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ECONOMICS AND MARKETING

Effects of Plant Population Density on Net Revenues from Ultra-Narrow-Row Cotton

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ABSTRACT

A common characteristic of ultra-narrow-row cotton (*Gossypium hirsutum* L.) production is the use of high plant population densities (PPD) compared to wide-row cotton. Farmers are concerned about the high seed costs and technology fees associated with these high planting densities. The objective of this study was to evaluate the impact of changes in PPD on net revenues for ultra-narrow-row cotton (UNRC) production. Yield data for 1997 through 2000 were obtained from a UNRC PPD study at Milan, TN. Partial budgeting and marginal analysis techniques were used to identify the PPD that would maximize profit, using North Delta spot cotton quotations. Results indicated that small yield gains were achieved by increasing PPD in UNRC. In addition, price discounts for fiber quality became larger with higher PPD. Given the impacts of PPD on lint yields and price discounts for fiber quality, farmers may be able to increase the profitability of UNRC by using a seeding rate that is considerably smaller than required to maximize lint yields. Results suggest that favorable trade-offs exist between reduced yields from using a lower PPD and savings from reduced seed costs and technology fees combined with smaller price discounts. Farmers may encounter problems with weed control and harvesting at PPDs below 15.5 plants m^{-2}, but should consider using PPDs as low as 15.5 plants m^{-2} to reduce seeding costs and curtail price discounts for fiber quality.

This study evaluates cotton (*Gossypium hirsutum* L.) net revenue trade-offs associated with the plant population density (PPD) decision for the ultra-narrow-row cotton (UNRC) production system. UNRC was initially defined in terms of row spacing <25 cm (Atwell, 1996), but some contemporary UNRC row spacings include 19, 25, and 38 cm (Parvin et al., 2000). A common practice in UNRC is the use of a finger-type stripper harvester instead of a spindle picker. The investment cost in a finger stripper is about one-half that of a spindle picker, and it has considerably lower operating (labor, fuel, maintenance, etc.) expenses (Larson et al., 1997). Even though harvest costs might be lower, finger-stripping cotton may result in more leaf and bark content in the lint than spindle picking because more of these plant parts are harvested by the finger stripper, and they are not completely removed during lint cleaning (Valco et al., 2001).

A common characteristic of UNRC is the use of high plant population densities (PPDs) relative to wide-row cotton (Perkins, 1998; Jones, 2001; Delaney et al., 2002). At one time, UNRC was referred to as "narrow-row, high population cotton" (Hawkins and Peacock, 1973). Plant population densities in contemporary UNRC often exceed 24.7 plants m^{-2} (Perkins, 1998; Jones, 2001). A major reason for relatively high PPD revolves around limitations of available planting and harvesting equipment for UNRC. Delaney et al. (2002) pointed out that UNRC is grown at relatively high PPDs to decrease branching and facilitate machine harvesting with a finger stripper, and indicated that recommended PPDs range from 19.8 to 49.4 plants m^{-2}. The University of Georgia Cotton Production Guide (2002) recommends at least 24.7 plants m^{-2} in UNRC. It suggests that spatial uniformity of the population is critical, because skips in the cotton stand may result in vegetative branching, which creates serious problems with harvest. Although large vegetative branches are known to interfere with finger-stripping, there are few published references on the relationship between PPD and vegetative branch size. This information would be useful in defining a lower limit on the PPD needed for efficient finger stripper harvest or a so called "agronomic minimum" PPD in UNRC.

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Achieving recommended PPDs in UNRC requires high seeding rates, particularly if traditional grain drills are used. Fluted-feed grain drills are difficult to calibrate and do not provide accurate seed placement, so they do not provide sufficient control to plant to a desired stand (Gerik et al., 1999). Stands planted with a modified grain drill were 82 to 88% (plants established per seed planted), but uniformity of seed distribution and placement was poor (Hawkins and Peacock, 1973). Stand establishment in plots planted with a no-till drill equipped with an air seeder averaged 68% in 1997 and 57% in 1998 (Buehring and Dobbs, 2000). Faced with uncertainties of planting to a stand with existing drill technology, some UNRC producers increased the seeding rate to as high as 56 kg ha^{-1} to ensure an adequate stand (Deterling, 1999). The University of Georgia Cotton Production Guide (2002) considered stand establishment to be the most critical production issue in UNRC.

High seed costs associated with high seeding rates are a major contributor to the relatively high variable costs of UNRC production (Parvin et al., 2000). All variable costs of production averaged \$42.48 ha^{-1} higher and seed costs averaged \$39.03 ha^{-1} higher for UNRC cotton on five farms participating in industry field tests in 1996 (Brown et al., 1998). Differences may be magnified for seed of transgenic, herbicide-resistant cultivars that have additional seed premiums and technology fees. In Georgia, Shurley et al. (2002) estimated that UNRC entailed \$148.20 ha^{-1} more in variable costs for seed and technology fees than conventional-row cotton, assuming no cap on technology fees in UNRC. Neither of these studies reported the actual seeding rates evaluated.

Several efforts have been made to determine optimum PPDs for UNRC. Equidistantly spaced plants at PPDs of 7.9 to 15.5 plants m^{-2} matured earlier and produced higher yields from hand-harvests than PPDs on either side of a range from 3.9 to 62 plants m^{-2} (Fowler and Ray, 1977). There was no evidence that higher PPDs improved yields or earliness in the year of this irrigated study, but vegetative branch growth was suppressed and micronaire was reduced at the highest PPD (62 plants m^{-2}). Hand-picked lint yields in non-irrigated 19-cm rows from PPDs with 17.5 to 26.5 plants m^{-2} in 1997, or with 13.2 to 23.8 plants m^{-2} in 1998 were not significantly different (Buehring and Dobbs, 2000). Lint yields each year varied by less than 8% across these PPDs. Hand-harvested lint yields from irrigated 19-cm rows, were not significantly different in PPDs between 12.2 and 40.5 plants m^{-2} (Jost and Cothren, 2001). Fiber length, strength, and micronaire were similar except for slightly shorter fibers and lower strength at high PPDs in 1 of 2 yr. In a 3-yr study of planting dates and PPD, lint yields from plantings in May tended to increase with PPD up to 49.4 plants m^{-2}, while yields tended to decrease with plantings in June (Delaney et al., 2002). These authors did not indicate if yield differences were significant, but they reported that bur and stick content was not affected by PPD within plantings. Of these studies, only Delaney et al. (2002) mentioned the extraneous matter that may be introduced during stripper harvesting. None of these studies directly estimated the total impact of PPD on all fiber quality characteristics, which are desired in the market, as measured by the lint price difference received by producers for UNRC quality.

Producers need information about cost and return trade-offs with different PPDs to evaluate the economic feasibility of UNRC and to optimize net revenues from this system. The objective of this study was to evaluate the impact of PPD on net revenues for UNRC production. Factors considered in this analysis were lint yield response to PPD, lint price adjustments for fiber quality as influenced by PPD, plant survival rates, transgenic cultivar seed costs and technology fees, and the potential effects of PPD on finger stripper harvest efficiency as measured by vegetative branch size.

MATERIALS AND METHODS

Yield and fiber quality data. Field experiments were conducted in 1997 through 2000 at the University of Tennessee Agricultural Experiment Station at Milan, TN. Production practices used in the experiments are summarized in Table 1. Prior to planting, 90 kg N ha^{-1} as ammonium nitrate was broadcast over the test site each year. Cotton was planted in 25.4-cm rows using a Kinze tandem planter (Kinze Manufacturing, Inc.; Williamsburg, IA) with no tillage each year. Seeding rates used to establish the crop were 51 kg ha^{-1} in 1997, 69 kg ha^{-1} in 1998, 62 kg ha^{-1} in 1999, and 60 kg ha^{-1} in 2000. Cotton cv. PM 1220 RR (Delta and Pine Land Co.; Scott, MS), was planted on a Memphis silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs) on 21 May 1997. In 1998 and 1999, PM 1220 RR was planted on Loring silt loams (fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs) on 12 May and 11 May, respectively. A closely related cultivar, PM 1218 BR, was planted on a Loring silt loam on 8 May 2000. Commercial two-way treated seed lots were used in all years. The combination fungicide, pentachloronitrobenzene (0.84 kg ha^{-1}) plus etridiazole (0.21 kg ha^{-1})(Terraclor Super X 2.5EC, Uniroyal Chemical Company; Middlebury, CT)], was applied in furrow at planting each year.

At the 1- to 2-leaf growth stage, plots were hand-thinned to four target PPD levels in 1997 and 1998 and five target PPD levels in 1999 and 2000. PPD treatments were arranged in a randomized complete block design with four or five replications. Average PPDs established by the treatment levels were 6.7, 11.6, 19.9, 28.8, and 38.2 plants m^{-2}. 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). No supplemental irrigation was applied. For weed control, glyphosate (Roundup Ultra; Monsanto Company, St. Louis, MO), was broadcast over the crop at 0.84 kg ha^{-1} prior to the 4-leaf growth stage each year. To regulate plant growth, mepiquat chloride (Pix; BASF, Research Triangle Park, NC) was applied from two to four times each year, between 34 and 83 days after planting. Mepiquat chloride rates varied with crop growth and field conditions, and seasonal totals varied between 0.049 and 0.074 kg ha^{-1}. A defoliant, thidiazuron (Dropp 50WP; Bayer Crop Science, Research Triangle Park, NC) and a boll opener, ethephon (Prep 6SL; Bayer Crop Science, Research Triangle Park, NC) were applied on the dates shown in Table 1. Thidiazuron rates varied between 0.056 and 0.112 kg ha^{-1}, and ethephon rates varied between 1.68 and 1.89 kg ha^{-1}. A second defoliant, tribufos (Def 6EC; Bayer Crop Science, Research Triangle Park, NC) was applied at 0.63 kg ha^{-1} along with the other harvest aids in 1997 only. Desiccants were

Table 1. Summary of production practices and growing conditions for the ultra-narrow-row cotton plant population study

Item	Year			
	1997	1998	1999	2000
Cultivar	PM 1220 RR	PM 1220 RR	PM 1220 RR	PM 1218 BR
Seeds (kg^{-1})	8,977	8,977	8,519	8,741
Planter	Kinze tandem	Kinze tandem	Kinze tandem	Kinze tandem
Row spacing	25.4 cm	25.4 cm	25.4 cm	25.4 cm
Soil type	Memphis silt loam	Loring silt loam	Loring silt loam	Loring silt loam
Planting date	21 May	12 May	11 May	8 May
Stand (%)[w]	63.6	43.3	68.3	81.0
Hand-thinning date	17 June	28 May	28 May	31 May
Defoliation date	30 Sept.	11 Sept.	14 Sept.	13 Sept.
Defoliant(s)	thidiazuron + tribufos	thidiazuron	thidiazuron	thidiazuron
Boll opener	ethephon	ethephon	ethephon	ethephon
Desiccation date	10 Oct.	21 Sept.	30 Sept.	26 Sept.
Desiccant(s)	sodium chlorate	paraquat	paraquat	paraquat
Harvest date	23 Oct.	1 Oct.	5 Oct.	4 Oct.
Harvester[x]	Allis-Chalmers 760	Allis-Chalmers 760	John Deere 7450	John Deere 7450
Degree-days[y]	1,036	1,381	1,210	1,234
Precipitation[z]	68 cm	91 cm	56 cm	60 cm

[w] Ratio of plants established to seeds planted (x100) prior to thinning.

[x] Finger stripper harvesters, each equipped with a bur extractor.

[y] Cumulative degree-days (base 15.6°C) from 1 Apr. through 31 Oct.

[z] Total for 1 Apr. through 31 Oct.

applied on the dates shown in Table 1. In 1997, sodium chlorate (Defol 6SL; Drexel Chemical Co., Mempis, TN) was applied at 5.6 kg ha^{-1}. In 1998, 1999, and 2000, paraquat dichloride (Gramoxone Max; Syngenta Crop Protection, Greensboro, NC) was applied at 0.63 kg ha^{-1}.

Shortly before crop termination each year, the length of the longest vegetative branch was measured on each of eight representative plants per plot. The mean vegetative branch length was associated with the PPD of each plot for statistical analysis.

Plots were harvested on 23 Oct 1997 and 1 Oct 1998 with an Allis Chalmers 760 harvester (Allis Chalmers Manufacturing Co.; Milwaukee, WI) equipped with a 3.9-m wide finger-type header and a bur extractor. A John Deere 7450 harvester (J. Deere & Company; Moline, IL) equipped with a 3-m finger-type header and bur extractor was used to harvest the plots on 5 Oct 1999 and 4 Oct 2000. Seedcotton harvested from each plot was weighed, and a grab sample was taken from each plot, weighed, and air-dried before ginning. Seedcotton samples were ginned with a 20-saw gin (Continental Gin Company; Prattville, AL) equipped with a stick machine, dual incline cleaners, and two lint cleaners at the West Tennessee Experiment Station, Jackson, TN. Lint was weighed to calculate gin turnout, and a subsample of lint was analyzed by high volume instrument (HVI) testing and hand-classing procedures at the USDA Agricultural Marketing Service Cotton Classing Office in Memphis, TN (USDA-AMS, 1995).

Cotton price data. Quotations collected by the USDA Agricultural Marketing Service were used to estimate premiums and discounts for fiber quality measured for each PPD treatment. Relevant quotations for Tennessee are from the North Delta market, which includes Northeast Arkansas, Missouri, and West Tennessee. The area market reporter determines daily prices by interviewing market participants and collecting sales information (Kuehlers, 1993). The accuracy of spot price quotations for the North Delta is unknown, because there has not been an objective evaluation of the price differences reported by the Agricultural Marketing Service for this region (Ethridge and Hudson, 1998). The statistical reliability of spot price quotations is difficult to determine because information about sample characteristics, such as number of observations and representativeness, are not known (Brown et al., 1995; Hudson et al., 1996). Irrespective of these data limitations, it was assumed that North Delta spot quotes reflect price differences for UNRC in Tennessee.

Starting August 1993, grade was divided into color and leaf grade for pricing by the industry (USDA-AMS, 1995). Prior to the 1993-1994 marketing year, grade was reported as a composite of color and trash. Between 1993 and 2001, season average base quality lint prices varied from \$0.71 kg^{-1} to \$1.92 kg^{-1} with a median base price of \$1.51 kg^{-1} (USDA-AMS, 2002). Differences in lint price for fiber quality associated with the median base price of \$1.51 kg^{-1} for the 1997/1998 growing season were used to evaluate price differences and net revenues as influenced by PPD (USDA-AMS, 1998). The equation used to estimate lint prices differences for fiber quality as influenced by UNRC PPD using North Delta market spot price data was

(1) $LPD_{i,j,t} = CLS_{i,j,t} + M_{i,j,t} + S_{i,j,t} + E_{i,j,t}$,

where LPD is the total lint price difference for each treatment i in the j^{th} experimental block from the base price of cotton (\$ kg^{-1}) for fiber quality obtained in year t of the experiment. CLS is the price difference for the combination of color grade, leaf grade, and staple (\$ kg^{-1}); M is the price difference for micronaire (\$ kg^{-1}); S is the price difference for strength (\$ kg^{-1}); and E is the price difference for extraneous matter (\$ kg^{-1}). Price differences for length uniformity were not reported for the 1997/1998 marketing year.

Analysis. The partial budgeting equation used to evaluate net revenues as a function of PPD (plants m^{-2}) was as follows:

(2) $NR(PPD) = [BLP + LPD(PPD)] \times LY(PPD) - RATE(PPD) \times SP - FEE(PPD)$,

where NR is net revenue (\$ ha^{-1}), BLP is base quality lint price (\$ kg^{-1}), LPD is lint price difference for fiber quality (\$ kg^{-1}), LY is lint yield (kg ha^{-1}), RATE is seeding rate (kg ha^{-1}), SP is price of seed for a transgenic cultivar (\$ kg^{-1}), and FEE is a technology fee (\$ ha^{-1}) for a transgenic cultivar.

Yield response as a function of PPD [Y(PPD)] for equation (2) was estimated using the lint yield and PPD data from the experiment. The theoretical relationship between cotton PPD and lint yield is approximately parabolic (Holliday, 1960a; 1960b). Results from prior field studies indicate that very high or very low PPDs have an adverse impact on lint yield (Hearn, 1972; Bridge et al., 1973; Hawkins and Peacock, 1973; Fowler and Ray, 1977; Kittock et al., 1986). Also, yield response immediately before and after the point of yield maximization has an extended (generally flat) plateau with respect to PPD. Given that yield response to PPD is expected to be parabolic, the following quadratic yield response function was specified:

$$(3)\quad LY(PPD)_{i,j} = \beta_1 + \beta_2 PPD_{i,j} + \beta_3 PPD_{i,j}^2 + \beta_4 D97 + \beta_5 D97 \times PPD_{i,j} + \beta_6 D97 \times PPD_{i,j}^2 ,$$

where PPD is plant population density (plants m^{-2}) for treatment i in the jth experimental block, D97 is a binary 0-1 variable for cotton produced on the Memphis silt loam for the 1997 growing season, and β_k are parameters estimated using maximum likelihood. The mixed model procedure in SAS release 8.20 (SAS Institute, Cary, NC) (Littell et al., 1996; Saxton, 1998) was used to estimate the yield response function specified in equation (3). The covariance structure in the mixed model procedure was specified to allow for heterogeneous variances among experimental blocks and heterogeneous variances among growing seasons.

The binary intercept and slope variables were specified to account for the potential of a different yield response in 1997. The 1997 growing season was an El Nino year with very cool growing conditions relative to 1998 through 2000 and historical weather averages for the area. Total degree-day (base 15.6°C) in 1997 was 1,036 (1 Apr. through 31 Oct.) compared with an average of 1,275 for 1998 through 2000 and the average of 1,271 for 1975 through 2000 (NOAA, 1975-2000). Only one other year between 1975 and 2000 had growing degree-days as low as that observed in 1997. The soil type for the plots in 1997 was also different from the soil type for the plots in 1998 through 2000. The yield hypotheses tested using the binary intercept and slope variables were as follows: H_O: $\beta_4 = \beta_5 = \beta_6 = 0$, i.e., yields were not different in 1997; H_A: $\beta_4 \neq 0$, $\beta_5 \neq 0$, or $\beta_6 \neq 0$, i.e., yields were different in 1997. If yields were different for 1997 versus 1998 through 2000, then the 1998 through 2000 model was used to evaluate net revenue response to PPD; otherwise the 1997 through 2000 model was used to evaluate net revenue response to PPD.

Differences in lint price as a function of PPD [LPD(PPD)] for equation (2) were estimated using the mixed model procedure (Littell, 1996;Saxton, 1998) and lint price differences calculated using the fiber quality data from the experiment, spot cotton price quotations, and equation (1) for the 1997/1998 marketing year median base price scenario outlined previously. The price difference function was specified as follows:

$$(4)\quad LPD(PPD)_{i,j} = \alpha_1 + \alpha_2 PPD_{i,j} + \alpha_3 D97 + \alpha_4 \times D97 \times PPD_{i,j},$$

where α_j are parameters estimated using maximum likelihood. The price difference hypotheses tested using the binary intercept and slope variables were as follows: H_0: $\alpha_3 = \alpha_4 = 0$, i.e., price differences were not different in 1997; H_A: $\alpha_3 \neq 0$ or $\alpha_4 \neq 0$, i.e., price differences were different in 1997.

Seeding rate as a function of plant population (RATE) in equation (2) was calculated as follows:

$$(5)\quad RATE(PPD) = PPD \times 10{,}000 \div PSR \div SEED,$$

where 10,000 is a factor to convert plants m^{-2} to plants ha^{-1} for calculating seeding costs, PSR is the plant survival rate that a farmer assumes when determining seeding rate, and SEED is the number of seeds kg^{-1} for the cultivar planted.

Monsanto Company (St. Louis, MO), which licenses glyphosate-resistant (Roundup Ready) and Bt (Bollgard) technologies through various seed companies, initially charged a technology fee (TF) based on planted area ($ ha^{-1}) in addition to the seed cost ($ kg^{-1}) charged by the seed company. Starting in 1998, Monsanto modified its technology fee policy for wide-row cotton and developed a separate policy for UNRC cotton (Monsanto Company, 1998). The revised wide-row technology fee policy converted the per-hectare technology fee to a per-kilogram basis. The fee was calculated using the seed drop rate (SDR) and the seed cultivar category (SVC). Monsanto defined the SDR as the number of seeds dropped from the planter to achieve a final plant population. The SDR varies by production region. For example, the SDR is 154,438 seeds ha^{-1} for West Tennessee compared with 128,492 seeds ha^{-1} for Georgia (Virginia Polytechnic Institute and State University, 1998). SVC defines the seed size category (seeds kg^{-1}) for a cultivar that is assumed by Monsanto for the purpose of calculating the technology fee. For example, the per-kilogram technology fee for a farmer in West Tennessee who plants PM 1220 RR with a SVC value of 9,261 seeds kg^{-1} and a technology fee of $22.24 ha^{-1} is calculated as follows: 9,261÷154,438×$22.24=$1.34 kg^{-1}. A farmer who uses a seeding rate of exactly 154,438 seeds

ha^{-1} pays a technology fee of \$22.24 ha^{-1}, while a farmer who plants less than 154,438 seeds ha^{-1} pays a technology fee of less than \$22.24 ha^{-1} under this pricing system.

Under Monsanto's UNRC exception policy, farmers are exempted from paying the per-kilogram technology fee on a portion of the seed that is planted in UNRC and instead pay the per-hectare fee (TF). Farmers are required to grow at least 50 acres of UNRC to be eligible for the exception. The seed drop rate is determined by estimating PPD in the field after planting and dividing that population by a PSR of 0.80. The seed drop rate is used to calculate the amount of seed excluded from the wide-row per-kilogram fee. Any seed used beyond the amount excepted is charged technology fees using the wide-row pricing policy. The technology fee for UNRC was modeled using the following formula:

$$\text{(6)}\quad \text{FEE(PPD)} = \text{TF} + (\text{PPD} \times 10{,}000 \div \text{PSR} \div \text{SEED} - \text{PPD} \times 10{,}000 \div 0.80 \div \text{SVC}) \times (\text{SVC} \div \text{SDR} \times \text{TF}) \text{ for PSR} < 0.80 \text{ and SEED} < \text{SVC; else FEE(PPD)} = \text{TF for PSR} \geq 0.80 \text{ and SEED} \geq \text{SVC.}$$

Farmers who use a lower PSR to determine their seeding rate rather than the 0.80 used by Monsanto, pay additional technology fees above the base per-hectare rate. The difference in the actual seed count kg^{-1} (SEED) versus the seed count kg^{-1} assumed by Monsanto to calculate the technology fee (SVC) also influences the fee paid.

A wide range of PPDs have been recommended for UNRC production (Delaney et al., 2002); therefore, equation (2) was used to evaluate UNRC net revenues for four PPD decision criteria: 1) the PPD that maximizes lint yields 2) a Georgia Agricultural Extension Service recommendation of 24.7 plants m^{-2} (University of Georgia, 2002), 3) an "agronomic minimum" PPD that may be needed to control weeds and facilitate efficient harvest with a finger stripper, and 4) the PPD required to maximize net revenues using the relationship between expected lint prices, seed prices, and technology fees. Numerical search techniques were used to determine the PPD that maximizes net revenues using equation (2).

Data measuring the relationship between mean vegetative branch length and PPD were evaluated to develop the "agronomic minimum" PPD decision criterion that places a lower limit on PPD to avoid weed and harvest problems. Vegetative branch length increases as PPD is reduced, which may increase the likelihood of branches being caught by the tines of the finger stripper. More frequent stopping by the operator to clean the finger-stripper header of large branches may reduce harvest efficiency and increase machinery and labor costs. Vegetative branch length (VBL) (cm) was modeled as an exponential decay function:

$$\text{(7)}\quad \text{VBL} = \delta_1 + \delta_2 \times e^{-\delta_3 \times \text{PPD}},$$

where δ_i are parameters estimated using nonlinear least squares and the exponent $e \approx 2.7$. The estimated model was used to determine the minimum PPD where mean vegetative branch length fits within an equidistant 25.4-cm plant spacing between and within rows. Equidistant 25.4-cm plant spacing may reduce vegetative branches relative to lower PPDs without lowering yields or reducing earliness (Fowler and Ray, 1977) and may improve light interception and crop growth rate per unit of ground area (Krieg, 1996).

To evaluate the influence of seed prices and technology fees on the UNRC-PPD decision, costs for the PM 1220 RR and PM 1218 BR cultivars used in the experiment were used to estimate net revenues (Bob Montgomery, Monsanto Company, personal communication, 10 Oct. 2002). As indicated previously, PM 1220 RR and PM 1218 BR are very similar cultivars and were not treated differently in the specification of the yield response model. Thus, the differences in seed premiums and technology fees for the two cultivars determine the difference in optimal PPD for the two seed cost scenarios. The assumed seed prices for PM 1220 RR and PM 1218 BR were \$1.94 kg^{-1} and \$2.51 kg^{-1}, respectively. The assumed technology fees charged under a UNRC exemption for the North Delta were \$22 ha^{-1} for PM 1220 RR and \$79 ha^{-1} for PM 1218 BR. Average seed counts from the experiment for PM 1220 RR and PM 1218 BR were used as values of SEED for calculating seed costs (Table 1).

The plant survival rate (PSR) was also varied to evaluate its influence on the PPD decision for UNRC. Mean, maximum, and minimum values of the average ratio of plants established to seeds planted prior to thinning measured over the 4 yr of the experiment (Table 1) were used to calculate seed costs and net revenues for alternative PSR scenarios.

RESULTS AND DISCUSSION

Lint yield response to PPD. The lint yield means for each PPD treatment in each year of the experiment are presented in Table 2. The estimated lint yield response function for UNRC PPD estimated from the experimental data is presented in Table 3. The estimated coefficients for quadratic yield response to PPD for 1998 through 2000, PPD and PPD^2, had the hypothesized signs and were significantly different from zero ($P = 0.01$). Results also indicate that lint yields for 1997 were different from the lint yields for 1998 through 2000. The estimated coefficient for the binary variable D97 for yields in 1997 was significant ($P \leq 0.05$) and had a negative sign. In addition, the estimated binary slope coefficient, D97 × PPD, was statistically significant ($P \leq 0.05$). The other binary slope coefficient, D97 × PPD^2, was not significantly different from zero.

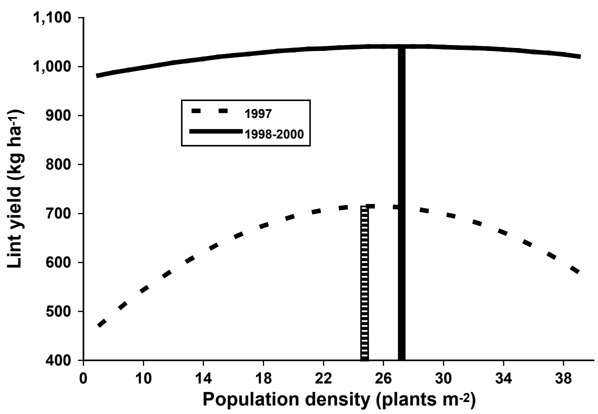

Figure 1. Mean lint yield response to plant population density for UNRC production from 1997 to 2000. Maximum yields were at 25.4 and 26.6 plants m^{-2} in 1997 and 1998 to 2000, respectively.

As illustrated in Figure 1, yield response to PPD was more parabolic for 1997 than for 1998 through 2000. The maximum lint yield of 715 kg ha^{-1} in 1997 was achieved at a PPD of 25.4 plants m^{-2}. The maximum yield for 1997 was 254 kg ha^{-1} (55%) more than the 461 kg ha^{-1} yield achieved at the average minimum PPD in the experiment of 6.7 plants m^{-2}. Unfortunately, a determination whether the difference in yield response to PPD in 1997 was due to weather, soil type, or a combination of weather and soil could not be made.

Lint yield response to PPD for 1998 through 2000 was not nearly as parabolic as the response function for 1997 (Figure 1). A maximum yield of 1,044 kg ha^{-1} for UNRC for 1998 through 2000 was achieved at a PPD of 26.6 plants m^{-2}. The yield maximum for 1998 through 2000 was only 68 kg ha^{-1} (7%) more than the 976 kg ha^{-1} yield achieved at the average minimum PPD in the experiment of 6.7 plants m^{-2}. Results indicate that the marginal productivity of PPD, or the incremental change in lint yield for a one unit increase in PPD, was much smaller under the average degree-day conditions for 1998 through 2000 than the marginal productivity of PPD in 1997. The relatively small incremental yield gains with increasing PPDs for the 1998 though 2000 model suggests that similar yields can be obtained for a wide range of PPDs in UNRC production under average weather conditions.

Lint price difference response to PPD. Fiber quality means for each PPD treatment in each year of the experiment are presented in Table 2. The lint price difference model is presented in Table 3. The coefficient for PPD was significant ($P = 0.01$) and had a negative sign, indicating that higher PPDs produced lower fiber quality and larger price discounts on average for the 1998 through 2000 data. Lint price discounts vary from −\$0.06 kg^{-1} to −\$0.12 kg^{-1} for the average minimum and maximum PPDs of 6.7 plants m^{-2} and 38.2 plants m^{-2}, respectively. Results indicate that increasing PPD by one plant m^{-2} resulted in a \$0.002 kg^{-1} larger discount for fiber quality. Fiber discounts at higher PPDs were mainly due to higher leaf grade and lower micronaire values. More leaf trash in the lint was associated with leaves 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 and contributed to leaf trash proportionally to PPD. The occurrence of bark discounts did not vary with PPD. Bark discounts did vary by year, apparently due to differences in crop desiccation associated with weather conditions. Lower micronaire values were observed as PPD exceeded 30 plants m^{-2} in 1999 and 2000. This response is consistent with earlier research cited by Bridge et al. (1973) and Hawkins and Peacock (1973), in which micronaire tended to decrease with increasing PPD.

The estimated coefficient for the binary variable, D97, for lint price differences in 1997 was significant ($P = 0.01$) 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.

Vegetative branch length response to PPD. Figure 2 illustrates the relationship between PPD and vegetative branch length from the 4-yr field study at

Table 2. Lint yield and fiber quality summary from the plant population density study, 1997-2000[z]

Item	Treatment				
	1	2	3	4	5
1997 Season					
Plant population (no. m^{-2})	9.9	17.0	21.8	29.1	—
Lint yield (kg ha^{-1})	537.9 b	656.7 a	726.8 a	686.7 a	—
Rd (%)	75.5 a	76.8 a	75.5 a	75.5 a	—
+b (units)	8.6 ab	8.4 bc	8.2 c	8.7 a	—
Fiber length (mm)	27.8 a	27.1 b	27.1 b	26.9 b	—
HVI Trash (%)	0.8 a	0.8 a	1.0 a	0.8 a	—
Micronaire (units)	44.5 a	44.5 a	44.5 a	43.5 a	—
Strength (KN m kg^{-1})	272.9 ab	264.3 b	271.6 ab	273.6 a	—
Uniformity (%)	84.0 ab	84.3 a	83.5 bc	83.3 c	—
1998 Season					
Plant population (no. m^{-2})	5.3	9.2	18.1	27.0	—
Lint yield (kg ha^{-1})	1163.7 a	1216.6 ab	1279.0 ab	1305.9 a	—
Rd (%)	77.6 a	78.0 a	77.8 a	77.8 a	—
+b (units)	7.7 a	7.6 a	7.4 a	7.6 a	—
Fiber length (mm)	28.5 a	28.4 ab	28.1 ab	28.0 b	—
HVI Trash (%)	1.2 a	0.8 b	0.9 ab	1.0 ab	—
Micronaire (units)	37.8 b	40.8 ab	42.0 a	41.2 a	—
Strength (KN m kg^{-1})	296.4 a	286.9 b	291.7 ab	293.8 ab	—
Uniformity (%)	83.2 a	83.6 a	83.6 a	83.8 a	—
1999 Season					
Plant population (no. m^{-2})	6.7	10.5	19.6	28.6	35.9
Lint yield (kg ha^{-1})	964.3 b	1000.7 ab	1030.3 ab	1049.0 a	1046.1a
Rd (%)	79.0 a	79.0 a	79.4 a	79.4 a	79.0 a
+b (units)	8.9 a	8.8 ab	8.7 bc	8.6 c	8.6 c
Fiber length (mm)	27.5 a	27.6 a	26.9 b	27.1 ab	27.0 b
HVI Trash (%)	0.3 b	0.3 ab	0.3 ab	0.4 a	0.3 ab
Micronaire (units)	46.0 ab	46.4 a	47.0 a	44.6 bc	43.4 c
Strength (KN m kg^{-1})	293.6 a	289.9 a	286.6 a	285.8 a	287.9 a
Uniformity (%)	83.0 a	83.0 a	82.8 a	82.8 a	82.4 a
2000 Season					
Plant population (no. m^{-2})	5.0	9.7	19.9	30.4	42.5
Lint yield (kg ha^{-1})	849.0 a	830.7 a	833.2 a	857.4 a	816.3 a
Rd (%)	76.0 b	76.8 ab	77.0 a	77.0 a	77.6 a
+b (units)	8.7 a	8.3 b	8.0 c	8.1 bc	8.0 c
Fiber length (mm)	27.0 a	26.8 a	27.2 a	27.1 a	26.7 a
HVI Trash (%)	0.8 b	0.9 ab	0.8 b	1.1 a	0.9 ab
Micronaire (units)	43.2 a	34.4 b	30.6 c	31.4 c	30.0 c
Strength (KN m kg^{-1})	275.0 ab	271.5 ab	275.2 ab	276.9 a	265.0 b
Uniformity (%)	81.4 a	80.4 b	81.0 ab	81.2 a	80.4 b

[z] Values within a year followed by the same letter are not significantly different (*P* = 0.05), according to the mixed model procedure in SAS.

Table 3. Lint yield and price difference response functions for the UNRC plant population density decision analysis

Variables/items[y]	Lint yield (kg ha^{-1}) [z]		Lint price difference($ kg^{-1}) [z]	
Intercept	923.440***	(23.62)	-0.045*	(-3.41)
PPD	9.056***	(3.48)	-0.002***	(-4.44)
PPD^2	-0.171***	(-2.98)		
D97	-675.040***	(-5.03)	-0.126***	(-3.76)
D97 × PPD	27.726**	(1.98)	0.003	(1.62)
D97 × PPD^2	-0.555	(-1.58)		
Observations	86		78	

[y] PPD is plant population density (plants m^{-2}) and D97 is a 0-1 binary variable, where D97 = 1 if year = 1997; otherwise D97 = 0.

[z] Values significantly different from zero at P ≤ 0.1, 0.05, and 0.01 are designated by *, **, and ***, respectively. Values in parenthesis are *t*-statistics.

the Milan Experiment Station. An exponential decay function fit the pooled data (n = 86) with an R^2 = 0.813. This regression suggests that vegetative branch lengths increased exponentially as PPD fell below 15 plants m^{-2}, which increases the likelihood of branches being caught by the tines of the finger stripper. At <10 plants m^{-2}, average lengths of the longest vegetative branches exceeded the row width of 25.4 cm.

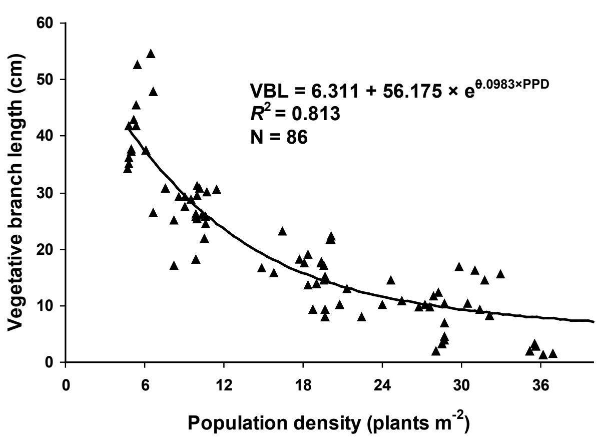

Figure 2. Mean vegetative branch length response to plant population density for UNRC production from 1997 to 2000.

Because branches can grow at any angle relative to row orientation, branch length control with PPD involves both between-row and in-row competition between plants. At equidistant 25.4-cm plant spacing between and within rows, PPD averaged 15.5 plants m^{-2}. Applying the exponential decay function in Figure 2 to this configuration, branch length averaged 18.6 cm at 15.5 plants m^{-2}. It was observed that branches of this length were quite pliable and likely to fold up next to the main stem as plants passed through the header tines, thus they were less likely to break off during finger stripping. In a field study by Fowler and Ray (1977), equidistant 25.4-cm plant spacing reduced vegetative branches of two cultivars, relative to lower equidistant PPDs, without sacrificing lint yield or earliness. Equidistant plant spacing is also known to optimize light interception and crop growth rate per unit ground area (Krieg, 1996). These observations and the present data indicate that 15.5 plants m^{-2} represents a reasonable estimate of an “agronomic minimum” PPD for UNRC.

Net revenue response to PPD. The 1998 through 2000 yield response function was used to estimate the net revenues reported in Tables 4 and 5. Several important findings can be derived from the net revenues (NR) results reported for the glyphosate-tolerant (Roundup Ready) cultivar PM 1220 RR in Table 4. First, farmers may be able to improve the profitability of UNRC by substantially reducing their target PPD from the 24.7 plants m^{-2} recommended by the University of Georgia Extension Service. The NR-maximization-with-price-differences criterion used to determine PPD produced a $27 ha^{-1} (2%) larger NR than the Extension-Service-PPD-decision criterion when the assumed plant survival rate (PSR) was 64%. Because of the relatively small marginal productivity (yield gains) with increasing PPD, the NR-maximizing PPD was 43% smaller than the GA Extension Service PPD decision rule (14.2 plants ha^{-1} versus 24.7 plants m^{-2}). A small trade-off was evident between reduced yields (25 kg ha^{-1}, 2%) and lower PPD at a PSR of 64% compared with the 34% savings ($42 ha^{-1}) in seed costs and technology fees by using the lower seeding rate of 25 kg ha^{-1}. A reduction in the price discount for fiber quality of

$0.03 kg^{-1} also occurred from using the NR maximizing PPD level.

The second important finding was that, for a given PPD, higher price discounts for fiber quality reduced the value of additional plants m^{-2} compared with the cost of those plants. Therefore, a NR-maximizing farmer would choose a lower PPD when the effects of PPD on price discounts were considered. The reduction in seed costs and technology fees and the additional revenue from smaller price discounts were greater than the loss of revenue from reduced yields with a lower PPD, thereby enhancing NRs. The effects of lint price discounts on optimal PPD are shown in Table 4. NRs under the NR-maximization-without-price-differences heading were determined using only the base quality price of $1.51 kg^{-1}. NRs under the NR maximization with price differences heading were determined using the base quality price and price discounts for fiber quality as influenced by PPD. Results indicate that for a PSR of 64%, the optimal PPD was smaller when price discounts for fiber quality were considered, but 14.2 plants m^{-2} compared with 18.8 plants m^{-2} was optimal when price discounts were not considered. In addition, the difference in NRs from using the NR maximization with and without price discount criteria represents the value of price discount information in determining the optimal PPD. For example, the value of using price discounts to determine the optimal PPD for a PSR of 64% was $5 ha^{-1}.

Table 4. Yields, price differences, seeding rates, seed costs, and net revenues for alternative UNRC plant population density (PPD) decision criteria with a glyphosate–tolerant (Roundup Ready) cultivar [u]

Item	UNRC plant population density (PPD) decision criteria [v]								
				Net revenue maximization [w]					
	Yield maximum[x]	GA extension[y]	Agronomic minimum[z]	Without price differences			With price differences		
				81%	64%	43%	81%	64%	43%
PPD m^{-2}	26.6	24.7	15.5	21.2	18.8	13.3	16.7	14.2	8.7
Lint yield (kg ha^{-1})	1,044	1,043	1,023	1,039	1,033	1,014	1,027	1,018	989
Price difference ($ kg^{-1})	−0.10	−0.09	−0.08	−0.09	−0.08	−0.07	−0.08	−0.07	−0.06
Net lint price ($ kg^{-1})	1.41	1.41	1.43	1.42	1.42	1.44	1.43	1.43	1.44
Seeding rate, 81% (kg ha^{-1})	37	35	22	30	----	----	23	----	----
Seeding rate, 64% (kg ha^{-1})	47	44	27	----	33	----	----	25	----
Seeding rate, 43% (kg ha^{-1})	70	65	41	----	----	35	----	----	23
Seed cost, 81% ($ ha^{-1})	72	67	42	57	----	----	45	----	----
Seed cost, 64% ($ ha^{-1})	91	85	53	----	64	----	----	49	----
Seed cost, 43% ($ ha^{-1})	136	126	79	----	----	68	----	----	45
Technology fee, 81% ($ ha^{-1})	24	24	23	24	----	----	23	----	----
Technology fee, 64% ($ ha^{-1})	37	36	31	----	33	----	----	30	----
Technology fee, 43% ($ ha^{-1})	68	65	49	----	----	45	----	----	37
Net revenue, 81% ($ ha^{-1})	1,375	1,383	1,399	1,394	----	----	1,399	----	----
Net revenue, 64% ($ ha^{-1})	1,343	1,353	1,380	----	1,375	----	----	1,380	----
Net revenue, 43% ($ ha^{-1})	1,267	1,283	1,336	----	----	1,342	----	----	1,348

[u] Cotton cultivar PM 1220 RR with a $1.94 kg^{-1} cost for the seed and a $22.64 ha^{-1} technology fee. The 1998 through 2000 yield response function presented in Table 3 was used to estimate the net revenues. PM 1220 RR and PM 1218 BR are similar cultivars and were not treated differently in the specification of the yield response model. Thus, the differences in seed premiums and technology fees for the two cultivars determine the optimal PPD for PM 1220 RR.

[v] Net revenues were calculated using a base quality price of $1.51 kg^{-1} plus the estimated price difference at the optimal PPD from the price equation presented in Table 3.

[w] Net revenue maximization was determined with and without price differences for fiber quality to determine the optimal PPD. The 81%, 64%, and 43% represent alternative scenarios of expected plant survival ratios used to determine the seeding rate.

[x] The PPD that maximizes lint yields estimated using the 1998 through 2000 yield response function presented in Table 3.

[y] Georgia Agricultural Extension Service UNRC PPD recommendation of 24.7 plants m^{-2} (University of Georgia, 2002).

[z] The minimum PPD of 15.5 plants m^{-2} that may be needed to control weeds and facilitate efficient finger stripper harvest.

The third major finding is the PSR influences the cost of establishing a cotton plant in UNRC production, and thus influences the optimal PPD. Results indicate that the cost per cotton plant successfully established rises when PSR declines. For example, for PM 1220 RR the cost of establishing 100 cotton plants was \$0.04 [(\$45 + \$23) ÷ (16.7 × 100)] when the PSR was 81%, but more than doubled to \$0.09 per 100 cotton plants [(\$45 + \$37) ÷ (8.7 × 100)] when the PSR was only 43%. When maximizing NR using price differences, the optimal PPD was 16.7 plants m^{-2} when PSR was 81%, but was reduced to 8.7 plants m^{-2} when the PSR was only 43%. The latter PPD is much lower than the agronomic minimum PPD needed to suppress growth of vegetative branches and weeds.

The final major finding that can be derived from Table 4 is the agronomic minimum PPD of 15.5 plants m^{-2} produced NRs similar to those obtained using the NR maximization PPD assuming a PSR of 64% or more. Results indicate that farmers may be able to substantially reduce their cotton plant stand establishment costs, while enhancing NRs, by suppressing the growth of vegetative branches and weeds, and maintaining finger stripper harvest efficiency using the agronomic minimum PPD criterion. For a PSR of 64%, the agronomic minimum PPD decision rule produces \$37 ha^{-1} and \$27 ha^{-1}

Table 5. Yields, price differences, seeding rates, seed costs, and net revenues for alternative UNRC plant population density (PPD) decision criteria with a glyphosate–tolerant (Roundup Ready), Bt (Bollgard) cultivar [u]

Item	UNRC plant population density (PPD) decision criteria[v]								
				Net revenue maximization [w]					
	Yield maximum[x]	GA Extension[y]	Agronomic minimum [z]	Without price differences			With price differences		
				81%	64%	43%	81%	64%	43%
PPD m^{-2}	26.6	24.7	15.5	19.3	14.0	6.7	14.7	9.5	6.7
Lint yield (kg ha^{-1})	1,044	1,043	1,023	1,035	1,017	976	1,020	994	976
Price difference (\$ kg^{-1})	−0.10	−0.09	−0.08	−0.08	−0.07	−0.06	−0.07	−0.06	−0.06
Net lint price (\$ kg^{-1})	1.41	1.41	1.43	1.42	1.43	1.45	1.43	1.44	1.45
Seeding rate, 81% (kg ha^{-1})	37	35	22	27	----	----	21	----	----
Seeding rate, 64% (kg ha^{-1})	47	44	27	----	25	----	----	17	----
Seeding rate, 43% (kg ha^{-1})	70	65	41	----	----	18	----	----	18
Seed cost, 81% (\$ ha^{-1})	93	87	54	68	----	----	52	----	----
Seed cost, 64% (\$ ha^{-1})	118	110	69	----	62	----	----	42	----
Seed cost, 43% (\$ ha^{-1})	176	164	103	----	----	44	----	----	44
Technology fee, 81% (\$ ha^{-1})	85	85	83	84	----	----	83	----	----
Technology fee, 64% (\$ ha^{-1})	132	128	110	----	107	----	----	98	----
Technology fee, 43% (\$ ha^{-1})	241	230	174	----	----	120	----	----	120
Net revenue, 81% (\$ ha^{-1})	1,292	1,302	1,327	1,322	---	---	1,327	---	---
Net revenue, 64% (\$ ha^{-1})	1,221	1,236	1,285	---	1,289	---	---	1,294	---
Net revenue, 43% (\$ ha^{-1})	1,054	1,081	1,188	---	---	1,251	---	---	1,251

[u] Cotton cultivar PM 1218 BR with a \$2.51 kg^{-1} cost for the seed and a \$79.07 ha^{-1} technology fee. The 1998 through 2000 yield response function presented in Table 3 was used to estimate the net revenues. PM 1220 RR and PM 1218 BR are similar cultivars and were not treated differently in the specification of the yield response model. Thus, the differences in seed premiums and technology fees for the two cultivars determine the optimal PPD for PM 1218 BR.

[v] Net revenues were calculated using a base quality price of \$1.51 kg^{-1} plus the estimated price difference at the optimal PPD from the price equation presented in Table 3.

[w] Net revenue maximization was determined with and without price differences for fiber quality to determine the optimal PPD. The 81%, 64%, and 43% represent alternative scenarios of expected plant survival ratios used to determine the seeding rate.

[x] The PPD that maximizes lint yields estimated using the 1998 through 2000 yield response function presented in Table 3.

[y] Georgia Agricultural Extension Service UNRC PPD recommendation of 24.7 plants m^{-2} (University of Georgia, 2002).

[z] The minimum PPD of 15.5 plants m^{-2} that may be needed to control weeds and facilitate efficient finger stripper harvest.

larger NRs, respectively, than the yield maximizing PPD of 26.6 plants m^{-2} and the GA Extension Service recommended PPD of 24.7 plants m^{-2}. Seed costs and technology fees for the agronomic minimum PPD criterion were 34% ($44 ha^{-1}) and 31% ($37 ha^{-1}) smaller, respectively, than the costs for the yield maximizing and GA Extension Service PPD criteria.

The important findings that can be derived from the NR results reported for the higher cost glyphosate-resistant (Roundup Ready), Bt (Bollgard) cultivar PM 1218 BR in Table 5 are as follows. First, the NR maximizing PPDs for PM 1218 BR were smaller than for the PM 1220 RR cultivar (i.e. 9.5 plants m^{-2} compared with 14.2 plants m^{-2} with PM 1218 RR when a PSR of 64% was used to determine the PPD). Given that the estimated yield response to PPD was assumed to be the same for both PM 1220 RR and PM 1218 BR, a NR-maximizing farmer would choose a lower PPD when using PM 1218 BR because the cost per 100 plants established is higher (i.e. $0.06 per 100 plants compared with $0.04 per 100 plants for PM 1220 RR). The cost savings from a lower PPD were even larger than the revenue loss from reduced yields with PM 1218 BR than with PM 1220 RR. For a PSR of 64%, the seed costs and technology fee savings total 41% ($98 ha^{-1}) compared with a 5% (49 kg ha^{-1}) reduction in lint yield from using a lower PPD. Also contributing to higher net returns was a $0.03 kg^{-1} increase in the net price received due to lower price discounts for fiber quality.

Results indicate that NR-maximizing farmers may have an incentive to plant a considerably smaller PPD than the agronomic minimum PPD of 15.5 plants m^{-2} with the more expensive cultivar, PM 1218 BR. A farmer may incur higher finger stripper harvest costs and additional price discounts from weed trash due to the low PPD suggested by the NR maximization criterion. The potentially higher harvest costs and weed contamination due to a lower PPD were not considered in the maximization of NRs. The difference in NRs for the agronomic minimum and the NR maximization with price discount criteria does suggest what the value of a higher PPD would need to be to avoid weed and harvest problems. For example, a farmer with a PSR of 64% could incur up to $9 ha^{-1} in additional weed control and harvest costs with the NR maximization criterion before its NRs equal those obtained for agronomic minimum PPD criterion.

CONCLUSIONS

An important factor influencing the profitability of ultra-narrow-row cotton (UNRC) is the seeding cost associated with relatively high plant population densities (PPDs) used in UNRC production. This study determined profit-maximizing PPDs and net revenues for UNRC production. Profit-maximizing net revenues were compared with the net revenues obtained from maximizing yields using a PPD of 26.6 plants m^{-2}, a GA Extension Service recommended PPD of 24.7 plants m^{-2}, and a minimum PPD of 15.5 plants m^{-2} needed to suppress weeds and to facilitate efficient finger stripper harvest.

Results show the incremental gains in lint yields with increasing PPDs were small, indicating that similar yields can be obtained for a wide range of PPDs in UNRC production. Increasing PPDs also had a small but statistically significant influence on price discounts for fiber quality. Given the small impact of PPD on yields and the negative effects of PPD on price discounts, the PPD required to maximize net revenues was considerably smaller than the PPD needed to maximize yields and the PPD recommended by the GA Extension Service. There was a favorable trade-off in seed cost and technology fee savings and smaller price discounts compared with the reduced yields from using a lower PPD. Results also indicate that the plant survival rate (PSR) used by a farmer to determine the seeding rate influences optimal PPD. A low PSR increases the cost per cotton plant established. The trade-off in lower seeding costs and smaller price discounts compared with the reduced yields from using a lower PPD was greater with a low PSR, thereby reducing the PPD required to maximize net revenues relative to a higher PSR. Finally, net revenues for the minimum PPD criterion of 15.5 plants m^{-2} needed to avoid weed and harvest problems were similar to the net revenues from using the profit maximizing PPDs.

A limitation of this research is that the potentially higher harvest costs and weed problems associated with lower PPDs were not directly determined. Future research should focus on large scale field research to examine the effect of PPD on finger harvester efficiency, weed competition, and other production practices. This research could be used to document any differences in harvest costs or other production costs (e.g., weed control) associated with the agronomic minimum PPD of 15.5 plants m^{-2}

when compared with higher PPD recommendations, such as the GA Extension Service recommendation of 24.7 plants m^{-2}.

REFERENCES

Atwell, S.D. 1996. Influence of ultra narrow row on cotton growth and development. p. 1187-1188. *In* Proc. Beltwide Cotton Conf., Nashville TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis TN.

Bridge R.R., Meredith W.R., Jr., Chism J.F. 1973. Influence of planting method and plant population on cotton (*Gossypium hirsutum* L.). Agron. J. 65:104-109.

Brown, A.B., T.L. Cole, and J. Alphin. 1998. Ultra narrow row cotton: Economic evaluation of 1996 BASF field plots. p. 88-91. *In* Proc. Beltwide Cotton Conf., 5–9 Jan. 1998. San Diego CA. Natl. Cotton Counc. Am., Memphis TN.

Brown, J.E., D.E. Ethridge, D. Hudson, and C.Engels. 1995. An automated econometric approach for estimating and reporting daily cotton market prices. J. Agric. Appl. Econ. 27: 409-422.

Buehring, N., and R. Dobbs. 2000. UNR cotton plant population effect on growth and yield. p. 660-661. *In* Proc. Beltwide Cotton Conf., San Antonio TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Delaney, D.P., C.D. Monks, D.W. Reeves, and R.M. Durbin. 2002. Plant populations and planting dates for UNR cotton. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 7-12 Jan. 2002. Natl. Cotton Counc. Am., Memphis, TN. (unpaginated CD-ROM).

Deterling, D. 1999. In search of the best row width. Prog. Farmer 114(3): Cotton Suppl. 20-22.

Ethridge, D., and D. Hudson. 1998. Cotton market price information: how it affects the industry. J. Cotton Sci. 2: 68-76 [Online]. Available at http://journal.cotton.org/1998/isue01/x_Comtemp/art01/article.pdf

Fowler, J.L., and L.L. Ray. 1977. Response of two cotton genotypes to five equidistant spacing patterns. Agron. J. 69:733–738.

Gerik, T.J., R.G. Lemon, and E.M. Steglich. 1999. Ultra-narrow row cotton performance under drought conditions. p. 581. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. 1999. Natl. Cotton Counc. Am., Memphis, TN.

Hawkins, B.S.,and H.A. Peacock. 1973. Influence of row width and population density on yield and fiber characterstics of cotton. Agron. J. 65:47–51.

Hearn A.B. 1972. Cotton spacing experiments in Uganda. J. Agric. Sci. (Cambridge). 78:13-25.

Holliday, R. 1960a. Plant population and crop yield: Parts I. Field Crop Abstr., 13: 159-167.

Holliday, R. 1960b. Plant population and crop yield: Parts II. Field Crop Abstr., 13: 247-254.

Hudson, D., D. Ethridge, and J. Brown. 1996. Producer prices in cotton markets: an evaluation of reported price information accuracy. Agribusiness 12:353-62.

Jones, M.A. 2001. Evaluation of ultra-narrow row cotton in South Carolina. p 522-524. *In* Proc. Beltwide Cotton Conf., Anaheim CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Jost, P.H., and J.T. Cothren. 2001. Phenotypic alterations and crop maturity differences in ultra-narrow-row and conventionally spaced cotton. Crop Sci. 41:1150–1159.

Kittock, D.L., Selley, R.A., Cain, C.J. and Taylor, B.B. 1986. Plant population and plant height effects on Pima cotton lint yield. Agron. J. 78: 534-8.

Krieg, D.R. 1996. Physiological aspects of ultra-narrow row cotton production. p. 66. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 9–12 Jan. 1996. Natl. Cotton Counc. Memphis, TN.

Kuehlers, T. 1994. 1993 crop spot quotations. p. 457. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-8 Jan. 1994. Natl. Cotton Counc. Am., Memphis TN.

Larson, J.A., B.C. English, C.O. Gwathmey, and R.M. Hayes. 1997. Economic feasibility analysis of ultra-narrow-row cotton in Tennessee. p. 315-317. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 7-10 Jan. 1997. Natl. Cotton Counc. Am., Memphis TN.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS® system for mixed models. SAS, Institute, Cary, NC.

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

National Oceanic and Atmospheric Administration (NOAA). 1997 to 2000. Climatological data, Tennessee. U. S. Department of Commerce, National Climatic Data Center, Asheville, N.C.

Parvin, D.W., F.T. Cooke, and S.W. Martin. 2000. Alternative cotton production systems. Dep. Agric. Econ. Res. Rep. 2000-010. Mississippi State, MS.

Perkins, W.R. 1998. Three year overview of UNRC vs. conventional cotton. p. 91. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5–9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

Saxton, A.M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. p. 1243-1246. *In* Proc. of the 23rd Annual SAS Users Group Int. Conf., Nashville, TN. 22-25 Mar. 1998. SAS Institute, Cary, NC.

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

Shurley, W.D., M.J. Bader, C.W. Bednarz, S.M. Brown, G. Harris, and P.M. Roberts. 2002. Economic assessment of ultra narrow row cotton production in Georgia. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 7-12 Jan. 2002. Natl. Cotton Counc. Am., Memphis, TN. (unpaginated CD-ROM).

USDA - Agricultural Marketing Service (AMS). 1995. The classification of cotton. USDA-AMS Agric. Information Bull. 566. U.S. Gov. Print. Office, Washington, D.C.

USDA - Agricultural Marketing Service (AMS). 1998. Cotton price statistics 1997-1998. 79(13):9. USDA-AMS, Cotton Division, Market News Branch, Memphis, TN.

USDA - Agricultural Marketing Service (AMS). 2002. Cotton price statistics 2001-2002. 83:13. USDA-AMS, Cotton Division, Market News Branch, Memphis, TN.

University of Georgia. 2002. Ultra narrow row cotton. p. 58-61. *In* 2002 Georgia Cotton Production Guide. CSS-02-01. Coop. Ext. Serv./College Agric. Environ. Sci., Athens, GA [Online]. Available at http://www.griffin.peachnet.edu/caes/cotton/2002Guide.pdf (verified 17 May 2004).

Valco, T.D., W.S. Anthony, and D.D. McAlister III. 2001. Ultra narrow row cotton ginning and textile performance results. p. 355-357. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Virginia Polytechnic Institute and State University. 1998. Seed drop rates and technology fees. Virginia Coop. Ext. Serv., Blacksburg, VA [Online]. Available at http://filebox.vt.edu/cals/cses/chagedor/droprate.html (verified 18 May 2004).