the seed cost and technology fee. Thus, for a given *PPD*, a higher seed count with a lower cost per seed increases the marginal productivity of additional plants/acre compared with the cost of those plants. Evidence suggests farmers have sought high seed count varieties to reduce seed and technology costs (Robinson, 2003a).

Monsanto's 2004–2005 UNRC Seed Pricing Policy

The pricing of cotton varieties again changed in 2004. Two major suppliers of cotton varieties in the United States, the Delta and Pine Land Company and the Stoneville Pedigreed Seed Company, changed from selling seed in 50-lb. bags to marketing seed in standardized seed count packages, similar to the practice used for hybrid corn (Robinson, 2003a, b). For example, the suggested price for DP 436 RR, a cultivar from Delta and Pine Land, was $79.95 per 250,000 count bag ($0.00032/seed) (Legé, 2005).

Monsanto changed the pricing of its transgenic technologies to correspond with the introduction of seed count packages and modified the technology fee policy for UNRC (Montgomery, 2005). The technology fee for both wide-row cotton and UNRC also was charged on a per seed basis. The Roundup Ready technology fee was capped at a maximum of $28/acre in 2005 if the farmer planted UNRC or grew wide-row cotton and participated in a Roundup herbicide rebate program. As with the 1998–2003 policy, technology fees vary by production region based on typical production practices, demand for different varieties, and other competitive factors. For example, a farmer in Mississippi in 2005 paid a Roundup Ready technology fee of $150.60/250,000 count bag ($0.0006024/seed) compared with $82.05/bag ($0.0003282/seed) for a farmer in north Alabama (Montgomery, 2005). With seed count packaging, seed cost in equation (2) becomes:

$$SC(PPD) = (PPD \div PSR) \times SPS, \tag{7}$$

where SPS is price per seed ($/seed). The technology fee term in equation (5) with seed count pricing and a cap on UNRC fees then becomes:

$$FEE(PPD) = (PPD \div PSR) \times TFS \text{ for } FEE(PPD) < CAP; \text{ else} \\ FEE(PPD) = CAP, \tag{8}$$

where TFS is technology fee per seed ($/seed) and CAP is an upper limit on technology fees ($/acre) for a farmer growing UNRC.

Data and Methods

Data

The impacts of the alternative cotton seed pricing scenarios described previously on UNRC net revenues were evaluated using equations (1)–(8). The lint yield ($LY(PPD)$) and lint price difference ($LPD(PPD)$) response functions for the analysis were estimated using data from a 1997–2000 UNRC plant density experiment at the Milan Experiment Station, Milan, TN (Larson et al., 2004). A summary of the data used to estimate the yield and lint price difference response functions is presented in table 1. A Roundup Ready variety was planted in 10-inch rows in each year. After plant emergence, plots were hand thinned to four target plant densities in 1997 and 1998 and five target plant densities in 1999 and 2000. The treatments were arranged in a randomized complete block design with four or five replications. Plot assignments of treatments were re-randomized as the experiment was moved to a new field site in each year of the study.

Table 1. Summary of 1997–2000 Ultra-Narrow-Row Cotton Data Used to Estimate the Cotton Lint Yield and Lint Price Difference Functions for the Analysis

Variable	Mean	Standard Deviation	Minimum	Maximum
Treatment 1 (19 observations):				
Plant Density (1,000s/acre)	26.3	8.1	18.9	43.6
Yield (lbs./acre)	800	219	453	1,219
Price Difference ($/lb.)	−0.013	0.036	−0.060	0.034
Treatment 2 (19 observations):				
Plant Density (1,000s/acre)	45.8	12.9	33.3	78.4
Yield (lbs./acre)	840	201	452	1,205
Price Difference ($/lb.)	−0.020	0.034	−0.063	0.035
Treatment 3 (19 observations):				
Plant Density (1,000s/acre)	80.0	6.7	66.6	97.3
Yield (lbs./acre)	875	203	562	1,322
Price Difference ($/lb.)	−0.028	0.035	−0.070	0.032
Treatment 4 (19 observations):				
Plant Density (1,000s/acre)	116.4	8.1	100.0	130.0
Yield (lbs./acre)	884	224	511	1,413
Price Difference ($/lb.)	−0.023	0.032	−0.073	0.023
Treatment 5 (10 observations):				
Plant Density (1,000s/acre)	158.8	21.2	133.3	194.7
Yield (lbs./acre)	831	117	711	997
Price Difference ($/lb.)	−0.019	0.036	−0.086	0.014
Degree Days (4 observations)	2,188	254	1,866	2,486

Notes: For each year (1977–2000), degrees days (*DD*) between 1 April and 31 October were calculated using:

$$DD = \sum_{n=1}^{N} (TMAX + TMIN)/2 - 60,$$

where *TMAX* and *TMIN* are the respective maximum and minimum temperatures (°F) on day *n*, and 60 is the base temperature (°F). *DD* was calculated using data from the Milan Experiment Station, Milan, TN (U.S. Department of Commerce, National Oceanic and Atmospheric Administration).

The University of Tennessee pest-control practices recommended for no-tillage cotton were followed during each growing season (Shelby, 1996). Roundup herbicide was broadcast over the crop prior to the four-leaf growth stage each year. Two other over-the-top herbicide applications were applied to all plant density treatments—one for grass control and one for broadleaf control.

Plots were harvested using a finger stripper and the seed cotton was ginned using a gin on the experiment station. Processes of this gin assembly resemble those of a commercial gin. Lint obtained after ginning was weighed and used to determine lint yields for each plant density in each year of the experiment. In addition, the lint for each plant density was hand classed and subjected to high volume instrument (HVI) testing at the USDA's Agricultural Marketing Service Cotton Classing Office in Memphis, TN. The fiber quality attributes used to price lint for each plant density were color grade, leaf grade, staple length, micronaire, fiber strength, length uniformity, and extraneous matter. North Delta (Missouri, northeast Arkansas, and west Tennessee) spot quotations for the 2003–04 marketing year (1 August–31 July) were used to calculate the sum of the lint price differences for the fiber quality attributes for each plant density ($LPD(PDD)$) [U.S. Department of Agriculture/Agricultural Marketing Service (USDA/AMS), 2004]. The average base quality price (BP) of $0.6078/lb. and the associated price differences for the 2003–04 marketing year were deemed to be representative of the lint prices received by farmers over the last several years. Limitations of the Agricultural Marketing Service spot quotations have been discussed by Ethridge and Hudson (1998) and Brown et al. (1995). Additional information about the experiment and the lint yield and fiber quality data are found in Larson et al. (2004).

Yield and Price Difference Response Estimation

As noted previously, the theoretical relationship between *PPD* and lint yield is approximately parabolic (Holliday, 1960; Bridge, Meredith, and Chism, 1973). Studies have shown maximum yields to occur for *PPD*s ranging from about 20,000 to 108,000 plants/acre (Bednarz et al., 2005; Bridge, Meredith, and Chism, 1973; Fernandez et al., 2002; Fowler and Ray, 1977; Gerik et al., 2000; Hawkins and Peacock, 1970; Larson et al., 2004). These maximum yields varied by region, production system (e.g., wide-row versus UNRC), and year (weather). In general, results from these studies indicate that very high or very low *PPD*s had an adverse impact on lint yields. Lint yield as a function of *PPD* is expressed as:

$$LY = \beta_1 + \beta_2 PPD_{ijt} + \beta_3 PPD_{ijt}^2 + \beta_4 LNDD_t, \tag{9}$$

where *PPD* represents plants/acre (1,000s) for treatment i in the jth experimental block of year t, *LNDD* is the natural log of the sum of degree days (base 60°F) between 1 April and 31 October for each year t of the experiment (table 1), and β_k ($k = 1, 2, 3, 4$) are the estimated parameters. "Degree days" is a weather index (Oosterhuis et al., 1996) commonly used by researchers, farmers, and crop consultants to track cotton crop status during the growing season, and was used as a proxy for growing conditions in each year of the experiment. Tennessee is at the northern end of the Cotton Belt. Temperature is generally the first environmental factor that limits yields in any one year. Degree days are also correlated with total seasonal rainfall. In general, additional degree days allow more seed cotton to accumulate in bolls that contribute to lint yield (Mauney, 1986). Thus, additional degree days within a growing season were expected to positively impact lint yields but at a diminishing rate.

Lint price difference as a function of *PPD* is represented by:

$$LPD = \alpha_1 + \alpha_2 PPD_{ijt} + \alpha_3 LNDD_t, \tag{10}$$

where *PPD* and *LNDD* are as defined in equation (9), and α_m ($m = 1, 2, 3$) are the estimated parameters. We chose the linear form for *PPD* after a plot of the lint price difference data showed a generally downward-sloping relationship in the range of plant density in the experiment. For *LNDD*, a growing season with more degree days was expected to reduce price discounts but at a diminishing rate.

The practices followed in the UNRC experiment (e.g., the new field sites in each year and the different number of *PPD* treatment levels in each year) may have introduced heteroskedasticity into the data used to estimate equations (9) and (10). Using response functions estimated from experiment plot data, Mjelde, Capps, and Griffin (1995) found differences of up to one-third the amount of profit-maximizing levels of inputs after corrections were made for heteroskedasticity. Equations (9) and (10) were estimated separately using the mixed model procedure in SAS (Littell et al., 1996). This procedure was used to account for the potential heterogeneous variances and correlations among the plots and growing seasons in the experiment. The general form of the mixed model is:

$$\mathbf{y} = \mathbf{X}\boldsymbol{\delta} + \mathbf{Zu} + \mathbf{e}, \tag{11}$$

where $\mathbf{y}$ denotes the dependent variable vector, $\mathbf{X}$ is the matrix of explanatory variables, $\boldsymbol{\delta}$ is the vector of estimated coefficients, $\mathbf{Z}$ is the known design matrix containing continuous and/or dummy variables, $\mathbf{u}$ is the vector of unknown random effects parameters, and $\mathbf{e}$ is the random error vector. The variance of $\mathbf{y}$ is given by:

$$\mathbf{V} = \mathbf{ZGZ}' + \mathbf{R}, \tag{12}$$

where $\mathbf{G}$ and $\mathbf{R}$ are covariance matrices. The generalized least squares estimate of $\boldsymbol{\delta}$ is written as:

$$\hat{\boldsymbol{\delta}} = (\mathbf{X}'\mathbf{V}^{-1}\mathbf{X})^{-1}\mathbf{X}'\mathbf{V}^{-1}\mathbf{y}. \tag{13}$$

The covariance structure was specified (Saxton, 2002) to account for the experimental design followed in the UNRC study (Larson et al., 2004). The $\mathbf{Z}$ matrix was specified with dummy variables for each experimental block j and an interaction term for block j with year of the experiment t. For the $\mathbf{G}$ matrix, a banded main diagonal covariance structure was specified for year of the experiment t and a variance components covariance structure was specified for the experimental block j and the block-year interaction terms. A likelihood-ratio test was used to determine whether the mixed model specification was superior to a model without the covariance structure (Littell et al., 1996).

Technology Fee Policies Evaluated and Base Scenario

The four technology fee regimes evaluated were: (*a*) the 1996–1997 area planted regime, (*b*) the 1998–2003 wide-row fee, (*c*) the 1998–2003 UNRC exception fee, and (*d*) the 2004–2005 UNRC fee cap. Data for the UNRC plant density analysis are presented in table 2. The base scenario assumed an expected *PSR* of 0.64 (Larson et al., 2004) and glyphosate-resistant technology fees for the Missouri, northeast Arkansas, and west Tennessee (North Delta) region (Montgomery, 2002, 2005). The impacts of *PSR*, *SEED*, and technology fees on costs and returns of UNRC cotton were evaluated using sensitivity analysis. The span of possible expected *PSR* was derived from Larson et al. (2004). *SEED* values were provided by the Delta and Pine Land Company. The range of possible Roundup Ready technology fees for the 1998–2003 policy was represented by the middle Tennessee and northern Alabama region (Tennessee Valley, minimum technology fees) and the Virginia, North Carolina, and South Carolina region (Piedmont, maximum technology fees) (Montgomery, 2002). The Tennessee Valley represented the minimum fee and the Louisiana, Mississippi, and southeast Arkansas (South Delta) region represented the maximum fee for the 2004–2005 policy; UNRC fees were capped at $28/acre

Table 2. Data for the Ultra-Narrow-Row Cotton Plant Density Analysis

Item	Base Scenario	Sensitivity Analysis	
		Minimum	Maximum
Plant Survival Ratio	0.64	0.64	0.80
1996–1997 RR Technology Fee Policy:			
Seed Price ($/50-lb. bag)	$79.95	—	—
Technology Fee ($/acre)	$9.00	—	—
1998–2003 RR Technology Fee Policy:			
Seed Price ($/50-lb. bag)	$79.95	—	—
Seed Drop Rate (seeds/acre)	62,500	52,000	76,000
Technology Fee ($/acre)	$9.00	—	—
Seed Size (seeds/lb.)	4,750	4,200	5,300
Seed Variety Category (*SVC*) (seeds/lb.)	4,800	—	—
2004–2005 RR Technology Fee Policy:			
Seed Price ($/250,000 count bag)	$79.95	—	—
Technology Fee ($/250,000 count bag)	$102.98	$82.05	$150.60
Technology Fee Cap ($/acre)	$28.00	$28.00	$28.00

Notes: Plant survival ratios were derived from Larson et al. (2004). The price of Roundup Ready seed (DP 436 RR) came from Legé (2005). The base scenario and range of Roundup Ready technology fees were taken from Montgomery (2002, 2005). The base scenario and range of seed size (count) values were provided by the Delta and Pine Land Company.

in all regions in 2005 (Montgomery, 2005). The price of DP 436 RR, a successor variety to those used in the UNRC experiment, was used to calculate seed costs for each scenario (Legé, 2005). The analysis assumed an expected base quality lint price of $0.61/lb. (USDA/AMS, 2004).

A wide range of *PPD*s have been recommended for UNRC production (Delaney et al., 2002); therefore, the following target *PPD* criteria were used to evaluate UNRC net revenues: (*a*) a Georgia Agricultural Extension Service recommendation of 100,000 plants/acre (University of Georgia, 2002); (*b*) an "agronomic minimum" of 63,000 plants/acre (Larson et al., 2004); and (*c*) the *PPD* required to maximize profit. The Georgia Extension Service target of 100,000 plants/acre was adopted to represent a typical *PPD* recommendation for UNRC. With the agronomic minimum, the equidistant plant spacing in 10-inch rows of 63,000 plants/acre is minimally sufficient for efficient finger stripper harvest. Numerical search was conducted to determine the *PPD* that maximizes profit using equations (1)–(8). Optimal *PPD* was constrained to not go below 26,000 plants/acre, the average minimum plant density in the 1997–2000 UNRC experiment (table 1).

Results and Discussion

Yield Response Function

The likelihood-ratio test, comparing the yield models with and without the covariance structure, produced a χ^2 statistic of 65.7, which was greater than the critical value of 28.3 at $p = 0.01$ with 13 degrees of freedom (i.e., the number of covariance parameters in the ML model) (Littell et al., 1996), suggesting the model with the covariance structure was superior. The estimated coefficients for *PPD* and PPD^2 had the hypothesized

Table 3. Estimated Lint Yield and Price Difference Models for the Ultra-Narrow-Row Cotton Plant Density Analysis

Parameter/Statistic	Lint Yields ML Model (lbs./acre)	Price Differences ML Model ($/lb.)
Intercept	-13,802***	-1.3906**
	(1,178.27)	(0.2806)
PPD	2.3906***	-0.00019***
	(0.5912)	(0.000041)
PPD^2	-0.01101***	NA
	(0.003242)	
LNDD	1,896.79***	0.1793***
	(152.51)	(0.03676)
-2 Log Likelihood	982.8	-440.1
No. of Observations	86	86

Notes: Single, double, and triple asterisks (*) denote statistically different at the 10%, 5%, and 1% significance levels, respectively. Values in parentheses are standard errors. Definitions of terms: NA is not applicable, *PPD* is plant density (1,000s plants/acre), and *LNDD* is the natural log of degree days (*DD*) between 1 April and 31 October (see table 1).

signs and were significantly different from zero ($p \leq 0.01$). The estimated coefficient for *LNDD* also had the hypothesized sign and was significantly different from zero ($p \leq 0.01$) (table 3).

The yield response model predicted a maximum lint yield of 917 lbs./acre at 110,000 plants/acre when LNDD was set at its mean value. Yields before the point of maximum yield were relatively unresponsive over a wide span of *PPD*s. The UNRC lint yield response to *PPD* was consistent with results reported by earlier UNRC *PPD* studies (e.g., Gerik et al., 2000; Fernandez et al., 2002). The relatively unresponsive yields have important implications for the *PPD* decision under the alternative technology fee regimes that will be discussed later.

Price Difference Function

The likelihood-ratio test for the lint price difference model had a χ^2 value of 97.3. Thus, the null hypothesis of no covariance among the *PPD* treatments was rejected ($p = 0.01$), indicating the price difference model with the covariance structure was more appropriate for the *PPD* analysis (table 3). The coefficient for *PPD* was significantly different from zero ($p = 0.01$) and had a negative sign, revealing that higher *PPD* produced lower fiber quality and larger price discounts on average. In addition, the coefficient for *LNDD* also was significantly different from zero ($p = 0.01$) and had the expected sign.

Fiber discounts at higher *PPD* were mainly due to higher leaf grade and lower micronaire values. More leaf trash in the lint was associated with leaves observed to be remaining on plants at harvest. Juvenile leaves in plant terminals were desiccated by harvest aids but did not fall from the plants prior to harvest, contributing leaf trash proportionally to *PPD*. While *PPD* did significantly influence price differences, the overall impact was small. Results show that an increase of 10,000 plants/acre caused a $0.0019/lb. larger discount for fiber quality. For a given *PPD*, higher price discounts for fiber quality reduce the value of additional plants per unit of crop area compared with the cost of those plants. Therefore, a profit-maximizing farmer would choose a lower UNRC *PPD* when the effects of *PPD* on price discounts are considered.

1996–1997 Fee Policy

Under the 1996–1997 policy, the technology fee was the same regardless of the *PPD* chosen by the farmer (figure 1). With an expected *PSR* of 0.64, seed cost for the Georgia Extension Service *PPD* of 100,000 plants/acre was $53/acre (table 4). The total seed cost plus technology fee cost for glyphosate-resistant cotton was $62/acre. Net revenue under this scenario was $469/acre. Even though the technology fee was not tied to *PPD*, the profit-maximizing *PPD* was only 55,700 plants/acre, 44% less than the Georgia Extension Service target *PPD*. A favorable tradeoff from a small reduction in lint yield of 31 lbs./acre (3%) compared with a small increase in lint price of $0.009/lb. (1%) and the large $30/acre (56%) reduction in seed costs was responsible for the considerably smaller *PPD* under profit maximization. Nonetheless, net revenue for the profit maximum was $482/acre, only $13/acre (3%) more than the Georgia Extension Service target *PPD* and identical to the $482/acre achieved with the agronomic minimum. Although not accounted for in the analysis, the potential harvest efficiency benefits with the agronomic minimum *PPD* of 63,000 plants/acre would need to be considered by a cotton producer when choosing a target plant density. Thus, the results suggest that the agronomic minimum would likely produce at least as much net revenue as the profit maximum.

1998–2003 Wide-Row Fee Policy

The target *PPD* chosen by a farmer had a considerable impact on the cost of glyphosate-resistant technology under the 1998–2003 wide-row technology fee policy, which was based on the seed drop rate. With an expected PSR of 0.64, wide-row technology fees for the North Delta rose from $6/acre for 25,000 plants/acre to $36/acre for 150,000 plants/acre (figure 1). On average, an increase of 1,000 plants/acre in the target *PPD* raised the technology fee by about $0.23/acre. Given a typical target *PPD* for wide-row cotton of 30,000 to 60,000 plants/acre, the technology fees ranged from $7/acre to $14/acre.

The Georgia Extension Service target *PPD* produced a fee of $23/acre under the wide-row policy (table 4). With a seed cost of $53/acre, the total cost of planting glyphosate-resistant cotton using the target *PPD* of 100,000 plants/acre was $76/acre. Net revenue for the *PPD* of 100,000 plants/acre under the 1998–2003 wide-row policy was $14/acre (3%) less than under the 1996–1997 policy.

Farmers planting UNRC under the 1998–2003 wide-row policy could have reduced technology fees by $9/acre (39%) to $14/acre by adopting the agronomic minimum *PPD* of 63,000 plants/acre. The total cost of planting glyphosate-resistant cotton using the agronomic minimum was $47/acre, a drop of $29/acre (38%) from the total cost of the target PPD criterion of 100,000 plants/acre. Because of the lower seeding cost with the agronomic minimum, net revenue was $21/acre (5%) larger than with the Georgia Extension Service criterion. Given that the technology fee was tied to *PPD* under the 1998–2003 wide-row policy, the profit-maximizing target *PPD* was only 38,600 plants/acre. Net revenue with the profit maximum was $4/acre more than with the agronomic minimum. Despite an economic incentive to use a low *PPD* because of the tradeoff between yield and seed cost, finger stripper harvest efficiency considerations likely would require a *PPD* near the 63,000 plants/acre with the agronomic minimum.

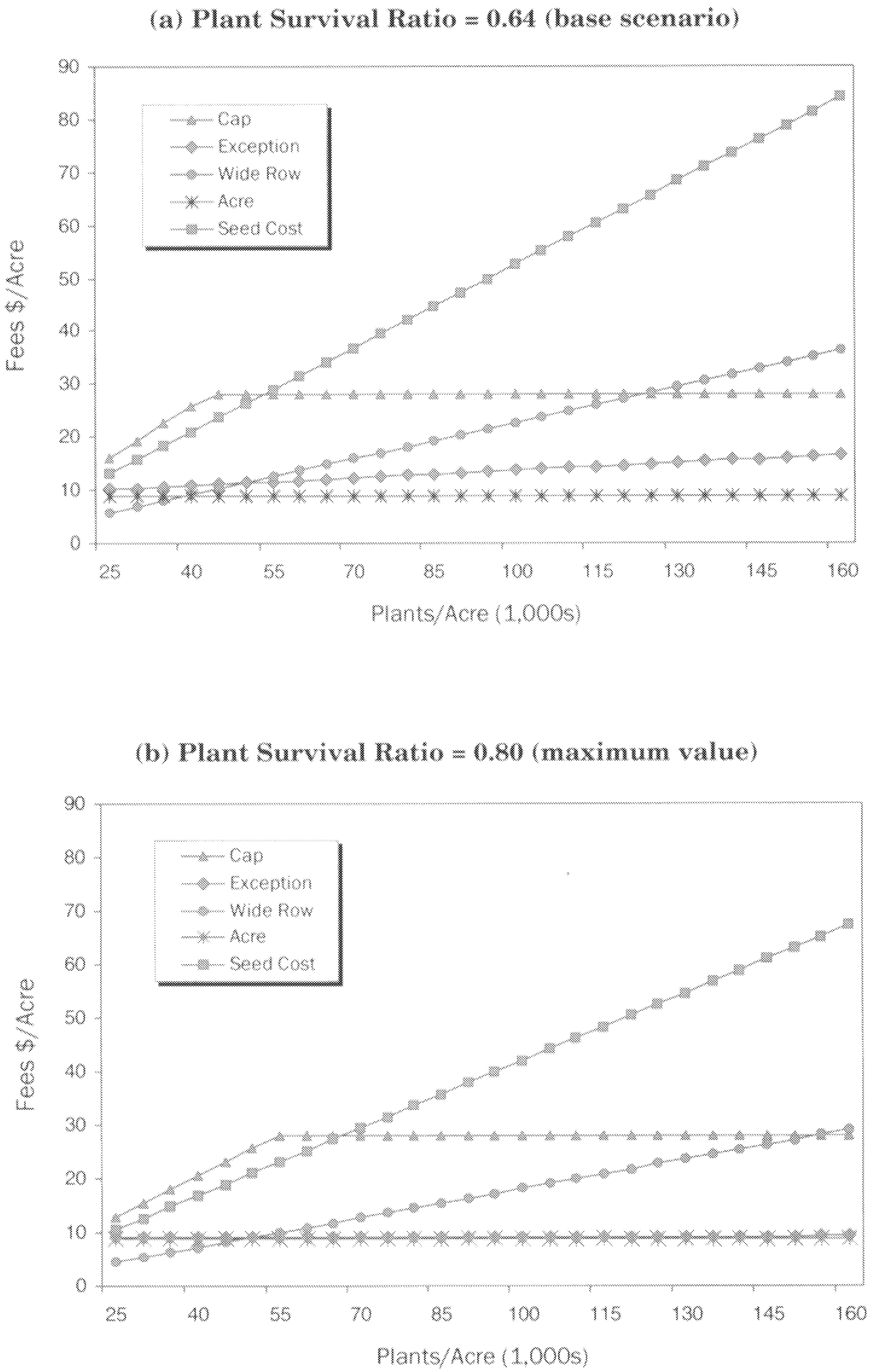

Figure 1. Alternative Roundup Ready technology policy fees for the North Delta region as influenced by plant survival ratio

Table 4. Ultra-Narrow-Row Cotton Plant Density Results for the Base Scenario

Technology Fee Policy/ Plant Density Criteria	Plant Density (1,000s/acre)	Lint Yield (lbs./acre)	Price Discount ($/lb.)	Seed Cost ($/acre)	Technology Fee ($/acre)	Net Revenue ($/acre)
1996–1997 Policy:						
Georgia Extension	100.0	916	−0.031	53	9	469
Agronomic Minimum	63.0	893	−0.024	33	9	482
Profit Maximum	55.7	885	−0.022	29	9	482
1998–2003 Wide Row:						
Georgia Extension	100.0	916	−0.031	53	23	455
Agronomic Minimum	63.0	893	−0.024	53	14	476
Profit Maximum	38.6	862	−0.019	20	9	480
1998–2003 UNRC:						
Georgia Extension	100.0	916	−0.031	53	14	464
Agronomic Minimum	63.0	893	−0.024	33	12	479
Profit Maximum	52.1	881	−0.022	27	11	479
2004–2005 Cap:						
Georgia Extension	100.0	916	−0.031	50	28	453
Agronomic Minimum	63.0	893	−0.024	31	28	464
Profit Maximum	26.0	841	−0.017	13	17	469

Notes: Cost and net revenue for each glyphosate-resistant technology fee policy and target plant density were calculated using text equations (1)–(8) for the base scenario (table 2). Lint yields for each plant density were estimated using the 1997–2000 yield response function (table 3). Lint prices for each plant density were calculated using a base quality lint price of $0.61/lb. and the 1997–2000 lint price difference function (table 3; USDA/AMS, 2004). Numerical search was used to determine the plant density for the profit maximum. Optimal plant density for the profit maximum was constrained to not go below 26,000 plants/acre, the average minimum plant density in the 1997–2000 experiment.

1998–2003 UNRC Exception Policy

Farmers who planted UNRC were able to reduce their technology fee per acre under the 1998–2003 exception policy when compared with the 1998–2003 wide-row policy (table 4). For the *PPD* of 100,000 plants/acre, the technology fee under the 1998–2003 exception policy was $14/acre, a savings of $9/acre (39%) over the fee for the 1998–2003 wide-row policy. The technology fee for the exception policy was slightly smaller for the agronomic minimum—$2/acre (14%) less than the Georgia Extension Service criterion. The majority of the cost saving from using the agronomic minimum *PPD* was the $20/acre (38%) lower seed cost than with the Georgia Extension Service criterion. Net revenue for the agronomic minimum was $15/acre (3%) more than the Georgia Extension Service criterion. The profit-maximizing *PPD* under the exception policy was 52,100 plants/acre and produced net revenue that was identical to the agronomic minimum (table 4).

As reported in table 5, seed count (size) also influenced the profit-maximizing *PPD* under the UNRC exception. The profit-maximizing *PPD* under the UNRC exception varied from 44,700 plants/acre for the large seed size scenario (4,200 seeds/lb.) to 58,000 plants/acre for the small seed size scenario (5,300 seeds/lb.). The difference in net revenue between the minimum and maximum seed count values ranged from $9/acre to $17/acre depending on the plant density criteria used to determine the seeding rate.

Table 5. Ultra-Narrow-Row Cotton Planting Decision Sensitivity Analysis Results for Seed Size (count)

	Large Seed Size (4,200 seeds/lb.)			Small Seed Size (5,300 seeds/lb.)		
Technology Fee Policy/ Plant Density Criteria	Plant Density (1,000s/acre)	Seed & Tech Fee Cost ($/acre)	Net Revenue ($/acre)	Plant Density (1,000s/acre)	Seed & Tech Fee Cost ($/acre)	Net Revenue ($/acre)
1998–2003 Wide Row:						
Georgia Extension	100.0	85	446	100.0	68	463
Agronomic Minimum	63.0	54	470	63.0	43	481
Profit Maximum	31.3	27	477	44.5	30	484
1998–2003 UNRC:						
Georgia Extension	100.0	76	455	100.0	59	472
Agronomic Minimum	63.0	51	472	63.0	40	484
Profit Maximum	44.7	39	475	58.0	38	484

Notes: Cost and net revenue for each glyphosate-resistant technology fee policy and target plant density were calculated using the minimum and maximum values for seed size while holding other values at base levels (table 2). For the other assumptions and data used to calculate costs and net revenues, refer to the text and to the footnote in table 4.

Hence, the results illustrate farmers' economic incentive under the 1998–2003 policy to purchase high seed count varieties.

Under the 1998–2003 UNRC exception policy, the revenue to the glyphosate-resistant cotton license holder, Monsanto, was $2/acre (22%) to $5/acre (56%) higher than under the 1996–1997 fixed-fee policy (table 4). The primary factor was the difference in the assumed *PSR* (0.64) for calculating the seeding rate and the *PSR* assumed by Monsanto (0.80) for calculating the technology fee. If the assumed *PSR* were 0.80, the technology fee under the 1998–2003 UNRC exception policy would be the same ($9/acre) as under the 1996–1997 per acre fee policy regardless of the target *PPD* chosen (figure 1).

2004–2005 Fee Cap Policy

Technology fees under the 2004–2005 cap policy were considerably larger for farmers growing UNRC. With generic glyphosate gaining market share on Roundup herbicide, Monsanto raised the technology fees with the 2004–2005 policy. Assuming a *PSR* of 0.64 and technology fees for the North Delta, a farmer who selected a target *PPD* of 45,000 plants/acre or more paid a flat fee of $28/acre while a farmer using a lower *PPD* paid a price of $0.0005 per seed (figure 1). For both the Georgia Extension Service and agronomic minimum criteria, technology fees were $14/acre (100%) and $16/acre (133%) higher, respectively, than under the 1998–2003 UNRC exception policy (table 4).

The practical effect of the 2004–2005 cap policy was to again fix the per acre amount paid by UNRC growers for glyphosate-resistant technology, but at a much higher level than under the 1996–1997 policy. Farmers likely would be unable to use a *PPD* of less than 63,000 plants/acre because of finger stripper harvest efficiency considerations. The cap of $28/acre also was binding on the UNRC target *PPD* decision for the higher priced South Delta and the lower priced Tennessee Valley regions (table 6). Under the 2004–2005 cap policy, UNRC farmers may have been able to save on seed cost, but not the technology fee, by reducing the target *PPD* to the agronomic minimum level.

Table 6. Ultra-Narrow-Row Cotton Planting Decision Sensitivity Analysis Results for Technology Fee

	Low Technology Fee Region			High Technology Fee Region		
Technology Fee Policy/ Plant Density Criteria	Plant Density (1,000s/acre)	Seed & Tech Fee Cost ($/acre)	Net Revenue ($/acre)	Plant Density (1,000s/acre)	Seed & Tech Fee Cost ($/acre)	Net Revenue ($/acre)
1998–2003 Wide Row:						
Georgia Extension	100.0	71	459	100.0	80	451
Agronomic Minimum	63.0	45	479	63.0	50	473
Profit Maximum	41.6	30	482	35.2	28	479
1988–2003 UNRC:						
Georgia Extension	100.0	65	465	100.0	67	463
Agronomic Minimum	63.0	45	479	63.0	46	478
Profit Maximum	52.7	39	480	51.4	39	479
2004–2005 Cap:						
Georgia Extension	100.0	78	453	100.0	78	453
Agronomic Minimum	63.0	59	464	63.0	59	464
Profit Maximum	26.0	26	472	26.0	37	461

Notes: Cost and net revenue for each glyphosate-resistant technology fee policy and target plant density were calculated using the low and high dollar values for technology fee while holding other values at base levels (table 2). For the other assumptions and data used to calculate costs and net revenues, refer to the text and to the footnote in table 4.

Conclusions

The availability of herbicide-resistant cotton has been an important factor influencing the revival of ultra-narrow-row cotton (UNRC) as an alternative cotton production system. UNRC typically is grown in row spacing ranging from 7.5 to 15 inches compared with the 38- to 40-inch row spacing in conventional cotton production. Farmers are concerned about the high costs of herbicide-resistant technology fees associated with the large plant densities recommended for UNRC production. This study evaluated the effects on UNRC net revenues of three different glyphosate-resistant (Roundup Ready) cotton technology fee policies used since 1996 by Monsanto, the technology license holder.

Results indicate that the yield gains with increased plant density for UNRC were small. As a consequence, farmers may have an incentive to use a lower plant density to reduce seed and technology costs by more than the loss of yield with the lower plant density. How far plant density was reduced depended on whether or not the glyphosate-resistant technology fee was tied to the seeding rate. Under the 1996–1997 policy, the technology fee was the same regardless of the target plant density used to determine the seeding rate at planting. Therefore, the choice of UNRC plant density was not influenced by the herbicide-resistant technology fee. Nevertheless, the profit-maximizing plant density was well below the 80,000 to 200,000 plants/acre typically recommended for UNRC. The glyphosate-resistant technology fee was higher under the 1998–2003 UNRC exception policy. Differences in the plant survival ratio assumed by Monsanto and the plant survival ratio assumed by some farmers in determining a target plant density were the primary factors influencing the higher technology fee cost. Because technology cost was tied to the seeding rate, the profit-maximizing plant density was lower than under the 1996–1997 policy. UNRC technology fees were the largest under the 2004–2005 cap policy. Farmers growing UNRC may be able to save on seed cost, but not the technology fee, by reducing the target plant density under the 2004–2005 cap policy. The maximum fee of $28/acre under the cap policy was in effect for the lowest feasible UNRC plant density of 63,000 plants/acre.

Results show that the 1996–97 technology fee policy was completely decoupled from choice of plant density. While not completely separated from the plant density decision, the 2004–05 fee cap policy has a similar effect because the fee cap was binding for the range of UNRC plant densities that might be used by farmers. The average glyphosate-resistant technology fee for ultra-narrow-row cotton has risen from $9/acre in 1996–97 to $28/acre in 2003–04. The results of this study appear to be consistent with anecdotal evidence indicating that farmers have been reducing their target plant density in response to rising transgenic variety costs. The two main effects of the most recent technology fee policy on farmers growing UNRC are to provide an incentive to switch from UNRC to wide-row picker cotton and to lower their seeding rate.

Finally, there may be several reasons why Monsanto has modified its technology fee policies over time, other than accommodating UNRC production. Pricing the technology fee on a seed package rather than on an area planted basis may have made it easier for Monsanto to police payment of technology fees. In addition, package pricing may make it easier to differentiate prices in separate growing regions based on factors such as the profitability of cotton in that region or the value of the technology in weed and insect control for that region. Package pricing also may have facilitated the tying of the technology fee to the sale of Roundup brand herbicide through a technology fee rebate program.

[*Received October 2005; final revision received March 2007.*]

References

Bednarz, C. W., W. D. Shurley, W. S. Anthony, and R. L. Nichols. "Yield, Quality, and Profitability of Cotton Produced at Varying Plant Densities." *Agronomy J.* 97(2005):235–240.

Bridge, R. R., W. R. Meredith, and J. F. Chism. "Influence of Planting Method and Plant Population on Cotton (*Gossypium Hirsutum* L.)." *Agronomy J.* 65(1973):104–109.

Brown, A. B., T. L. Cole, and J. Alphin. "Ultra Narrow Row Cotton: Economic Evaluation of 1996 BASF Field Plots." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, pp. 88–91. Proceedings of a conference held in San Diego, CA, 5–9 January 1998. Memphis, TN: National Cotton Council of America, 1998.

Brown, A. B., and J. Reeves. "UNRC: Where Does It Fit?" Cotton, Inc., Cary, NC, 2002.

Brown, J. E., D. E. Ethridge, D. Hudson, and C. Engels. "An Automated Econometric Approach for Estimating and Reporting Daily Cotton Market Prices." *J. Agr. and Appl. Econ.* 27(1995):409–422.

Delaney, D. P., C. D. Monks, D. W. Reeves, and R. M. Durbin. "Plant Populations and Planting Dates for UNR Cotton." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, unpaginated CD-ROM. Proceedings of a conference held in Atlanta, GA, 7–12 January 2002. Memphis, TN: National Cotton Council of America, 2002.

Delta and Pine Land Company. Cotton variety product information, Delta and Pine Land Co., Piedmont, AL. Online. Available at http://www.deltaandpine.com/cotton_products_rr.asp. [Accessed January 2006.]

Doane Agricultural Services, Inc. St. Louis, MO. Unpublished data received 6 July 2005.

Ethridge, D., and D. Hudson. "Cotton Market Price Information: How It Affects the Industry." *J. Cotton Sci.* 2(1998):68–76.

Fernandez, C. J., C. W. Livingston, B. Prince, and M. Kocurek. "Yield Response of Cotton to Narrow-Row Planting and Three Plant Populations in the Coastal Bend of Texas." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, pp. 464–467. Proceedings of a conference held in Atlanta, GA, 8–12 January 2002. Memphis, TN: National Cotton Council of America, 2002.

Fowler, J. L., and L. L. Ray. "Response of Two Cotton Genotypes to Five Equidistant Spacing Patterns." *Agronomy J.* 69(1977):733–738.

Gerik, T. J., R. G. Lemon, A. Abrameit, T. D. Valco, E. M. Steglich, J. T. Cothren, and J. Prigg. "Using Ultra-Narrow Rows to Increase Cotton Production." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, p. 653. Proceedings of a conference held in San Diego, CA, 4–8 January 2000. Memphis TN: National Cotton Council of America, 2000.

Gwathmey, C. O., and R. M. Hayes. "Ultra-Narrow-Row Systems of No-Till Cotton Production: Research Progress in Tennessee." In *Proceedings: 19th Annual Southern Conservation Tillage Conference for Sustainable Agriculture*, pp. 61–67. Proceedings of a conference held in Jackson, TN, 23–25 July 1996. Tennessee Agr. Exp. Sta. Special Pub. No. 96-07, Knoxville, 1996.

Hawkins, B. S., and H. A. Peacock. "Yield Response of Upland Cotton (*Gossypium Hirsutum* L.) to Several Spacing Arrangements." *Agronomy J.* 62(1970):578–580.

Holliday, R. "Plant Population and Crop Yield: Parts I and II." *Field Crop Abstracts* 13(1960):159–167, 247–254.

Jenkins, P. Administrative Assistant, Delta and Pine Land Company, Piedmont, AL. Personal communication, 7 October 2002.

Johnson, E. M. "Roundup Ready™ Gene in Cotton." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, p. 51. Proceedings of a conference held in Nashville, TN, 9–12 January 1996. Memphis TN: National Cotton Council of America, 1996.

Jost, P. H., and J. T. Cothren. "Growth and Yield Comparisons of Cotton Planted in Conventional and Ultra-Narrow-Row Spacings." *Crop Sci.* 40(2000):430–435.

Kerby, T. A., S. J. Hake, K. D. Hake, L. M. Carter, and R. H. Garber. "Seed Quality and Planting Environment." In *Cotton Production Manual*, eds., S. J. Hake, T. A. Kerby, and K. D. Hake, Chapter 16. Pub. No. 3352, Dept. of Agr. and Nat. Resour., University of California, Oakland, 1996.

Larson, J. A., B. C. English, C. O. Gwathmey, and R. M. Hayes. "Economic Feasibility Analysis of Ultra-Narrow-Row Cotton in Tennessee." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, pp. 315–318. Proceedings of a conference held in New Orleans, LA, 7–10 January 1997. Memphis TN: National Cotton Council of America, 1997.

Larson, J. A., C. O. Gwathmey, R. K. Roberts, and R. M. Hayes. "Effects of Plant Population Density on Net Revenues from Ultra-Narrow-Row Cotton." *J. Cotton Sci.* 8(2004):69–82.

Legé, K. Regional Technical Services Director, Delta and Pine Land Company, Piedmont, AL. Personal communication, 24 June 2005.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. "SAS® System for Mixed Models." Cary, NC: SAS Institute, Inc., 1996.

Mauney, J. R. "Carbohydrate Production and Distribution in Cotton Canopies." In *Cotton Physiology*, eds., J. R. Mauney and J. M. Stewart, pp. 183–191. Memphis, TN: The Cotton Foundation, 1986.

Mjelde, J. W., O. Capps, Jr., and R. C. Griffin. "Examination of Alternative Heteroscedastic Error Structures Using Experiment Data." *J. Agr. and Appl. Econ.* 27(1995):197–211.

Monsanto Company. "Monsanto Cotton Technologies: 1998 Pricing Platform and Reporting Process Information." Monsanto Company, St. Louis, MO, 1998.

———. "Monsanto Announces Simpler Pricing for Biotech Traits in 2002." Monsanto Company Press Release, St. Louis, MO, 14 June 2001. Online. Available at http://www.biotech-infor.net/simpler_pricing.html. [Accessed June 2005.]

———. "Roundup Ready® Flex Cotton." Technical Bulletin, Monsanto Company, St. Louis, MO, 2005.

Montgomery, R. Agronomic Research Manager and Market Development Specialist, Monsanto Co., Union City, TN. Personal communication, 10 October 2002.

———. Personal communication, 3 June 2005.

Oosterhuis, D. M., F. M. Bourland, N. P. Tugwell, and M. J. Cochran. "Terminology and Concepts Related to the COTMAN Crop Monitoring System." Special Rep. No. 174, Arkansas Agr. Exp. Sta., University of Arkansas, Fayetteville, 1996.

Parvin, D. W., F. T. Cooke, and S. W. Martin. "Alternative Cotton Production Systems." Res. Rep. No. 2000-010, Dept. of Agr. Econ., Mississippi State University, Mississippi State, MS, 2002.

Robinson, E. "Company Changes to Seed-Count Bag." *Delta Farm Press* (23 May 2003a). Online. Available at http://deltafarmpress.com/mag/farming_company_changes_seedcount/. [Accessed July 2005.]

———. "Cost Per Acre Issues in NE Louisiana: D&PL Goes to Fixed-Count Seed Bags." *Delta Farm Press* (25 July 2003b). Online. Available at http://deltafarmpress.com/mag/farming_costper_acre_issues. [Accessed July 2005.]

———. "Deere's Spindle Cotton Picking Head." *Delta Farm Press* (16 January 2004). Online. Available at http://deltafarmpress.com/mag/farming_deeres_spindle_cotton/. [Accessed July 2005.]

Saxton, A. Professor of Quantitative Genetics and Experimental Statistics, The University of Tennessee, Knoxville. Personal communication, 29 October 2002.

Shelby, P. P. "Cotton Production in Tennessee." In *Cotton Production in Tennessee*, pp. 3–7. Pub. No. PB1514, Agr. Ext. Ser., University of Tennessee, Knoxville, 1996.

University of Georgia. "Ultra Narrow Row Cotton in Georgia." In *2002 Georgia Cotton Production Guide*, pp. 58–61. Coop. Ext. Ser., University of Georgia, Athens. Online. Available at http://www.griffin.peachnet.edu/ caes/cotton/2002Guide.pdf. [Accessed May 2004.]

U.S. Department of Agriculture, Agricultural Marketing Service. *Cotton Price Statistics* 85,13(2004): 2–8. USDA/AMS, Cotton Division, Market News Branch, Memphis, TN.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. "Climatological data, Tennessee," 1975–2000. National Climatic Data Center, Asheville, NC.

Valco, T. D., W. S. Anthony, and D. D. McAlister, III. "Ultra Narrow Row Cotton Ginning and Textile Performance Results." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, pp. 355–357. Proceedings of a conference held in Anaheim, CA, 9–13 January 2001. Memphis, TN: National Cotton Council of America, 2001.

Virginia Cooperative Extension Service. "Seed Drop Rates and Technology Fees." Virginia Polytechnic Institute and State University, Blacksburg, VA, 1998. Online. Available at http://filebox.vt.edu/cals/cses/chagedor/droprate.html. [Accessed May 2004.]

Ward, R. G., C. D. Berry, B. Coulumbe, D. M. Panter, and J. Stanton. "New Cottons for 1995 from Stoneville: BXN 58 and ST 474." In *Proceedings: Beltwide Cotton Conferences*, eds., P. Dugger and D. Richter, p. 39. Proceedings of a conference held in Anaheim, CA, 4–7 January 1995. Memphis, TN: National Cotton Council of America, 1995.