Effects of Herbicide-Resistant Technology Fees on the Plant Population Decision for Cotton Production

James A. Larson, Associate Professor
Department of Agricultural Economics
The University of Tennessee
Knoxville, Tennessee 37996-4518
Phone: (865) 974-7231
Fax: (865) 974-4829
E-mail: jlarson2@utk.edu

Roland K. Roberts, Professor
Department of Agricultural Economics
The University of Tennessee
Knoxville, Tennessee 37996-4518
Phone: (865) 974-7231
Fax: (865) 974-4829
E-mail: rrobert3@utk.edu

C. Owen Gwathmey, Associate Professor
Department of Plant Sciences
The University of Tennessee
West Tennessee Research and Education Center
Jackson, TN 38301
Phone: (731) 424-1643
Fax: (731) 425-4760
E-mail: cogwathmey@utk.edu

Selected paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Long Beach, CA, July 23-26, 2006

Abstract: This study evaluated effects on cotton net revenues of four herbicide-resistant technology policies used since 1996 by Monsanto. Results indicate that farmers may have an incentive to switch from narrow-row to wide-row cotton and to use a lower plant density when the technology fee is tied to the seeding rate.

Effects of Herbicide-Resistant Technology Fees on the Plant Population Decision for Cotton Production

Introduction

Herbicide-resistant technology has been widely adopted in United States cotton production. About 80% of U.S. cotton acreage in 2004 was planted in transgenic varieties (Doane Agricultural Services). Monsanto, which licenses glyphosate (herbicide)-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 cotton production (Doane Agricultural Services). 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. After the four leaf stage, Roundup can still be applied on row planted cotton but must be post-directed between rows with a hooded sprayer so the herbicide does not contact the cotton plants and cause plant injury. Roundup Ready Flex, a new technology introduced this year by Monsanto, allows for later over-the-top application of Roundup herbicide through the early bloom period in cotton (Monsanto Company 2005).

Seeding rates for planting used by cotton farmers have fallen 26% since the introduction of transgenic technology—dropping from 13.9 lb/acre in 1997 to 10.3 lb/acre in 2003 (USDA-ERS). The use of lower seeding rates by cotton farmers may be in response to changes in variety pricing with transgenic characteristics. Since 1996, the year that Roundup Ready cotton was introduced, Monsanto has billed cotton farmers for a technology fee that is in addition to the seed cost charged by the seed company (Johnson). This practice contrasts with corn and soybeans where in 2002 Monsanto started charging a royalty to seed companies rather than charging a separate technology fee to farmers (Monsanto Company, 2001). The way Monsanto charges technology fees to farmers growing cotton has changed several times since the introduction of Roundup Ready cotton.

Besides the potential influence on farmer seeding rates, the changes in technology fee policies may have influenced farmer adoption of other production technologies such as ultra-narrow-row cotton. 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 (Parvin, Cooke, and Martin). Reported advantages of UNRC include lower machinery and labor costs and higher yields (Parvin, Cooke, and Martin; Jost and Cothren). UNRC has been advocated as a way to bring marginal land into cotton production while minimizing equipment costs (Brown and Reeves). Reduced soil erosion and runoff are other potential advantages of the UNRC system (Gwathmey and Hayes). UNRC has become more feasible with the availability herbicide-resistant cotton which has facilitated weed control in solid planted cotton. Notwithstanding the positive effects of herbicide-resistant cotton on the viability of UNRC through better early-season weed control, cotton farmers are concerned about the profitability of UNRC because of high planting costs associated with high seeding rates and transgenic varieties. The objective of this study was to evaluate the effects on UNRC cotton net revenues of four different glyphosate-resistant technology fee regimes used since 1996 by Monsanto, the technology license holder.

Analytical Framework

The alternative fee regimes described below are representative of the methods used by Monsanto since 1996 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, the target UNRC plant population density (*PPD*) for a profit-maximizing farmer could be characterized as:

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

where *NR* is net revenue ($/acre), *BLP* is base quality lint price ($/lb), *LPD* is the expected lint price difference for fiber quality ($/lb), *LY* is the expected lint yield (lb/acre), and *SC* is seed cost ($/acre). Functional notation in Equation (1) indicates that *NR*, *LPD*, *LY*, and *SC* are functions of *PPD* (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; Holliday). In addition, research has shown that higher *PPDs* in UNRC may result in larger price discounts for fiber quality (Valco, Anthony, and McAlister; Larson et al., 2004). Thus, the price difference term, *LPD*, 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*. Thus, the seed cost, *SC*, based on a farmer's expectation of plant survival can be modeled using:

(2) $$SC(PPD) = (PPD \div PSR \div SEED) \times SPLB,$$

where *PSR* is 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) and a $9/acre technology fee (*TFA*) that was charged by Monsanto (Montgomery, 2002). Farmers provided documentation of area planted for the purpose of billing technology fees. A key assumption for this analysis is the benefits of glyphosate-resistant cotton in weed control are the same regardless of the *PPD* chosen. As indicated 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:

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

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 Agricultural Extension Service). 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 supposed to represent common planting practices for different production areas across the U.S. Cotton Belt (Monsanto Company, 1998). *SVC* defined the seed size category (seeds/lb) for a variety that was assumed by Monsanto for the purpose of calculating the technology fee.

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

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

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

The revised technology fee policy in 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 a *SVC* of 4,200 seeds/lb and a 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 that was 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). Thus, there was an incentive for farmers 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*. Farmers were required to grow at least 50 acres of UNRC to be eligible for the exception. 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 (Monsanto Company, 1998). 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:

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

Under the UNRC exception policy, the minimum fee paid by farmers was TFA ($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 4-year UNRC experiment. Soil temperature and moisture conditions after planting influence the *PSR* (Kerby et al.). 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, 2003b). 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 that farmers sought high seed count varieties to reduce seed and technology costs (Robinson, 2003b).

Monsanto's 2004-05 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; Robinson, 2003b). 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).

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 through 2003 policy, technology fees vary by production region based on typical production practices, demand for different varieties, and other competitive factors (Montgomery, 2005). 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:

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

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

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

where *TFS* is the 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 impact of the alternative cotton seed pricing scenarios described previously on UNRC net revenues was evaluated using Equations (1) through (8). Lint yield (*LY*(*PPD*)) was modeled using data from a 1997-2000 UNRC plant population density experiment at the Milan Experiment Station, Milan, TN (Larson et al., 2004). A Roundup Ready variety was planted in 10-inch rows in each year. After plant emergence, plots were hand thinned to four or five target plant densities in each year. 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.

University of Tennessee recommended pest-control practices for no-tillage cotton were followed during each growing season (Shelby, 1996). Roundup herbicide was broadcast over the crop prior to the 4-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. The cotton was hand classed and subjected to high volume instrument (HVI) testing at the USDA Agricultural Marketing Service Cotton Classing Office in Memphis, TN.

Lint Yield Response Estimation

As indicated previously, the theoretical relationship between *PPD* and lint yield is approximately parabolic (Holliday; Bridge, Meredith, and Chism). Studies have shown maximum yields to occur for *PPDs* ranging from about 20,000 to 108,000 plants/acre (Bednarz et al.; Bridge, Meredith, and Chism; Fernandez et al., Fowler and Ray; Gerik et al.; Hawkins and Peacock; 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 *PPDs* had an adverse impact on lint yields. The following quadratic yield response function was estimated from the UNRC experiment data:

(9) $$LY(PPD) = \beta_1 + \beta_2 PPD_{ijt} + \beta_3 PPD_{ijt}^2 + \beta_4 D97 + \beta_5 D97 \times PPD_{ijt} + \beta_6 D97 \times PPD_{ijt}^2 ,$$

where *PPD* was plants/acre (1,000s) for treatment i in the j^{th} experimental block of year t; *D97* was a binary variable equal to 1 for cotton produced in the 1997 growing season and 0 otherwise; and β_k were the estimated parameters. The binary intercept (*D97*) and slope shifting ($D97 \times PPD_{ijt}$ and $D97 \times PPD_{ijt}^2$) variables were specified to account for the potential of a different yield response in 1997. The 1997 growing season was an El Niño year with very cool growing conditions relative to 1998 through 2000 and historical averages. Total growing degree days (base 60°F) in 1997 was 1,866 (1 Apr through 31 Oct) compared with an average of 2,295 for 1998 through 2000 and a longer term average of 2,289 for 1975 through 2000 (U.S. Department of Commerce, NOAA). Only one other year between 1975 and 2000 had growing degree days as low as observed in 1997. If yield response was different for 1997 than for 1998-2000, the 1998-2000 model would more closely represent typical growing conditions than a model estimated with data for 1997 through 2000.

Lint Price Difference Estimation

The lint price difference function (*LPD*(*PPD*)) estimated using fiber quality measured in the UNRC experiment was:

(10) $$LPD(PPD) = \alpha_1 + \alpha_2 PPD_{ijt} + \alpha_3 D97 + \alpha_4 \times D97 \times PPD_{ijt},$$

where α_l are the estimated parameters. We chose the linear form after a plot of the lint price difference data showed a generally downward sloping relationship in the range of plant density in the experiment. As with the yield equation, the binary intercept and slope variables were specified to account for El Niño weather effects in 1997. North Delta (Missouri, Northeast Arkansas, and West Tennessee) spot quotations for the 2003-04 marketing year (1 Aug.-31 Jul.) were used to estimate lint price differences for Equation (10) (U.S. Department of Agriculture, Agricultural Marketing Service). The average base quality price 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 and Brown et al.

The procedures 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 heteroscedasticity into the data used to estimate Equations (9) and (10). Mjelde, Capps, and Griffin using response functions estimated from experiment plot data, found differences of up to one-third the amount of profit maximizing levels of inputs after corrections were made for heteroscedasticity. To account for the potential heterogeneous variances and correlations among the plots and growing seasons in the experiment, the mixed model procedure in SAS (Littell et al.) was used to estimate Equations (9) and (10).

Technology Fee Policies Evaluated and Base Scenario

The four technology fee regimes evaluated were: (1) the 1996-97 area planted regime, (2) the 1998-2003 wide-row fee, (3) the 1998-2003 UNRC exception fee, and (4) the 2004-05 UNRC fee cap. 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; Table 1). The impact of *PSR*, *SEED*, and technology fees on costs and returns of UNRC cotton were evaluated using sensitivity analysis (Table 1). The span of possible expected *PSR* was from Larson et al. (2004). SEED values were from 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; Table 1). 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 (Montgomery, 2005; Table 1). UNRC fees were capped at $28/acre in all regions in 2005 (Montgomery, 2005; Table 1). 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, Table 1). An expected base quality lint price of $0.61/lb was used in the analysis (U.S. Department of Agriculture, Agricultural Marketing Service).

A wide range of *PPD* have been recommended for UNRC production (Delaney et al.); therefore, the following target *PPD* criteria were used to evaluate UNRC net revenues: (1) a

Georgia Agricultural Extension Service recommendation of 100,000 plants/acre (University of Georgia), (2) an "agronomic minimum" of 63,000 plants/acre (Larson et al., 2004), and (3) the *PPD* required to maximize profit. The Georgia Extension Service target of 100,000 plants/acre was used to represent a typical *PPD* recommendation for UNRC. With the agronomic minimum, the equidistant plant spacing in 10-in rows of 63,000 plants/acre is minimally sufficient for efficient finger stripper harvest. Numerical search was used to determine the *PPD* that maximizes profit using equations (1) through (8). Optimal *PPD* was constrained to not go below 26,000 plants/acre, the average minimum plant density in the 1997-2000 UNRC experiment.

Results and Discussion

Yield Response Function

The likelihood ratio test, comparing the OLS and ML yield models, produced a chi-square statistic of 122.3, 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.), suggesting that ML was a superior estimation method than OLS. The estimated ML coefficients for *PPD* and PPD^2 had the hypothesized signs and were significantly different from zero ($p \leq 0.01$) (Table 2).

Lint yields for 1997 were different from lint yields for 1998-2000 as evidenced by the coefficients for *D97* and *D97*×*PPD* being significantly different from zero. Results indicate that 1997, as an extreme weather year, had a different yield response than the more typical weather years of 1998-2000. Consequently, the yield response model for 1998-2000 estimated with ML was used in the analysis.

The yield response model predicted a maximum lint yield of 932 lb/acre at 107,500 plants/acre. Yields before the point of maximum yield were relatively unresponsive over a wide span of *PPDs*. The relative lack of UNRC lint yield response to *PPD* was consistent with results from other UNRC *PPD* studies (e.g., Gerik et al.; Fernandez et al.). The flat yield response has 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 chi-square value of 77.6. Thus, the null hypothesis of no covariance among the *PPD* treatments was rejected ($p = 0.01$) indicating that the ML price difference model was more appropriate for the *PPD* analysis (Table 2). The coefficient for *PPD* was significantly different from zero ($p = 0.01$) and had a negative sign, indicating that higher *PPD* produced lower fiber quality and larger price discounts on average. 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*.

The estimated coefficient for the binary variable, *D97*, for lint price differences in 1997 was significantly different from zero ($p = 0.01$) and had a negative sign. The estimated binary slope coefficient, *D97*×*PPD*, was not significantly different from zero. Lint price differences for fiber quality for the 1997 data were significantly larger than those observed with the 1998 through 2000 data. All of the plots uniformly received extraneous matter discounts in 1997. The ML model for 1998-2000 was used in the analysis for consistency with the yield response model and because price discounts for 1997 were much larger than for the 1998-2000 period.

While *PPD* did significantly influence price differences, the overall impact was small. Results indicate that an increase of 10,000 plants/acre caused a $0.002/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 1996-97 policy, the fee was the same regardless of the *PPD* chosen by the farmer (Figure 2). With an expected *PSR* of 0.64, seed cost for the Georgia Extension Service *PPD* of 100,000 plants/acre was $53/acre (Table 3). The total seed cost plus technology fee cost for glyphosate-resistant cotton was $62/acre. Net revenue under this scenario was $481/acre. Even though the technology fee was not tied to *PPD*, the profit maximizing *PPD* was only 43,600 plants/acre, 55% less than the Georgia Extension Service target *PPD*. A favorable tradeoff between a small reduction in lint yield of 37 lb/acre (4%) and a small increase in the lint price of $0.011/lb (2%) compared with the $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 $499/acre, $18/acre (4%) more than the Georgia Extension Service target *PPD* and almost identical to the $497/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/acres could potentially offset the small $2/acre increase in net revenue with the smaller profit maximizing *PPD* of 44,000 plants/acres.

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. 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 3). With a seed cost of \$53/acre, the total cost of planting glyphosate-resistant cotton using the target *PPD* of 100,000 plants/acres was \$76/acre (Table 3). 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 1996-97 policy (Table 3).

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* of 100,000 plants/acre criterion. Because of the lower seeding cost with the agronomic minimum, net revenue was \$24/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 26,000 plants/acre (the average minimum *PPD* in the UNRC experiment). Net revenue with the profit maximum was \$9/acre more than with the agronomic minimum. Even though there was an economic incentive to use a very 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.

1998-2003 UNRC Exception Policy

Farmers who planted UNRC were able to reduce technology fee per acre under the 1998-2003 exception policy when compared with the 1998-2003 wide-row policy (Table 3). 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%) from 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 $18/acre (4%) more than the Georgia Extension Service criterion. The profit maximizing *PPD* under the exception policy was 39,500 plants/acre and produced net revenue that was similar to the agronomic minimum (Table 3). Seed count (size) had a substantial impact on the profit maximizing *PPD* under the UNRC exception. The profit maximizing *PPD* varied from 31,300 to 46,700 plants/acre (not shown). Results illustrate the economic incentive that farmers had 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 1996-97 fixed fee policy (Table 3). The primary factor was the difference in the *PSR* assumed (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.

2004-2005 Fee Cap Policy

Technology fees under the 2004-05 cap policy were considerable larger for farmers growing UNRC. With generic glyphosate gaining market share on Roundup herbicide, Monsanto raised the technology fees with the 2004-05 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 (not shown). 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 3). Net revenues for the two *PPD* criteria were respectively reduced by the same dollar amounts, $14/acre (3%) and $16/acre (3%).

The practical effect of the 2004-05 cap policy was to again fix the amount that UNRC growers paid per acre for glyphosate-resistant technology, but at a much higher level than under the 1996-97 policy. Farmers likely would not be able 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 (not shown). Under the 2004-05 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.

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 four 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 are very small. As a consequence, farmers have an incentive to use a much 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 1996-97 policy, the technology fee was the same regardless of the target plant density used to determine the seeding rate at planting. As a consequence, 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 1996-97 policy. UNRC technology fees were the largest under the 2004-05 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 2004-05 cap policy. The maximum fee of $28/acre under the cap policy was in effect for the lowest feasible plant density for UNRC 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 seem 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 besides 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 may also have facilitated the tying of the technology fee to the sale of Roundup brand herbicide through a technology fee rebate program.

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 Journal* 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 Journal* 65(1973): 104–109.

Brown, A.B., and J. Reeves. "UNRC: Where Does It Fit." Cotton Incorporated, Cary, N.C. 2002.

Brown, J.E., D.E. Ethridge, D. Hudson, and C.Engels. "An Automated Econometric Approach for Estimating and Reporting Daily Cotton Market Prices." *Journal of Agricultural and Applied Economics* 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* P. Dugger and D. Richter (eds.), Proceedings Beltwide Cotton Conferences, 7–12 Jan. 2002, Atlanta GA. (CD-ROM). Memphis, TN: National Cotton Council of America, 2002.

Delta and Pine Land Company. 2005. Cotton Variety Product Information. Online. Available at: http://www.deltaandpine.com/cotton_products_rr.asp.

Doane Agricultural Services, Inc. Unpublished data received 6 Jul. 2005.

Ethridge, D., and D. Hudson. "Cotton Market Price Information: How It Affects the Industry." *Journal of Cotton Science* 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 Costal Bend of Texas." pp. 464–67 *In* P. Dugger and D. Richter (eds.), Proceedings Beltwide Cotton Conferences, 8–12 Jan. 2002, Atlanta, GA. 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 Journal* 69(1977): 733–738.

Gerik, T.J., R.G. Lemon, Abrameit, and T.D. Valco. "Using Ultra-Narrow Rows to Increase Cotton Production." p. 653. *In* P. Dugger and D. Richter (eds.), Proceedings Beltwide Cotton Conferences, 4–8 Jan. 2000, San Diego, CA. 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." p. 61–67. *In* Proc. 19th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, 23–25 Jul. 1996, Jackson, TN. Tennessee Agric. Exp. Sta. Sp. Publ. 96-07, Knoxville, TN, 1996.

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

Holliday, R. "Plant Population and Crop Yield: Parts I and II." *Field Crop Abstracts*, 13(1960):159–67 and 247–54.

Jenkins, P. Personal communication, 7 Oct. 2002. Delta and Pine Land Company, Piedmont, AL, 2002.

Johnson, E.M. "Roundup Ready™ Gene in Cotton." p. 51. *In* P. Dugger and D. Richter (eds.), Proc. Beltwide Cotton Conf., 9–12 Jan. 1996, Nashville, TN. National Cotton Council of America, Memphis, TN, 1996.

Jost, P.H., and J.T. Cothren. "Growth and Yield Comparisons of Cotton Planted in Conventional and Ultra-Narrow Row Spacings." *Crop Science* 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." Ch. 16. *In* S.J. Hake, T.A. Kerby, and K.D. Hake (eds.), Cotton Production Manual. University of California DANR Publication 3352, Oakland, CA., 1996.

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

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

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

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

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

Monsanto Company. "Monsanto Announces Simpler Pricing For Biotech Traits in 2002." Monsanto Company, St. Louis, MO, 14 Jun 2001. Online. Available at: http://www.biotech-infor.net/simpler_pricing.html.

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

Montgomery, R., Personal communication 10 Oct. 2002, Monsanto Company, Union City, TN. 2002.

Montgomery, R., Personal communication 3 Jun. 2005, Monsanto Company, Union City, TN. 2005.

Parvin, D.W., F.T. Cooke, and S.W. Martin. "Alternative Cotton Production Systems." Dept. Agric. Econ. Res. Rep. 2000–010, Mississippi State, MS, 2002.

Robinson, E. "Cost-per Acre Issues in NE Louisiana: D&PL Goes to Fixed-Count Seed Bags." *Delta Farm Press*. 23 May 2003. Online. Available at: http://deltafarmpress.com/mag/farming_costper_acre_issues/. 2003a.

Robinson, E. "Company Changes to Seed-Count Bag." *Delta Farm Press*. 25 Jul 2003 Online. Available at: http://deltafarmpress.com/mag/farming_company_changes _seedcount/. 2003b.

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

Shelby, P.P. "Cotton Production in Tennessee." p. 3-7. *In* Cotton production in Tennessee. Publ. PB1514. Univ. Tennessee, Agric. Ext. Serv., Knoxville, TN, 1996.

University of Georgia. "Ultra Narrow Row Cotton in Georgia." p. 58–61. *In* 2002 Georgia Cotton Production Guide. Univ. Georgia Coop. Ext. Serv. Online. Available at: http://www.griffin.peachnet.edu/ caes/cotton/2002Guide.pdf.

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

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

U.S. Department of Agriculture, Economic Research Service. Unpublished Agricultural Resource Management Survey (ARMS) data. Online. Available at: http://www.ers.usda.gov/Data/ARMS/

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

Virginia Polytechnic Institute and State University. 1998. Seed Drop Rates and Technology Fees. Virginia Cooperative Extension Service. Online. Available at: http://filebox.vt.edu/cals/cses/chagedor/droprate.html.

Table 1. Data for the Ultra-Narrow-Row Cotton Plant Density Analysis

Item	Base Scenario	Sensitivity Analysis Minimum	Sensitivity Analysis Maximum
Plant Survival Ratio	0.64	0.64	0.80
1996-97 RR Technology Fee Policy			
Seed Price ($/50 lb bag)	$79.95	---	---
Technology Fee ($/acre)	$9	---	---
1998-2003 RR Technology Fee Policy			
Seed Price ($/50 lb bag)	$79.95	---	---
Seed Drop Rate (Seeds/acre)	62,500	52,000	76,000
Technology Fee ($/acre)	$9	---	---
Seed Size (Seeds/lb)	4,750	4,200	5,300
Seed Variety Category (SVC) (Seeds/lb)	4,800	---	---
2004-05 RR Technology Fee Policy			
Seed Price ($/250,000 count bag)	$79.95	---	---
Technology Fee ($/250,000 count bag)	$102.98	$82.05	$150.60
Technology Fee Cap ($/acre)	$28	$28	$28

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

Table 2. Estimated Lint Yield and Price Difference Models for the Ultra-Narrow-Row Cotton Plant Density Analysis

Parameter/Statistic	Lint Yields ML Model	Price Differences ML Model
	lb/acre	$/lb
Intercept	824.5***	−0.00758
	(34.9009) [z]	(0.005788)
PPD	1.998***	−0.0002***
	(0.5736)	(0.000042)
PPD^2	−0.00929***	NA
	(0.003118)	
D97	−602.72***	−0.04769***
	(119.75)	(0.01344)
D97×PPD	6.117*	0.000202
	(3.0933)	(0.000149)
$D97 \times PPD^2$	−0.03025	NA
	(0.01916)	
−2 Log Likelihood	977.8	−443.6
Observations	86	86

Note: ***,**,* Significantly different at the 1-, 5-, or 10-percent level, respectively Values in parentheses are standard errors. *PPD* is plant density in plants/acre (1,000s) and *D97* is 1 if year equals 1997 and 0 otherwise.

Table 3. Ultra-Narrow-Row Cotton Plant Density Results for the Base Scenario

Technology Fee Policy/ Plant Density Criterion	Plant Density	Lint Yield	Price Discount	Seed Cost	Tech Fee	Net Revenue
	(No./acre)	(lb/acre)	($/lb)	($/acre)	($/acre)	($/acre)
1996-97 Policy						
Georgia Extension	100,000	931	−0.028	53	9	481
Agronomic Minimum	63,000	914	−0.020	33	9	497
Profit Maximum	43,600	894	−0.016	23	9	499
1998-2003 Wide Row						
Georgia Extension	100,000	931	−0.028	53	23	467
Agronomic Minimum	63,000	914	−0.020	33	14	491
Profit Maximum	26,000	870	−0.013	14	6	500
1998-2003 UNRC						
Georgia Extension	100,000	931	−0.028	53	14	476
Agronomic Minimum	63,000	914	−0.020	33	12	494
Profit Maximum	39,500	889	−0.015	21	11	497
2004-05 Cap						
Georgia Extension	100,000	931	−0.028	50	28	464
Agronomic Minimum	63,000	914	−0.020	31	28	479
Profit Maximum	26,000	870	−0.013	13	17	490

Note: Cost and net revenue for each glyphosate-resistant technology fee policy and target plant density were calculated using Equations (1) to (8) in the text for the base scenario (Table 1). Lint yields for each plant density were estimated using the 1998-2000 yield response function (Table 2). Lint prices for each plant density were calculated using a base quality lint price of $0.61/lb and the 1998-2000 lint price difference function (Table 2, U.S. Department of Agriculture, Agricultural Marketing Service). 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.