OPTIMIZATION OF ROW SPACING AND NITROGEN FERTILIZATION FOR COTTON

A Dissertation

by

ERNEST LESLIE CLAWSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2003

Major Subject: Agronomy

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ABSTRACT

Optimization of Row Spacing and Nitrogen

Fertilization for Cotton. (May 2003)

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Chair of Advisory Committee: Dr. J. Tom Cothren

Ultra-narrow row (UNR) cotton (*Gossypium hirsutum* L.) is a production system using high plant populations in reduced row spacings. The responses of this production system to nitrogen fertilizer have not been fully investigated. Evaluations of yield and earliness of harvest are also important.

A three-year study was conducted at the Texas Agricultural Experiment Station farm, Burleson County, TX, on a Ships clay (very-fine, mixed, active, thermic Chromic Hapluderts) and a Weswood silty clay loam (fine-silty, mixed, superactive, thermic Udifluventic Haplustepts). A split plot design was used. Nitrogen fertilizer rates of 0, 50, 101, and 151 kg N ha^{-1} were applied as the whole plots and row spacings of 19, 38, and 76 cm were established as the split plots. Data included lint yield and yield components, as well as earliness of crop maturity and earliness-related parameters such as boll distribution.

Lint yield was increased by higher nitrogen rate. There was no nitrogen rate by row spacing interaction on lint yield, implying fertilizer rates do not need to be changed for UNR systems. Reductions in row spacing did not significantly affect lint yield in any year. Responses such as reduced bolls per plant, increased plant populations, increased ginout, and decreased boll size were often significant and combined to allow the crop to maintain equivalent yields as row spacings were reduced. The slight UNR earliness advantages were probably due to changes in boll distribution. Based on these results, increases in lint yield and earliness may not reliably contribute to the profitability of UNR cotton.

DEDICATION

To my father who has always believed in me regardless of circumstances.

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Finally, I acknowledge the hand of God in my life, in helping me complete my education and in so many other ways, and pray for His continued blessing.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF TABLES

TABLE Page

TABLE Page

INTRODUCTION

Cotton (G*ossypium hirsutum* L.) can be produced under a variety of row spacings, including rows closer than the traditional 102 cm. Such reduced row spacing systems are known as narrow, or if highly reduced, ultra-narrow row (UNR) cotton. Although interpretations differ, both 19- and 38-cm row spacings can be considered to be UNR cotton according to the definition of McFarland et al. (2002). UNR cotton typically is produced using higher plant populations than in conventional rows. One recommendation is to achieve between 247,100 to 395,360 plants per hectare for UNR cotton (BASF Corporation, 1999). In conventional cotton 74,176 to 123,550 plants per hectare has been recommended in California (Hake et al., 1996a), and similar populations are utilized elsewhere.

Several agronomic traits of UNR cotton may result in an economic advantage to producers. Specific parameters that may help increase profit margins are yield and early maturity. Many experiments have compared UNR and conventionally spaced cotton for lint yield. The results to this point have been mixed. For example, Cawley et al. (1999) showed that UNR cotton had equivalent yields to wider rows in one year, but significantly higher yields in the next. Lower yields were obtained for UNR cotton fertilized with 90, 112, 134 or 157 kg nitrogen $^{ha-1}$ when compared with wide row checks at 90 kg nitrogen ha^{-1}, although it should be noted that a replanting of only the UNR

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treatments was probably partially responsible for their lower yields (Boquet et al., 1998). Because nitrogen fertilizer rate impacts cotton yield, an important question for research is the potential interaction between nitrogen fertilizer rate and row spacing on lint yield.

A common goal in cotton production is early maturity. Metzer (not dated) points out that if cotton matures earlier, the prevailing weather is more favorable while fiber is maturing and for the operations of defoliation and harvest. He also associates potential for lower input expenses with shorter fruiting duration. Some studies have shown evidence that UNR cotton can mature earlier than cotton in conventional row spacings. One example is earlier occurrence of 60 percent harvest, found by Jost and Cothren in the first year reported (2001). A less direct measurement, earlier cutout, was noted by Cawley et al. (1999). Nitrogen also can impact the earliness of the cotton crop (Weir et al., 1996). Since both of these parameters influence the length of the season, the interaction between nitrogen fertilizer rate and row spacing on earliness is an important topic of research.

Therefore, this research focused on UNR cotton and cotton in a wider row spacing, examining main effects and interactions between row spacing and nitrogen fertilizer rate on yield, earliness, and parameters contributing to them. From the data, the question of whether UNR cotton requires different nitrogen fertilizer rates than conventional cotton was also addressed.

Yield

Despite the mixed yield results, certain characteristics of UNR cotton appear to provide high yield potential. McFarland et al. (1999) suggest that improvements in water use efficiency and use of light are associated with UNR cotton. Earlier canopy closure has been documented in 19- or 38.1-cm spacings as compared to 76.2- or 101.6-cm spacings (Jost and Cothren, 2000). This early canopy closure was thought to have potential to curtail direct soil evaporation losses (Jost and Cothren, 2000, 2001; Krieg, 1996). In a study utilizing different plant populations at 19- and 38.1-cm spacings, the higher populations at these spacings tended to have a more rapid increase in their leaf area indices than 76.2- or 101.6-cm rows (which were at one population each) (Jost and Cothren, 2001). Heitholt et al. (1992) calculated seasonal insolation interception for both normal-leaf and okra-leaf cotton, as affected by row spacing and planting date. They found significant increases in seasonal insolation interception in 0.5-m as compared to 1-m rows in most cases. Because the level of sunlight and the amount of available water are potentially limiting in many areas, any increase in efficiency of use of these resources may improve yield.

In terms of the nitrogen fertilizer and row spacing interaction on lint yield, several factors are important. McFarland et al. (1999) point out that certain characteristics of UNR cotton have implications for nitrogen requirements. Greater need for nitrogen could be indicated by factors such as higher yield potential, while the opposite is implied by attributes that include “more effective use of soil N”. Although such attributes themselves may require further verification, their contrasting implications illustrate the questions that remain in this area. A factor that could affect the nitrogen use of UNR cotton is the vegetative to reproductive ratio. If the biomass, (and thus potentially the nitrogen) in the plant was partitioned more highly to bolls, this could imply greater nitrogen use efficiency in terms of boll mass per unit nitrogen applied. Jost and Cothren (2001) found significant differences among row spacings in percent aboveground biomass partitioned to bolls at 91 days after planting, in the first year reported. This included a significantly higher percent for medium and high planting density 19-cm rows as compared to the one 102-cm row treatment. Although no significant differences in this parameter were found in the following year, if the first year is typical, this might imply greater nitrogen use efficiency for UNR cotton. The question of whether or not UNR cotton is more efficient at converting nitrogen to lint yield may have important implications on fertilizer requirements and profitability.

Earliness

Earliness in UNR cotton originates from the fact that each cotton plant in UNR or similar systems has a reduced number of blooms per plant, allowing more rapid completion of the fruiting period (Lewis, 1971). In conventional cotton, the producer must wait to harvest until bolls set later in the extended fruiting period are mature. In UNR cotton, the crop may be ready for harvest more quickly due to of the lack of late set bolls.

However, certain factors could counteract this potential. Munro (1971) emphasized four factors contributing to the rapidity of fruiting point production, along with various other items that influence earliness. These factors were the first fruiting branch node, the first position flowering date of a given main stem node, the "vertical flowering interval," and the "horizontal flowering interval." Reductions in these factors lead to increased earliness. Likewise, increases could work against earliness advantages that might otherwise occur in UNR cotton.

Over-fertilization with nitrogen has well-known effects on the earliness of cotton. Excessive nitrogen fertilization can cause the season to be prolonged (Weir, et al., 1996). In contrast, growth of plants (in general) is inhibited when nitrogen is deficient (Taiz and Zeiger, 1998), which could potentially delay node and fruiting site addition in cotton and also counteract earliness advantages, as discussed above. Therefore, either insufficient or excessive fertilization of UNR cotton can reduce the system's potential for earliness.

Leaf Size

A factor that may have an indirect relationship to yield and earliness is individual leaf size. Considerable research has been done on leaf carbon assimilation, growth and size in cotton. Ashley (1972) found that the leaf subtending the boll on the fruiting branch contributed a substantial part of its photosynthate to that boll. Constable and Rawson (1980) demonstrated that $^{14}CO_2$ applied to 33- and 45-day-old 7th node main stem leaves was partially translocated to fruit. Thus, the fruit may receive photosynthate from subtending and main stem leaves. All else being equal, a leaf can assimilate more carbon if it has a greater area. Leaf size has been found to be influenced by light and temperature (Mutsaers, 1983), planting density (Constable, 1986) and nitrogen nutrition (Radin and Parker, 1979). Because of the potential importance of leaf size to boll photosynthate supply, and thus indirectly on overall yield, it is also of interest to examine the interaction of row spacing and nitrogen nutrition on leaf size.

EXPERIMENTAL OBJECTIVES

The overall objectives of this study were to compare cotton in two UNR spacings and one conventional row spacing for yield and earliness, and to observe effects of nitrogen fertilizer rate to determine if nitrogen requirements differ among the three row spacing systems.

Lint yield was assessed for each treatment. To help explain the data from lint yield, certain yield components were measured such as boll weight, average ginout, and number of bolls. Objectives also included the comparison of the size and growth of leaves from each treatment in order to understand any potential impacts on or relationship to yield. Earliness objectives included estimating the days to reach 60% seedcotton harvest and examining earliness components that contributed to this result. To provide understanding of yield and earliness data, the height, total nodes, height to node ratio, and distribution of bolls were compared among the different treatments.

MATERIALS AND METHODS

Location and Cultural Practices

The study was located at the Texas Agricultural Experiment Station farm in Burleson County, near College Station, Texas. The field used in 2000 was a Ships clay (very-fine, mixed, active, thermic Chromic Hapluderts), and that used in 2001 was a Weswood silty clay loam (fine-silty, mixed, superactive, thermic Udifluventic Haplustepts). In 2002, the cotton was planted in the same field used in 2000. In each year, the field on which the cotton was established had been depleted of nitrogen by growing sorghum without nitrogen fertilization in the preceding year. This practice was effective in reducing preseason soil nitrate levels in the surface 15.2 cm to an average of 7, 9, and 8 ppm in 2000, 2001, and 2002 respectively, as shown in Table 1. Low residual nitrate was found throughout the soil profile as well (Table 1). Analysis of soil samples was performed by the Texas A&M University System Soil Testing Laboratory, in College Station, TX. Based on the nitrate levels in the surface 15.2 cm, this laboratory provided a recommendation of 101 kg N ha^{-1} for the 2000 cropping season. The fields were irrigated by means of an overhead linear sprinkler system.

Production practices applicable to the local area were utilized as far as possible. Preplant herbicide applications of Prowl 3.3 EC, active ingredient pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) were made in all three years at a rate of 2.7 liters per ha. Preemergence applications of Dual II Magnum, active ingredient

Table 1. Preseason soil tests.

	2000	2001	2002
Surface†			
nitrate (ppm)	5	8	9
organic matter (%)	1.6	1.1	1.5
Profile nitrate (ppm)‡			
0 - 15.2 cm	6	7	8
15.2 - 30.5 cm	5	7	7
30.5 - 45.7 cm	4	6	5
45.7 - 61.0 cm	4	6	5
61.0 - 91.4 cm	2	6	5

†Mean of multiple soil tests. Sample(s) were of the surface 15.2 cm of the entire field.
‡Mean of four locations in the field

s-metolachlor (acetamide, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl]-,(S) at 1.6 liters per ha and Caparol 4L, active ingredient prometryn (2,4-bis(isopropylamino)-6-(methylthio)-s-triazine) at 4.7 liters per ha were made in 2000 and 2001. Based on the preseason soil tests, the only fertilizer nutrient applied was nitrogen, which is discussed below as one of the experimental treatments. Although glyphosate-tolerant cotton was planted, no applications of glyphosate were made in any year. After emergence, weeds were controlled by hoeing or hand pulling. Mepiquat Chloride (N, N-dimethylpiperidinium chloride) applications were made in each year as needed. Insect pests were controlled aggressively as guided by scouting. The Texas Boll Weevil Eradication Program, initiated in the area in 2001 (Texas Boll Weevil Eradication Foundation, Inc., 2003), became instrumental in maintaining low populations of insects in 2002. Climatic conditions for the experimental area are reported in Table 2, although precipitation is probably underestimated in some periods in these data.

Experimental Design and Establishment

The experimental design was a split plot, with whole plots being nitrogen fertilizer rates of 0, 50, 101, and 151 kg ha^{-1}. These levels were chosen to bracket the 2000 recommended fertilizer rate of 101 kg N ha^{-1} and to include a control level of 0 kg N ha^{-1}. The split plots were row spacings of 19, 38, and 76 cm. Although 76 cm is considered a "narrow row" spacing, since it is quite common it is considered to be conventional for the purposes of this study. Information on fertilization and planting is

Table 2. Weather data, Texas Agricultural Experiment Station Farm, Burleson County, TX. †

Month	2000	2001	2002
Precipitation (mm)‡			
May	136	125	216
Jun	88	115	41
Jul	9	5	80
Aug	17	130	123
Sep	37	193	57§
Average high temperature (C)			
May	30.8	30.5	30.5
Jun	32.6	32.4	33.7
Jul	37.2	35.3	33.8
Aug	37.3	35.5	34.9
Sep	34.2	31.0	33.0§
Average low temperature (C)			
May	20.1	18.5	18.1
Jun	22.2	21.3	21.2
Jul	22.0	22.8	22.5
Aug	21.5	22.9	22.4
Sep	18.9	19.0	19.4§
dd60s			
May	552.6	499.4	488.3
Jun	639.7	610.3	641.3
Jul	782.7	754.6	702.4
Aug	774.1	759.4	730.4
Sep	594.9	510.6	558.0§

†Sources: Witten T.K. 2000, 2001, and 2002, personal communications.
‡Precipitation is probably underestimated in this data for July 2002 and potentially other periods
§Includes only Sep 1 - 29, 2002

Table 3. Fertilization and planting dates.

	2000	2001	2002
Fertilization			
Date	April 27	April 19	April 24
Days before planting	18	29	7
Planting	May 15†	May 18‡	1-May

†Second planting. First planting was April 28, 2000
‡Second planting. First planting was May 4, 2001

provided in Table 3. The nitrogen fertilizer material was UAN-32, surface applied with flood nozzles (TeeJet Flow Regulators 4916-48 with Fertilizer Stream Caps) and incorporated within approximately three hours. Cotton was planted flat using a Great Plains grain drill set on 19-cm row spacings, closing off seed drop tubes as needed to establish the 38- and 76-cm row spacing treatments. The cultivar used was DeltaPine 422 B/RR. In 2000 and in 2001, severe storms prevented cotton emergence after planting on 28 April and 4 May respectively. Cotton was replanted in 2000 on 15 May, and in 2001 on 18 May, with a satisfactory stand resulting at each replanting. In 2002 an excellent stand was achieved from cotton planted on 1 May (Table 3). The cotton was planted at high populations and hand thinned, with resulting populations as described in the Results and Discussion section.

Data Collection

Yield and Earliness

Lint yield was collected by multiple hand harvests of a 1.52- by 4.57-m area in each plot. Harvests were initiated when approximately of 5 to 15 percent of bolls were open, repeated at three- to four-day intervals (weather permitting) until the greater part of the bolls had been harvested, and then performed less frequently thereafter. Once the majority of bolls were harvested, a harvest aid application was made to help open the remaining bolls, and one final harvest was performed. Eight hand harvests were performed in 2000. In 2001, only three hand harvests were performed due to heavy rainfall during boll opening. In 2002, seven hand harvests were performed. Seedcotton from each harvest was weighed separately, and the total seedcotton yield was calculated as the sum of all harvests in a given year.

For each harvest date, the weight of the seedcotton harvested was added to that of previous harvests, and this subtotal was divided by the total seedcotton from all harvests to calculate the percent of total yield harvested by that date. This is termed cumulative percent seedcotton harvested (CSH) in this report, and is used as a measure of earliness. Estimates of days after planting (DAP) to 60 percent seedcotton harvest were made by linear regression between the CSH from the two harvests immediately above and below 60 percent CSH for each plot. This regression was done on the treatment means in question, rather than individually for each plot. The final CSH harvest date was 100 percent for all plots by definition.

Ginout was obtained by mixing the seedcotton from all harvests in each plot in each year, pulling a sample from this composited harvest, and ginning it on an 8-saw laboratory gin. The resulting lint was sent to the International Textile Center in Lubbock, TX for HVI quality analysis. In 2002, the sample was pulled from a mix of all but the last harvest. As of the 6^{th} harvest (of 7) in 2002, each nitrogen and row spacing mean was at 93 percent CSH or higher, showing that the great majority of cotton had already been picked. Therefore, the exclusion of the last harvest from the sample is not thought to have substantially impacted ginout or quality.

To determine earliness, the seedcotton weight from each harvest date was added to the weight of all previous harvests, giving the weight of seedcotton harvested to that point. This subtotal was then divided by the total weight of all harvests to find the percent of total seedcotton picked by each harvest date. Sixty percent seedcotton harvest was considered a critical value because it is an approximation of 60 percent open boll (although this approximation could be affected by diminishing boll size with time), at which point harvest aids are often applied. The date each plot reached this value was approximated by a linear regression between the harvests immediately prior and immediately following 60 percent seedcotton harvest. This estimation was made only in 2000 and 2002, when the dates of these two harvests were close together. In 2001, when harvests could only be made near the beginning and end of the boll-opening period, estimates of 60 percent seedcotton harvest were not thought to be as meaningful and are not reported

Plant Population

To calculate final plant populations, a 3.05 m pole was placed at random in the hand-harvested area of each plot, and the number of plants within its length in each adjacent row was counted. Based on the area that 3.05 m of row represented in each row spacing, the mean of these two stand counts was converted to plants per hectare.

Individual Bolls

In each plot, one meter of row was reserved to obtain information on individual boll development. Each flower within that meter of row was tagged with the date of floral opening. As bolls opened in this meter of row, they were harvested daily. Bolls were considered to be open when the maximum distance between carpel tips was approximately 1 cm or greater. The main stem node and sympodial branch position of the harvested bolls on the plant was noted, as well as the dates of harvest. Bolls on monopodial branches were simply classified as vegetative. From each boll, the locks were counted, and the seedcotton was removed from the carpels to dry. Once air dry, the weight of the seedcotton from the boll was obtained. If the boll was produced on a damaged branch or peduncle, or was itself damaged, this was noted. Damage to branches or peduncles was uncommon, while damage to bolls was dependent on the level of insect pressure experienced, and was much higher in 2001 than in the other years.

In 2000, boll numbers and distribution information (discussed below) was obtained from this “tagged meter”. Since many of the damaged bolls still contained harvestable lint, all damaged bolls were included in this analysis, as well as bolls occurring on damaged branches or peduncles. However, bolls containing less than 1 g seedcotton were excluded as being unharvestable. Because the identification of a plant with terminal damage was only made on the boll when it was harvested, it was not always clear how many such plants had been in the tagged meter. This created the necessity for the boll numbers and distribution statistics to be carried out on slightly varying subsets of bolls. For the number of bolls per hectare (based on the area included in the meter of row) and total bolls per plant, bolls from plants with aborted terminals were included. Bolls on plants with terminal damage were excluded from means on boll distribution within regions of the plant.

Average seedcotton weight per boll was obtained from the bolls within the tagged meter in each year. To determine the most accurate weights possible, bolls with damage, or which originated on damaged branches or peduncles were excluded from the analysis. As in the mapping dataset for 2000, bolls containing less than 1 g seedcotton were excluded as unharvestable. Bolls located on plants having terminal damage were not included in the analysis. An exception to this procedure occurred in 2001, when terminal damaged plants where a branch had clearly taken over as the main stem, or in which the terminal damage occurred high on the plant, were counted as normal and bolls from these plants included.

Boll maturation period was determined as the number of heat units between flowering and boll opening for an individual boll in the tagged meter. The bolls included in this analysis were the same subset used to calculate average seedcotton weights per boll. However, bolls missing either a date of bloom or harvest were of necessity excluded. Since bolls were set and matured at various times in the season, boll maturation period is reported in heat units to reduce the influence of climatic variables on the data. All other parameters which involve the timing of events are reported in days after planting, which provides a uniform starting time.

The data on specific site flowering date originated with all bolls located at mainstem node 8, position 1 from which a date of bloom could be collected. All bolls in this location were included since the data of interest were the timings of flowering rather than properties specific to the boll itself.

Boll Numbers and Distribution

End-of-season box mapping data were obtained for each plot. This provided similar data to the method of Jenkins et al., (1990a); however, boll counts and seedcotton weights were obtained for node groupings rather than individual nodes, and plants were not taken from a continous length of row. In the method used, six representative plants per plot were selected and removed from the field. For each plot, seedcotton was removed from the plants and sorted by main stem node range (nodes 3-5, 6-10, 11-15, or 16-20) and position (1, 2, 3, or 4 and above) on the sympodial branch. All bolls on vegetative branches were grouped together. As part of the mapping process, the number of bolls at each position within each node range was counted, and the weight of the seedcotton in that grouping recorded. Similar information was obtained for vegetative branch bolls as a group. Final plant populations were used to convert boll totals into bolls per hectare, in contrast to the method used in 2000. Box mapping was performed only in 2001 and 2002. As discussed above, individual boll information from one meter of row per plot was used in 2000 to provide similar data to box mapping.

Plant Architecture

In 2000, heights and total nodes were measured from all plants without terminal damage within the tagged meter. Nodes were counted as done by Bednarz et al. (2000), with the node immediately above the cotyledonary node considered to be node 1. Heights were divided by total nodes to calculate the height to node ratio for each plant. In 2001 and 2002, heights, total nodes, and height to node ratios were similarly obtained for the six plants used in box mapping.

Leaf Area

Leaf area can be estimated using measurements of properties such as length and width (Bange et al., 2000). Data was collected on leaf area in two steps. The first step, designed to determine the relationship between leaf length and leaf area, consisted of sampling main stem leaves of various sizes from the field. Length and area were measured for each. Linear regression analysis was performed to find the relationship of area (ha) to length (L), under the assumption that this relationship is the same for each treatment.

The second step, which allowed the application of the above relationship to leaves in the various treatments, was periodic determination of the length of leaves in the field during their development. Approximately a month and a half after planting, three newly unfolded main stem leaves per plot were tagged for identification. Their lengths were measured every two to three days for approximately three weeks, and with less frequency thereafter as their growth began to slow. In 2000, main stem leaves were unfolding at differing nodes in the various nitrogen treatments on the day leaves were tagged. Thus, the marked leaves were at the 9th, 10th, 11th, and 12th nodes in the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, respectively. In 2001 and 2002, the numbers of nodes were more uniform across nitrogen treatments, and each tagged leaf was at the 10th node. Using the regressions from the first step, the lengths measured in the field were converted to areas.

Statistical Analysis

Analysis of variance followed by Duncan's New Multiple Range Test separation of treatment means was completed using PROC GLM in SAS (SAS Institute, 1999). Differences in row spacing and plant populations resulted in widely varying numbers of plants and bolls (i.e. subsamples) from the tagged meters. Because of this unequal subsampling, the use of approximate F tests using Satterthwaite's procedure was required for certain data from the tagged meter (individual bolls parameters as opposed to percentages or counts) (Lentner and Bishop, 1993). Satterthwaite's procedure was carried out in SAS using PROC GLM with a RANDOM statement and the /TEST option (SAS Institute, 1999). Using this syntax, some tests were done under the assumption that "one or more other fixed effects are zero." The meaning and implications of this assumption are not clear. The approximate mean separations were carried out by hand, as outlined in Lentner and Bishop (1993). Leaf area data had a small number of missing leaves, potentially creating unequal subsamples as well. However, the p values generated by F-tests using Satterthwaite's approximation were highly similar to those of the non-approximated F-tests, and therefore analysis was carried out as if completely equal subsamples had existed for leaf area.

Homogeneity of variance between years was tested as described by Gomez and Gomez (1984), including the testing of both error terms of the split plot design. When approximated error terms were utilized for Satterthwaite's procedure, the test for homogeneity of variance was performed on the error terms for the nitrogen, row spacing, and nitrogen by row spacing interaction effects. Data were combined over years only homogeneity of variance existed for each tested error. All percent data, such as percent seedcotton harvested, were transformed using the arcsin of the square root as listed by Lentner and Bishop (1993). No other data were transformed, although this may be required for future analysis. Linear regression analysis of the relationship between leaf length and leaf area was performed with SPSS (SPSS, 2000; 2001).

RESULTS AND DISCUSSION

Lint Yield

Lint yield data are reported in Table 4. In 2000, mean yields were 949, 1133, 1340, and 1479 kg lint ha^{-1} for the 0-, 50-, 101-, and 151-kg N ha^{-1} fertilizer rates, respectively. All differences were significant except that between the two highest rates, 101 and 151 kg N ha^{-1}. Row spacing did not cause significant differences in lint yield in 2000. Numerically, the mean lint yield of the 19-cm row spacing was the lowest, at 1127 kg ha^{-1}, while the mean lint yields of the 38- and 76-cm row spacings were 1308 and 1293 kg ha^{-1}, respectively (Table 4).

In 2001, there were significant increases in lint yield by nitrogen fertilizer rate. As in 2000, the only difference that was not significant occurred between 101 and 151 kg N ha^{-1}. Mean yields were 541 kg N ha^{-1} with no nitrogen applied, and 856, 963, and 1011 kg lint ha^{-1} at the 50-, 101-, and 151-kg N ha^{-1} rates. Row spacing treatments did not affect lint yield in 2001. Mean lint yields were 889, 799, and 826 kg ha^{-1} for the respective 19, 38, and 76-cm row spacings (Table 4).

Significant increases were found in lint yield with each additional nitrogen fertilizer increment (including 151 kg N ha^{-1}) in 2002. Yields means were 1039, 1394, 1618, and 1757 kg lint ha^{-1} at the 0-, 50-, 101-, and 151-kg N ha^{-1} fertilizer treatments. Lint yields in the three row spacings were almost identical in 2002, with mean values of

Table 4. Mean lint yield. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Mean	2000	2001	2002
	----------kg lint ha^{-1}----------		
Year	1 227	838	1 452
Nitrogen†			
0	949c	541c	1 039d
50	1 133b	856b	1 394c
101	1 340a	963a	1 618b
151	1 479a	1 011a	1 757a
Row spacing (cm)			
19	1 127a	889a	1 451a
38	1 308a	799a	1 462a
76	1 292a	826a	1 442a

†Nitrogen fertilizer rate, kg N ha^{-1}

1451, 1462, and 1442 for the 19-, 38-, and 76-cm row spacings, respectively. No significant differences existed among row spacing means (Table 4).

When lint yield data were combined over years, neither nitrogen by row spacing nor year by nitrogen by row spacing interactions were present. However, F tests generated p values of 0.0379 and 0.0480 for the respective the year by nitrogen and the year by row spacing interactions, showing that these were slightly significant. Therefore, treatment effects on lint yield will be discussed separately by year[1].

A highly significant year effect was evident in data combined over years. Over all treatments, lint yield means were 1238, 838, and 1452 kg ha^{-1} in 2000, 2001, and 2002, respectively, with all differences significant. Although there were differences in this effect by treatment as evidenced by the year by treatment interactions, the same trend of greatest yield in 2002 and least in 2001 was present within each treatment.

Discussion

Several factors, including soil type, climatic conditions, and insect pressure may have contributed to the large year effect apparent in the lint yield data. In 2000, when yields were intermediate, the weather was hot and in-season rainfall was extremely limited. During July 9 mm of rainfall was received, and during August 17 mm was

[1] If the slight year by nitrogen and year by row spacing interactions are disregarded, the mean lint yields combined over years were 842, 1128, 1306, and 1452 kg lint ha-1 for the respective 0-, 50-, 101-, and 151-kg N ha-1 treatments, with all differences significant. By row spacing, mean lint yields combined over years were 1162, 1193, and 1197 kg ha-1 for the 19-, 38-, and 76-cm rows, respectively, with no difference significant.

received. In 2002, by contrast, 80 and 123 mm of rain were received, respectively, during July and August (Table 2). Available irrigation water was not sufficient to fully prevent plants from suffering drought stress, which was probably the limiting factor on lint yields in this year.

Yields were lowest in 2001. Soil type may have played a role in this yield reduction, as the field was a Weswood silty clay loam in 2001 and a Ships clay in the other years. Jost and Cothren (2001), in a study performed on similar soils, found that in the year that their study was carried out on a Weswood silt loam, the cotton had a much higher leaf area index than in the year when it had been grown on a Ships clay. They attributed this difference mainly to soil type. In 2001, indications were seen in individual leaf area as well as plant architectural data, as discussed below, that vegetative growth was greater than in 2000 or 2002. If this growth came at the expense of reproductive development, such growth could have been partly responsible for yield reductions. However, other factors were probably very important, especially insect pressure. There appeared to be more plants with damaged terminals as well as many more bolls damaged by insects in 2001. During the boll-opening period, large amounts of rainfall may have caused losses of seedcotton to some degree in this year as well (Table 2).

In 2002, excellent growing conditions were present, bringing about the highest yields of the three years. As mentioned previously, this was the only season in which replanting was not required, allowing the stand to be established approximately two weeks earlier than in previous years. Good rainfall was received, especially during July while cotton was fruiting, and a late irrigation was also applied. There was little rain during harvest. Mid- and late-season insect control was excellent, assisted in part by pesticide applications for the Texas Boll Weevil Eradication Program.

Nitrogen effects on lint yield were significant in each year. In 2000, nitrogen deficiency symptoms including chlorosis and reduced growth were very apparent in the 0- and, to a lesser degree, in the 50-kg N ha^{-1} treatments. Mean lint yields were surprisingly high in plots receiving the 0- and 50-kg N ha^{-1} rates despite the visual symptoms observed. Although plants in these treatments were small and chlorotic, boll retention appeared to be high relative to plant size and consistent within the plots. In 2001, visual nitrogen deficiency symptoms were much less prominent and appeared later in the season. Significant differences in mean lint yield by nitrogen rate followed the same pattern as in 2000, showing that nitrogen still impacted yields although preharvest deficiency symptoms were less obvious. In 2002, nitrogen deficiency symptoms were again highly apparent in the field, although not as early as in 2000. Each increase in lint yield due to higher nitrogen rate was significant in 2002, including the difference between 101 and 151 kg N ha^{-1}, which was not significant in 2000 or 2001. Because the magnitude of the lint yield difference between 101 and 151 kg N ha^{-1} was similar in 2000 and 2002, its lack of significance in 2000 may simply have been due to increased variability in the data or missing values in that year rather than a different nitrogen response. As in 2000, mean lint yields were high even in 0- and 50-kg N ha^{-1} treatments. Although preseason soil nitrate was low (Table 1), mineralization of soil organic matter may have been responsible for this response. Franzluebbers et al. (1996) found that in a

Weswood silty clay loam, a net of 0.05 g N per m^2 per day could be mineralized from soils in a conventionally tilled sorghum-wheat-soybean rotation.

There were no significant effects of row spacing on lint yield in any year, and the numeric ranking of the three row spacing means was inconsistent between years. In 2000, the 19-cm rows produced the lowest lint yields, while in 2001 the lint yields of the 19-cm row spacing were the highest. All three row spacings produced similar lint yields in 2002. The effects of the row spacing treatments and their respective plant populations on parameters such as bolls per hectare, ginouts, and average boll weights combined to result in lint yields that did not significantly differ by row spacing in any year.

Plant Populations

Plant populations were targeted to be constant over all nitrogen rates, and to increase with each reduction in row spacing. Plants per hectare data are reported in Table 5. However, in 2000, a significant nitrogen by row spacing interaction on final plant population was seen. Unusually high populations occurred in the 19-cm, 101-kg N ha^{-1} treatment, which averaged 344,433 plants ha^{-1} as compared to the other three 19-cm treatment means which ranged from 277,699 to 297,073 plants ha^{-1}. This difference was almost certainly due to inconsistency in thinning rather than a physiological response.

The 38-cm row spacing means ranged from 191,591 to 212,042 plants ha^{-1}, while the 76-cm treatment means ranged from 127,548 to 146,384 plants ha^{-1}. Data on population means for each treatment in 2000 is reported in Table 6.

In 2001, final plant population means were 289,323, 183,410, and 127,625 plants ha^{-1} for the 19-, 38-, and 76-cm row spacings, respectively, with all differences significant. There were no significant differences in final plant populations by nitrogen rate in 2001 (Table 5).

In 2002, final plant populations for the 19-, 38-, and 76-cm row spacings were 298,688, 204,776, and 145,710 plants ha^{-1}, respectively. As in 2001, nitrogen rate did not significantly affect final plant populations (Table 5).

Over all treatments, mean final plant populations were 213,438 plants ha^{-1} in 2000, 201,767 plants ha^{-1} in 2001, and 216,392 plants ha^{-1} in 2002, with the average for 2001 significantly lower than that of the other two years in an analysis of variance combined over years. A significant year by nitrogen by row spacing interaction occurred, probably due to the variation present in 2000, as discussed above.

Table 5. Final plant populations. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Mean	2000†	2001	2002
	---plants ha^{-1}---		
Year	213 438	201 767	216 392
Nitrogen‡			
0		212 725a	220 114a
50		197 690a	217 064a
101		200 203a	216 526a
151		195 896a	211 863a
Row spacing (cm)			
19		289 323a	298 688a
38		183 410b	204 776b
76		127 625c	145 710c

†Nitrogen and row spacing main effect means are not listed due to significant nitrogen by row spacing interaction
‡Nitrogen fertilizer rate, kg N ha^{-1}

Table 6. Final plant populations by treatment, 2000.

	Nitrogen Rate (kg N ha^{-1})			
Row spacing (cm)	0	50	101	151
	---plants ha^{-1}---			
19	290 615	277 699	344 433	297 073
38	212 042	191 591	192 667	194 820
76	146 384	127 548	134 544	131 315

Discussion

In Texas, conventional cotton populations are considered low if below 74,129 and high if above 148,258 plants per ha. For UNR cotton, recommended populations are 197677 to 247097 plants per ha (Sansone et al., 2002). Another recommendation, not directed toward a particular state, is 247,097 to 395,355 plants ha^{-1} (BASF, 1999). The 76-cm row spacing plant population means in this study fell within the recommendations for conventional rows, and the 19-cm means were within the higher recommendations for ultra-narrow rows. The 38-cm row final plant population means were intermediate between those of the other two row spacings. Although the yearly mean populations differed significantly, the differences were relatively small.

The treatment means within the 19-cm row spacing varied by a maximum of 66,733 plants ha^{-1}, and all means were within the recommendations given by BASF (1999). Bednarz et al. (2000) compared seedcotton yield from 3 meters of row in widely varying populations, including a minimum population range of 25,000 to 45,000 and a maximum population range of 205,000 to 230,000 plants per ha. No significant differences in seedcotton yield were present among the treatments. Therefore, the interaction between row spacing and nitrogen rate found in 2000 probably had little impact on lint yield.

Plant Architecture

Plant architecture data included plant height, total nodes, and height to node ratio (HNR), and are reported in Table 7. As discussed in the materials and methods section, the data were taken from a different type of sample in 2000 from that used in 2001 and 2002, and therefore combination of the data over the three years was not attempted. Homogeneity of variance between 2001 and 2002 allowed data to be combined over these years for two of the three plant architecture variables—total nodes and height to node ratio (HNR).

Height

In 2000, mean heights were 33.0, 36.4, 49.6, and 54.1 cm in the respective 0-, 50-, 101-, and 151-kg ha^{-1} nitrogen rates, with all differences significant other than that between 0 and 50 kg N ha^{-1}. Height was significantly affected by row spacing in 2000 as well, with means of 34.4, 42.1, and 48.9 cm in the 19-, 38-, and 76-cm row spacings respectively. Each difference between row spacing means was significant (Table 7).

Height differences were much less pronounced in 2001. By nitrogen rate mean heights were 62.2, 70.3, 62.3, and 74.8 cm in the 0-, 50-, 101-, and 151-kg N ha^{-1} rates, respectively. The 151-kg N ha^{-1} mean was significantly greater than those of the 101- and 0-kg N ha^{-1} rates. Numerically, the 50-kg N ha^{-1} mean was greater than that of the

Table 7. Height, total nodes, and height to node ratio (HNR). Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Year	Mean	Height	Total Nodes†	HNR
		cm	no. plant^{-1}	cm node^{-1}
2000	Year	42.8	16.5	2.6
	Nitrogen‡			
	0	33.0c	15.8c	2.1c
	50	36.4c	15.3c	2.4b
	101	49.6b	16.9b	2.9a
	151	54.1a	18.0a	3.0a
	Row spacing (cm)			
	19	34.4c	15.0b	2.3c
	38	42.1b	16.6a	2.5b
	76	48.9a	17.3a	2.8a
2001	Year	66.9	20.3	3.4
	Nitrogen‡			
	0	62.2b		3.1c
	50	70.3ab		3.4ab
	101	62.3b		3.3b
	151	74.8a		3.6a
	Row spacing (cm)			
	19	64.5a		3.3a
	38	65.6a		3.3a
	76	70.6a		3.5a
2002	Year	51.9	18.2	2.8
	Nitrogen‡			
	0	42.1d	17.2a	2.4c
	50	47.8c	17.4a	2.7b
	101	54.6b	18.5a	2.9ab
	151	63.6a	19.9a	3.2a
	Row spacing (cm)			
	19	42.4c	17.0c	2.5c
	38	49.6b	18.3b	2.7b
	76	63.7a	19.3a	3.3a

†In 2001, nitrogen and row spacing main effect means are not listed due to significant nitrogen by row spacing interaction
‡Nitrogen fertilizer rate, kg N ha^{-1}

101-kg N ha^{-1} rate, showing some variability in height response in 2001. The effects of row spacing were not significant in 2001 (Table 7).

In 2002, all differences between nitrogen means for height were significant, with values of 42.1, 47.8, 54.6, and 63.6 cm for the 0-, 50-, 101-, and 151 kg N ha^{-1} rates. Row spacing means in 2002 were 42.4, 49.6, and 63.7 cm for the respective 19-, 38-, and 76-cm spacings, with all differences between row spacing means significant as well (Table 7).

Across all treatments, heights averaged 42.8, 66.9, and 51.9 cm in 2000, 2001, and 2002 (Table 7). Because of differences in method of sampling the plants, the heights collected in 2000 may not be comparable to those in the following years. Comparison of 2001 and 2002 only, showed the tallest plants overall were found in 2001.

Total Nodes

In 2000, significant differences were present in total nodes between all nitrogen rates with the exception of 0 and 50 kg N ha^{-1}. Means were 15.8, 15.3, 16.9, and 18.0 nodes per plant for the respective 0-, 50-, 101-, and 151-kg N ha^{-1} treatments. By row spacing, total node means were 15.0, 16.6, and 17.3 nodes per plant for the 19-, 38-, and 76-cm rows, respectively, with the 19-cm row spacing mean significantly lower than that of the other two spacings (Table 7).

In 2001, a significant interaction was present between row spacing and nitrogen rate for total nodes. The response to nitrogen was irregular between the various levels of row spacing. For example, the highest total nodes per plant mean for the 19-cm row spacing was at 50 kg N ha^{-1}, and the highest total nodes mean for the 76-cm row spacing was found at 0 kg N ha^{-1}. Data on total nodes by treatment in 2001 is reported in Table 8.

The response in 2001 of total nodes to row spacing within most nitrogen rates was more typical. The trend within the 0-, 101-, and 151-kg ha^{-1} nitrogen rates was for lower mean total nodes with each reduction in row spacing, although the magnitude of the differences was usually small. However, at 50 kg N ha^{-1} this pattern was not seen (Table 8).

In 2002, nitrogen rates did not significantly affect total nodes. All differences between row spacings were significant for total nodes in 2002. Means were 17.0, 18.3, and 19.3 nodes per plant for the 19-, 38-, and 76-cm row spacings, respectively. Averaged across all treatments, the total nodes means for 2000, 2001, and 2002 were 16.5, 20.3, and 18.2, respectively (Table 7). When 2001 and 2002 were combined over years, the difference between them was significant. However, a significant year by nitrogen by row spacing interaction occurred for total nodes. This is probably due to the nitrogen by row spacing interaction present in 2001. Despite this interaction, the mean number of nodes for each nitrogen by row spacing combination in 2001 was greater than (or in one case equal to) the mean of the corresponding treatment in 2002.

Table 8. Total nodes by treatment, 2001.

	Nitrogen Rate (kg N ha^{-1})			
Row spacing (cm)	0	50	101	151
	--nodes $plant^{-1}$--			
19	17.4	21.5	19.4	20.2
38	20.5	19.3	20.2	20.6
76	22.0	20.6	20.9	20.9

Height to Node Ratio (HNR)

In 2000, HNR means were 2.1, 2.4, 2.9, and 3.0 cm per node for the respective 0-, 50-, 101-, and 151-kg ha^{-1} nitrogen rates. All differences between nitrogen means were significant except for that between the 151- and the 101-kg N ha^{-1} rates. Significant differences in HNR were present between all row spacing means in 2000. The values of these means were 2.3, 2.5, and 2.8 cm per node in the 19-, 38-, and 76-cm row spacings, respectively (Table 7).

In 2001 the respective 0-, 50-, 101-, and 151-kg ha^{-1} nitrogen rates had HNR means of 3.1, 3.4, 3.3, and 3.6 cm per node. Differences between nitrogen means were significant except between 50 and 101 kg N ha^{-1} and between 50 and 151 kg N ha^{-1}. As was the case for height, the 50-kg N ha^{-1} treatment was numerically higher in mean HNR than the 101-kg N ha^{-1}. Row spacing effects on HNR were not significant in 2001 (Table 7).

Mean HNRs were 2.4, 2.7, 2.9, and 3.2 cm per node in the 0-, 50-, 101-, and 151-kg ha^{-1} nitrogen rates, respectively, in 2002. Differences between the means were significant other than those between 101 and 151 and between 101 and 50 kg N ha^{-1}. Row spacing significantly impacted HNR in 2002, with all differences between means significant. Row spacing means were 2.5, 2.7, and 3.3 cm per node for the 19-, 38-, and 76-cm row spacings, respectively (Table 7).

Yearly means for HNR were 2.6, 3.4, and 2.8 cm/node for 2000, 2001, and 2002 respectively (Table 7). When data were combined over 2001 and 2002, differences between the yearly means were significant. Although, a significant year by row spacing interaction was present for height to node ratio, each row spacing mean was greater in 2001 than the corresponding mean in 2002.

Discussion

In 2001 and 2002, years in which the same plant sampling procedure was used, differences in plant architecture reflected the soil type and environmental conditions. Heights, total nodes, and HNR were each greater in 2001 than in 2002. Lighter soil in 2001 may have encouraged this growth similar to effects discussed by Jost and Cothren (2000). In 2001, a reduced percentage of first position fruit was found, as discussed below. The lesser amount of first position fruit may indicate increased levels of early season fruit abscission, which would have made resources available for additional vegetative growth. Heavy late season rains in 2001 (Table 2) could have stimulated plant growth as bolls began to mature during the harvest period.

Higher nitrogen rates increased heights and total nodes in accordance with published reports on nitrogen effects (Jackson and Gerik, 1990; Bondada et al., 1996). Height to node ratio was increased as well. Nitrogen effects were significant for heights and HNR in each year. They were also significant for total nodes in 2000. In 2001, a significant row spacing by nitrogen interaction was found for total nodes, which may have been caused by erratic responses of each row spacing to changes in nitrogen rate. The interaction may have occurred due to variability in the soil or as a response to uneven insect pressures. Although significant row spacing by nitrogen interactions were not found for height and HNR in 2001, some variability was evidenced by the greater values of the 50- than the 101-kg N/a treatment for these variables. Thus, row spacing by nitrogen interaction on total nodes probably resulted from effects of variability in the environment that outweighed the row spacing and nitrogen responses (Table 8). Significant row spacing by nitrogen interactions were not seen for any other plant architecture data.

Reductions in row spacing caused significant decreases in heights, total nodes, and HNR for 2000 and 2002. The same trend was apparent in heights and HNR in 2001, but differences were of much smaller magnitude and were not significant. Despite the nitrogen by row spacing interaction, cotton produced in three of the four nitrogen rates in 2001 showed some decrease in total nodes with reduction in row spacing. Height and total nodes have been reported to be lower in ultra-narrow row cotton (Jost and Cothren, 2000).

Overall, the data show that UNR systems tended to cause smaller plants in terms of height, total nodes and in HNR. Higher nitrogen rates, excepting the total nodes in 2001, tended to increase these parameters similarly for each row spacing.

Boll Numbers and Distribution

In 2001 and 2002, data on boll numbers and distribution were obtained by box mapping six representative plants per plot, as described in the Materials and Methods section, and these two years were combined for analysis where possible. In 2000, data on boll numbers and distribution were found from the tagged meter, a continuous meter of row, with the sizes and numbers of plants varying to some extent. These data were not combined with the other years. As explained in the Materials and Methods section, bolls per plant and bolls per acre are included for 2000, but unlike the other years they include plants with aborted terminals. Data on boll distribution as a percent of total bolls is found in Table 9. Bolls per plant and per hectare are reported in Table 10, and the number of bolls by region within the plant is included in Table 11.

2000

Across all treatments, there were 4.8 bolls per plant in 2000, which was equivalent to 960,798 bolls per hectare (Table 10). In 2000, averaged across all treatments, 79 and 17 percent of total bolls collected were in the first and second positions, respectively. Bolls located on reproductive branches at nodes 6 through 10 (N6-10) and nodes 11 through 15 (N11-15) were 77 and 15 percent respectively, of the total collected (Table 9).

Table 9. Percent of total bolls by location on the plant. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Year	Mean	Position 1	Position 2	Nodes 6 - 10	Nodes 11-15
		%			
2000	Year	79	17	77	15
	Nitrogen†				
	0	82a	16a	80a	13a
	50	81a	16a	82a	11a
	101	77a	17a	77a	16a
	151	73a	22a	71a	21a
	Row spacing (cm)				
	19	89a	9b	82a	10b
	38	76b	21a	79ab	17a
	76	70b	24a	71b	20a
2001	Year	66	23	70	20
	Nitrogen†				
	0	65a	22a	75a	17a
	50	66a	24a	70a	18a
	101	65a	24a	70a	20a
	151	67a	23a	64a	28a
	Row spacing (cm)				
	19	79a	19a	82a	13c
	38	64b	26a	72b	19b
	76	54b	26a	57c	28a
2002	Year	78	18	69	20
	Nitrogen†				
	0	82a	15a	75a	12c
	50	78a	17a	74a	18b
	101	77a	18a	68ab	21ab
	151	73a	22a	60b	29a
	Row spacing (cm)				
	19	85a	14b	75a	16b
	38	79b	17b	71a	18b
	76	68c	24a	61b	26a

†Nitrogen fertilizer rate, kg N ha^{-1}

Table 10. Total bolls per plant and per hectare. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Year	Mean	bolls plant^{-1}	bolls ha^{-1}
2000†	Year	4.8	960 798
	Nitrogen‡		
	0	4.2a	880 359b
	50	4.6a	885 827b
	101	5.2a	980 971ab
	151	5.5a	1 108 327a
	Row spacing (cm)		
	19	2.8a	938 320a
	38	4.7b	1 007 218a
	76	7.1c	935 258a
2001	Year	5.4	1 005 102
	Nitrogen‡		
	0	4.6a	880 848a
	50	5.4a	988 868a
	101	5.5a	1 005 673a
	151	6.3a	1 177 848a
	Row spacing (cm)		
	19	4.0b	1 152 511a
	38	5.0b	954 008a
	76	7.2a	905 379a
2002	Year	5.5	1 105 676
	Nitrogen‡		
	0	4.1d	826 551d
	50	4.9c	1 003 939c
	101	6.0b	1 217 803b
	151	6.9a	1 374 413a
	Row spacing (cm)		
	19	4.0a	1 168 382a
	38	5.4a	1 100 615a
	76	7.2a	1 048 031a

†Data from 2000 taken from continous meter of row, and plants with terminal damage are included in the means
‡Nitrogen fertilizer rate, kg N ha^{-1}

Table 11. Number of bolls by location on plant. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Year	Mean	Position 1	Position 2	Nodes 6 - 10	Nodes 11-15
		------------	------------no. plant^{-1}	------------	------------
2000	Year	3.5	1.0	3.5	0.9
	Nitrogen†				
	0	3.4a	0.8a	3.3a	0.6a
	50	3.3a	0.9a	3.4a	0.7a
	101	3.7a	1.0a	3.7a	1.0a
	151	3.7a	1.4a	3.7a	1.3a
	Row spacing (cm)				
	19	2.6c	0.3c	2.4c	0.3b
	38	3.4b	1.1b	3.6b	0.9b
	76	4.7a	1.7a	4.8a	1.6a
2001	Year	3.3	1.4	3.6	1.2
	Nitrogen†				
	0	2.9a	1.1a	3.3a	0.9b
	50	3.3a	1.4a	3.6a	1.1b
	101	3.3a	1.4a	3.7a	1.2b
	151	3.9a	1.6a	3.8a	1.9a
	Row spacing (cm)				
	19	3.1b	0.8b	3.2b	0.6b
	38	3.1b	1.4ab	3.6ab	1.0b
	76	3.8a	1.9a	3.9a	2.1a
2002	Year	4.1	1.1	3.6	1.3
	Nitrogen†				
	0	3.3c	0.7b	3.0c	0.6c
	50	3.7b	1.0b	3.6b	0.9c
	101	4.5a	1.1b	4.0a	1.3b
	151	4.9a	1.6a	4.0a	2.1a
	Row spacing (cm)				
	19	3.3c	0.6c	2.9c	0.7a
	38	4.2b	1.0b	3.7b	1.1b
	76	4.9a	1.7a	4.3a	2.0c

†Nitrogen fertilizer rate, kg N ha^{-1}

The number of bolls per plant showed no significant differences by nitrogen rate in 2000, although the mean of the 0-kg N ha^{-1} plot was the least and that of the 151-kg N ha^{-1} the greatest. There were significant nitrogen differences, however, in bolls per hectare, with means of 880,359, 885,827, 980,971, and 1,108,327 bolls per hectare for the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments. The 151-kg N ha^{-1} mean was significantly higher than the 0- and 50-kg N ha^{-1} means. Bolls per plant at specific regions were not significantly affecte by nitrogen rate. All locations analyzed (position 1, position 2, N6-10, and N11-15) showed a trend toward increases with higher nitrogen rates (Table 10). No nitrogen effects were significant for boll location on a percentage basis in 2000. The 0 kg N ha^{-1} treatment was numerically highest for both percent first position bolls and percent of total bolls within N6-10. This treatment also had close to the lowest percent second position bolls and percent of total bolls within N11-15. The 151 kg N ha^{-1} treatment was least in percent of total bolls at position 1 and percent of total bolls within N6-10, but greatest in percent second position bolls and percent of total bolls within N 11-15 (Table 9).

By row spacing, there were significant differences in bolls per plant, with the 19-, 38-, and 76-cm treatments averaging 2.8, 4.7, and 7.1 bolls per plant. All differences were significant. Bolls per hectare were not significantly affected by row spacing (Table 10). The numbers of bolls at the analyzed locations on the plant were significantly increased by wider row spacing at each location in 2000. Significant differences in boll distribution as a percent of total bolls were found by row spacing. First position bolls were 89, 76, and 70 percent, respectively, of the total collected in the 19-, 38-, and 76-

cm row spacings. Differences between the 19-cm and each of the other two spacings were significant. Percent second position bolls were least in the 19-cm spacings and greatest in the 76-cm, with significant differences between the 19- and the other two row spacings as well. Similar to the pattern seen by position, the bolls on reproductive branches at N6-10 were 82, 79, and 71 percent, respectively, of the total collected in the 19-, 38-, and 76-cm row spacings, with the 19-cm spacing having a significantly higher percentage than the 76-cm. The percent of bolls at N11-15 was least for the 19-cm row spacing and greatest for the 76-cm (Table 9).

2001

In 2001 the study averaged 5.4 total bolls per plant across all treatments. Using mean plant populations to convert this to a per hectare basis, the average across all treatments was 1,005,102 bolls per hectare (Table 10). The study averaged 66 and 23 percent of bolls at position 1 and position 2 respectively, 70 percent of bolls at N6-10, and 20 percent at N11-15 (Table 9).

While total bolls per plant, as well as bolls per hectare, were least in the 0 kg N ha^{-1} and greatest in the 151 kg N ha^{-1} treatment, the nitrogen rate differences were not significant in 2001 (Table 10). As a percent of the total, boll location by position or node range was not significantly affected by nitrogen rates in 2001. However, useful information was still found from the trends present. Means for percent bolls at position 1 and at position 2 were very similar across nitrogen rates. For node ranges, trends existed similar to those of 2000. The 0 kg N ha^{-1} had the highest percentage of total bolls at N6-10 and the lowest percent at N11-15, while the 151 kg N ha^{-1} treatment had the lowest at N6-10 and the highest at N11-15 (Table 9). At all four zones analyzed, the number of bolls per plant was least for 0 kg N ha^{-1} and greatest for 151 kg N ha^{-1}. Significant nitrogen differences in boll numbers, however, existed only at N11-15 (Table 11)

The 19-, 38-, and 76-cm row spacings exhibited 4.0, 5.0, and 7.2 bolls per plant, respectively, with the 76-cm mean significantly higher than the other two. No significant differences were found in bolls per hectare, although the 19-cm spacing was the greatest (Table 10). Row spacing affected the distribution of bolls within the plant. The means for percent first position bolls were 79, 64, and 54 percent in the respective 19-, 38-, and 76-cm row spacings, with the 19-cm spacing differing significantly from the 38-and 76-cm spacings differing significantly. The average for percent second position bolls was lowest in the 19-cm spacing, although differences were not significant. By node range, the respective 19-, 38-, and 76-cm row spacings averaged 82, 72, and 57 percent of total bolls at N6-10, with all differences being significant. The percent of bolls at N11-15 were least for the 19-cm spacing and greatest for the 76-cm, with all differences significant as well (Table 9). In general, the number of bolls per plant at the position and node ranges analyzed showed significant differences at each row spacing, with the 19-cm rows having the least and 76-cm rows the most bolls per plant regardless of the zone of the plant analyzed (Table 11).

2002

In 2002 total bolls averaged 5.5 bolls per plant across all treatments, or 1,105,676 bolls per hectare (Table 10). By position, overall means were 78 and 18 percent of bolls at position 1 and position 2 respectively. By node range, 69 percent of total bolls were at N6-10, and 20 percent were located within N11-15 (Table 9).

The 0-, 50-, 101-, and 151-kg N ha^{-1} treatments means for total bolls per plant were 4.1, 4.9, 6.0, and 6.9, respectively, with all nitrogen differences being significant (Table 10). Bolls per hectare showed the same trend, with all nitrogen rate differences showing significance as well. By position, means for percent of total bolls did not differ significantly by nitrogen rate. Numerically, for position 1 the mean percent of total bolls was greatest at 0 kg N ha^{-1} and least at 151 kg N ha^{-1}, while for position 2 the percent was least at 0 kg N ha^{-1} and greatest at 151 kg N ha^{-1}. Significant differences were seen, however, in percent bolls by node range, unlike 2000 and 2001. The respective 0-, 50-, 101-, and 151-kg N ha^{-1} treatment means for percent of total bolls at N6-10 were 75, 74, 68, and 60 percent, with the 151-kg N ha^{-1} mean significantly lower than all but that of the 50-kg N ha^{-1} treatment. At N11-15, the nitrogen means were 12, 18, 21, and 29 percent of total bolls at the respective 0-, 50-, 101-, and 151-kg N ha^{-1} rates. Significant differences were present between all means with the exception of 101 and 50 kg N ha^{-1} as well as 101 and 151 kg N ha^{-1} (Table 9). In all four zones analyzed, the number of bolls per plant was significantly impacted by nitrogen rate, being least for 0 kg N ha^{-1} and greatest for 151 kg N ha^{-1}, with differences being significant (Table 11).

No row spacing differences in bolls per plant were significant (Table 10). As in 2001, when population differences between row spacings were accounted for, no significant differences were found in bolls per hectare, although this estimate was highest in the 19-cm spacing. The percent first position bolls were 85, 79, and 68 in the respective 19-, 38-, and 76-cm row spacings, with all differences being significant (Table 9). The 19-cm row spacing had the lowest percent second position bolls, while the 76-cm had the greatest, and was significantly higher than the others. The respective 19-, 38-, and 76-cm row spacing means were 75, 71, and 61 percent of total bolls at N6-10. The 76-cm mean was significantly lower than the other two. The average percent of bolls at N11-15 was least for the 19-cm spacing and greatest for the 76-cm, with the 76-cm mean being significantly higher than that of the more narrow spacings. Each position and node range analyzed showed significant row spacing differences in number of bolls per plant. As in 2001, plants in 19-cm rows had the fewest and those in 76-cm rows the most bolls regardless of the location (Table 11).

Combined Over Years

Most variables discussed in this section had heterogeneity of variance over years for one or both error terms, and were not combined over years. However, the percent bolls at N6-10 and at N11-15, and the number of bolls per plant at N11-15 could be combined over years for 2001 and 2002, when the data were collected by the same

Table 12. Boll distribution parameters, combined over 2001 and 2002. Nitrogen and row spacing means represent both years. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

	Percent total bolls within		Number of bolls
Mean	Nodes 6 - 10	Nodes 11-15	Nodes 11-15
	--------------------------------%	--------------------------------	no. plant^{-1}
Year			
2001	70a	20a	1.2a
2002	69a	20a	1.3a
Nitrogen†			
0	75a	14a	0.8b
50	72a	18a	1.0b
101	69a	21a	1.3b
151	62a	29a	2.0a
Row spacing (cm)			
19	78a	14c	0.7b
38	71a	19b	1.0b
76	59a	27a	2.0a

†Nitrogen fertilizer rate, kg N ha^{-1}

method. Means for this combined data are reported in Table 12. The effects of year were not significant for any of these three variables, nor were the year by nitrogen, year by row spacing, nitrogen by row spacing, or year by nitrogen by row spacing interactions.

Nitrogen effects were not significant at the 0.05 level for percent of bolls at N 6-10 or N11-15. However, nitrogen did significantly affect the number of bolls per plant at N11-15. The 0-, 50-, 101-, and 151-kg N ha^{-1} treatments had 0.8, 1.0, 1.3, and 2.0 bolls per plant, respectively, within this range, with the 151-kg N ha^{-1} mean significantly higher than the others (Table 12).

Row spacing effects were not significant for percent bolls at N6-10, but were significant for percent bolls at N11-15, with 14, 19, and 27 percent of total bolls being located in this region for the 19-, 38-, and 76-cm spacings, respectively. All differences were significant. The number of bolls per plant at N11-15 showed significant effects as well. The 19-, 38-, and 76-cm spacings averaged 0.7, 1.0, and 2.0 bolls per plant, respectively, with the 76-cm row significantly higher than the more narrow spacings (Table 12).

Discussion

The lowest lint yields of the three years were experienced in 2001. The number of bolls per hectare could have impacted this, as shown by the difference in estimates of this factor between 2001 and 2002 (Table 10). However, boll distribution may also have been important. Jenkins et al. (1990b) found that larger bolls were present in the first position on fruiting branches than on the second or third. Averaged across all treatments, the percent first position bolls was reduced in 2001 in comparison to 2000 and 2002, potentially limiting boll size (Table 9). Factors that may have contributed to the overall reduction in percent first position bolls in 2001 were insect pressure, a less uniform stand, and and a lighter textured soil which encouraged more vegetative growth.

Although this trend was not significant, higher levels of nitrogen decreased the percent of total bolls at position 1 and increased it at position 2 in 2000 and 2002. By node range, a significant effect of nitrogen on boll distribution was shown in 2002, in which higher nitrogen rates shifted bolls, on a percentage basis, toward higher main stem nodes. The effect of nitrogen was similar but not significant in 2000 and in 2001. Although the differences were usually not significant, the numeric trends are similar to the results of Boquet et al. (1994), who found reductions in the percent of yield from within main stem nodes 5 through 10, as well as increases in the percent of yield located at the combined positions 2 and 3, as applied nitrogen levels increased. The nitrogen effects on boll distribution in 2000, and especially 2001, may have been due to environmental conditions. The excellent growing conditions experienced in 2002 may have allowed greater responses to nitrogen, whereas in previous years, especially 2001, water, insect pressure, or other environmental stresses may have constrained plants and diminished or masked their nitrogen response.

Row spacing effects on boll distribution were significant in each year, and followed a consistent trend in which the percent of total bolls at position 1 and at N6-10 were lowest in the 76-cm spacing and highest in the 19-cm. Similar trends were found by Jost and Cothren (2000). In terms of the magnitude of differences, boll distribution responses to row spacing were greatest in 2001. The tendency toward distal position fruit in that year may have induced wider row spacings to show a larger drop in percent first position bolls.

The relationship between boll numbers and boll location was similar for nitrogen and row spacing. Wide row spacing and high nitrogen rates usually caused a decrease in the percent of bolls within “key” zones of position 1 and N6-10. This percentage effect was due to the presence of additional bolls to a greater degree in other areas of the plant rather than reduction in the number of fruit in these key areas. Likewise, increases in percent of bolls at position 1 or N6-10, caused by reduced nitrogen and row spacings, originated with the presence of proportionally fewer bolls in other areas of the plant rather than an increase in the number of bolls in these key areas. On a per plant basis, it is not known if increases in number of bolls changed the percent of fruiting sites occupied, since the number of fruiting sites may have increased along with number of bolls. Wide row spacing or high nitrogen rate caused the greatest number of total bolls per plant as well as number of bolls within each subgroup discussed.

Boll Weight

The average weight of all reproductive branch bolls was used to provide insight into individual boll reproductive branch boll contribution to total lint yield (the specific set of bolls analyzed is discussed in the Individual Boll section of Materials and Methods). In an attempt to examine boll weight without the effects of location on the plant, analysis was also performed using only the weights of first position bolls within nodes 6 through 10 (key bolls). Table 13 shows seedcotton weights per boll separately by year. Table 14 shows this information combined over all three years.

Entire Plant Reproductive Branch Bolls

Significant effects by both nitrogen and row spacing were seen on reproductive branch boll weight in 2000. For the nitrogen treatments, mean seedcotton weights per boll were 3.20 g for the 0-kg N ha^{-1} rate, and 3.53, 3.67, and 3.91 for the 50-, 101-, and 151-kg N ha^{-1} treatments, respectively. All differences were significant except for that between 50- and 101- kg N ha^{-1}. Row spacing differences were also significant in 2000. Bolls averaged 3.39, 3.49, and 3.70 g seedcotton for the respective 19-, 38-, and 76-cm row spacings, with the 76-cm spacing being significantly higher than the other two spacings (Table 13).

Table 13. Seedcotton weight per boll. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Year	Mean	Entire plant†	Key bolls‡
		--------------------------g boll^{-1}--------------------------	
2000	Year	3.59	3.79
	Nitrogen§		
	0	3.20c	3.34d
	50	3.54b	3.65c
	101	3.67b	3.94b
	151	3.91a	4.28a
	Row spacing (cm)		
	19	3.39b	3.47b
	38	3.49b	3.69b
	76	3.70a	3.98a
2001	Year	3.77	3.88
	Nitrogen§		
	0	3.58a	3.76a
	50	3.88a	3.98a
	101	3.89a	3.96a
	151	3.69a	3.80a
	Row spacing (cm)		
	19	3.71a	3.77a
	38	3.71a	3.76a
	76	3.83a	4.04a
2002	Year	4.45	4.81
	Nitrogen§		
	0	4.15a	4.39b
	50	4.43a	4.77a
	101	4.53a	4.98a
	151	4.58a	5.04a
	Row spacing (cm)		
	19	4.33a	4.45b
	38	4.46a	4.82a
	76	4.48a	4.96a

†Bolls larger than 1 g seedcotton boll^{-1} on any reproductive branch
‡First position bolls larger than 1 g seedcotton boll^{-1} on reproductive branches within nodes 6 through 10
§Nitrogen fertilizer rate, kg N ha^{-1}

Table 14. Seedcotton weight per boll, combined over years. Nitrogen and row spacing means represent all three years. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Mean	Entire plant†	Key bolls‡
	----------g $boll^{-1}$----------	
Year		
2000	3.59b	3.79b
2001	3.77b	3.88b
2002	4.45a	4.81a
Nitrogen§		
0	3.59b	3.79b
50	3.95a	4.12ab
101	4.05a	4.35a
151	4.12a	4.44a
Row spacing (cm)		
19	3.81a	3.89b
38	3.89a	4.12b
76	4.02a	4.35a

†Bolls larger than 1 g seedcotton boll-1 on any reproductive branch
‡First position bolls larger than 1 g seedcotton boll-1 on reproductive branches within nodes 6 through 10
§Nitrogen fertilizer rate, kg N ha^{-1}.

There were no significant effects in 2001 on boll weight by nitrogen, to which the response was somewhat variable, or by row spacing. In 2002, neither nitrogen rate nor row spacing significantly affected the seedcotton weight per boll (Table 13).

For data combined over years, mean boll weights were 3.59, 3.77, and 4.45 g seedcotton for 2000, 2001, and 2002 respectively (Table 14). The mean for 2002 was significantly greater than those of 2000 and 2001. Thus, the contribution of individual bolls to seedcotton yield was greatest in 2002. Nitrogen effects on seedcotton weight per boll were significant. Three-year means for boll weights were 4.12, 4.05, 3.96, and 3.59 g seedcotton per boll, for the respective 151-, 101-, 50-, and 0-kg N ha^{-1} fertilizer treatments. The 0 kg N ha^{-1} treatment mean for seedcotton weight per boll was significantly lower than the other three. Significant differences were not found for row spacing in data combined over years, but the numeric trend was for increased seedcotton weight per boll as the row spacing increased.

Key Bolls

In 2000, mean seedcotton weights for key bolls were 3.34, 3.65, 3.94, and 4.28 g for the 0-, 50-, 101-, and 151-kg N ha^{-1} fertilizer rates, respectively, with all differences being significant. Row spacing means were 3.47, 3.69, and 3.98 g for the respective 19-, 38-, and 76-cm row spacings in 2000, with the 76-cm spacing significantly greater than the other two. All differences in mean seedcotton per boll by row spacing were significant as well (Table 13).

In 2001, significant differences in the seedcotton weights of key bolls were not found for nitrogen rate or row spacing (Table 13).

In 2002, nitrogen effects on seedcotton weight for key bolls were again significant. The means by nitrogen treatment were 4.39, 4.77, 4.98, and 5.04 for the 0-, 50-, 101-, and 151-kg N ha^{-1} rates respectively, with the mean of the 0-kg N ha^{-1} treatment significantly lower than the other means. Row spacing also caused significant differences in seedcotton weights of the key bolls, with means of 4.45, 4.82, and 4.96, respectively, for the 19-, 38-, and 76-cm row spacings. The 19-cm spacing mean was significantly lower than the other two means for mean seedcotton weight per boll (Table 13).

When combined over years, yearly means for key boll seedcotton weights were 3.79, 3.88, and 4.81 for 2000, 2001, and 2002 respectively. The mean for 2002 was significantly greater than either of the other two years. Nitrogen means were 3.79, 4.12, 4.35, and 4.44 g seedcotton per boll for the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, respectively, with the 0-kg N ha^{-1} treatment mean significantly lower than the 90- and 135-kg means. Row spacing differences were also significant, with the 19-cm treatments averaging 3.89 g seedcotton per boll, and the 38- and 76-cm treatments averaging 4.12 and 4.35 g seedcotton per boll, respectively. The difference between the 76- and both of the reduced spacings was significant (Table 14).

Discussion

As mentioned previously, boll location impacts boll size. Jenkins et al. (1990b) found that second or third position bolls were smaller than those at position 1. Although the overall means followed a similar pattern, discussion of yearly differences is limited to the key bolls (first position bolls located within nodes 6 through 10) to minimize effects of any differences in boll distribution or location of damaged bolls (which were not included in the analysis) on yearly differences.

The difference in seedcotton weight of key bolls between years may be explained by several factors. The first factor is the varying water stress levels experienced in each year. As mentioned in the yield section, crop demand for water could not be fully met under the prolonged periods of little or no rainfall that occurred (see Table 2). Gerik et al. (1996) found water stress treatments that were begun during flowering reduced boll size in comparison to a well watered control. Similar water stress may have been responsible for small size of the key bolls in 2000.

In 2001, key bolls were somewhat larger overall than they were in 2000. This could have partly been due to improved moisture availability. Another factor that contributed to the larger size was the lack of nitrogen differences in 2001. Key bolls were actually comparable or larger in size in the two highest nitrogen treatments in 2000 than they were in 2001. However, in 2001 the low nitrogen treatments showed virtually no reduction in weight from the high nitrogen treatment, causing the average across treatments to be higher than that of 2000. Likewise, the 19-cm treatments were more similar to the 76-cm in 2001 than in 2000.

In 2002, very large key bolls were seen. Good growing conditions, including good precipitation distribution, were probably the cause of the increased boll size.

Nitrogen effects on boll weight were significant in 2000 for all reproductive branch bolls as well as key bolls. Nitrogen effects were significant in 2002 only for key bolls. The trend in 2000 and 2002 was for seedcotton weight to increase with higher nitrogen. However, this trend was not seen in 2001, when no significant differences were seen in either key bolls or all reproductive branch bolls. In data combined over year, key bolls showed significant increases in seedcotton weight with higher nitrogen rates.

Row spacing effects were significant for overall and key bolls in 2000 and for key bolls in 2002, while neither parameter was significantly impacted by row spacing in 2001. In key bolls, in data combined over years, the general trend was for reductions in seedcotton per boll as row spacings were decreased.

Ginout

Row spacing effects on ginout were significant in 2000, as listed in Table 15. Means were 39.8, 39.1, and 38.9 percent for the 19-, 38-, and 76-cm row spacings, respectively. The mean for the 19-cm rows was significantly higher than that of the other row spacings. Nitrogen effects were not significant, and the means differed very little between rates.

There was a significant row spacing by nitrogen interaction on ginout in 2001. Data showing this interaction are included in Table 16. When examined as the response of cotton fertilized at each nitrogen rate to changes in row spacing, the overall trend for most nitrogen rates was for higher ginouts at reduced row spacing (The 50-kg N ha^{-1} rate was an exception, showing little change in ginout by row spacing). When averaged over all nitrogen treatments, the row spacing treatment means were accordingly greatest for 19-cm spacings and least for 76-cm. However, the response of ginout within each row spacing to nitrogen rate was variable, peaking at 151-, 101-, and 50-kg N ha^{-1}, respectively, for the 19-, 38-, and 76-cm spacings (Table 16).

Significant row spacing effects were again present on ginout in 2002. Row spacing means were 42.1, 41.8, and 40.8 percent, respectively, for the 19-, 38-, and 76-cm spacings, with the 19- and 38-cm row spacings being significantly higher than the 76-cm spacing. Nitrogen effects were not significant for ginout in 2002 (Table 15).

Ginout was not analyzed in a combined analysis over years due to heterogeneity of variance. Averaged across all treatments, ginouts were similar in each year. The yearly means for ginout were 39.3, 38.4, and 41.6 percent in 2000, 2001, and 2002 respectively (Table 15). The high values reflect the hand picking method used for harvest.

Table 15. Ginout from hand harvested area. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Factor	2000	2001†	2002‡
	--------------------	%	--------------------
Year	39.3	38.4	41.6
Nitrogen§			
0	39.0a		42.0a
50	39.5a		41.7a
101	39.5a		41.4a
151	39.1a		41.1a
Row spacing (cm)			
19	39.8a		42.1a
38	39.1b		41.8a
76	38.9b		40.8b

†Nitrogen and row spacing main effect means are not listed due to significant nitrogen by row spacing interaction
‡Sample did not include the final (7th) harvest in 2002
§Nitrogen fertilizer rate, kg N ha^{-1}

Table 16. Ginout by treatment, 2001.

	Nitrogen Rate (kg N ha^{-1})			
Row spacing (cm)	0	50	101	151
	%			
19	38.3	38.8	38.8	39.3
38	37.9	38.8	39.1	37.6
76	37.7	38.7	37.7	37.4

Discussion

Ginout was highest in 2002, probably due to the favorable growing conditions experienced. Treatment effects were consistent in 2000 and 2002, when row spacing produced significant impacts and nitrogen did not. In both years reductions in row spacing significantly increased ginout. This was also found by Jost and Cothren (2001) in a hand picked comparison of UNR and wider row spacings. A decrease in seed size was thought to be the reason for the increased percent lint. The row spacing by nitrogen interaction on ginout in 2001 does not appear to have a clear-cut explanation. As mentioned, however, even in this year the cotton produced at most nitrogen rates tended to have higher ginouts at reduced row spacings, which is in accordance with results obtained in 2000 and 2002.

Fiber Quality

Data on fiber quality by treatment is reported for 2001 and 2002. Tables 17 and 18 show main effect means for 2001 and 2002, respectively, and Table 19 shows data combined over years for quality parameters for which homogeneity of variance for both error terms was found. References to premiums and discounts or base quality values refer to those defined for cotton by the Commodity Credit Corporation (CCC) (National Cotton Council, 2002).

Table 17. Fiber quality, 2001. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05)

Mean	Micronaire	Fiber length	Length uniformity index	Fiber strength	Elongation	Percent reflectance (Rd)	Hunter's +b
	units	in.	%	g tex^{-1}	--------------------%--------------------		
Year	4.5	1.09	83.5	27.8	6.4	72.3	8.0
Nitrogen†							
0	4.6a	1.11a	83.7a	27.8a	6.3a	73.2a	7.6b
50	4.6a	1.10ab	84.0a	27.6a	6.5a	72.3a	7.9ab
101	4.5a	1.09b	83.3a	28.2a	6.3a	71.8a	8.4a
151	4.4a	1.08c	83.1a	27.4a	6.4a	72.1a	8.1ab
Row spacing (cm)							
19	4.5a	1.10a	83.4a	27.4b	6.5a	72.1a	8.0a
38	4.5a	1.09a	83.6a	27.6b	6.4ab	71.6a	8.0a
76	4.5a	1.10a	83.5a	28.3a	6.3b	73.3a	7.9a

†Nitrogen fertilizer rate, kg N ha^{-1}

Table 18. Fiber quality, 2002. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Mean	Micronaire	Fiber length	Length uniformity Index	Fiber strength	Elongation	Percent reflectance (Rd)	Hunter's +b
	Units	in.	%	g tex^{-1}	--------------------%	--------------------	
Year	4.5	1.10	83.3	29.2	6.2	74.9	9.9
Nitrogen†							
0	4.6ab	1.08b	84.2a	29.1a	6.2a	74.7a	9.9a
50	4.6a	1.09b	84.1a	28.8a	6.4a	74.9a	9.8a
101	4.4b	1.11a	84.6a	29.3a	6.0a	74.7a	10.0a
151	4.4b	1.12a	84.5a	29.6a	6.1a	75.3a	9.9a
Row spacing (cm)							
19	4.4a	1.10a	84.3a	29.2a	6.2a	75.1a	9.8a
38	4.6a	1.10a	84.4a	28.9a	6.1a	74.7a	9.9a
76	4.5a	1.10a	84.4a	29.5a	6.2a	74.9a	10.0a

†Nitrogen fertilizer rate, kg N ha^{-1}

Table 19. Quality means combined over 2001 and 2002. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05)

Mean	Micronaire	Fiber length†	Length uniformity index†
	units	in.	%
Year			
2001	4.5a	1.09a	83.5b
2002	4.5a	1.10a	84.3a
Nitrogen‡			
0	4.6a		
50	4.6a		
101	4.5b		
151	4.4b		
Row spacing (cm)			
19	4.5a		
38	4.5a		
76	4.5a		

†Nitrogen and row spacing means not reported because of a significant year by nitrogen interaction. Marginal means are in effect reported in the data from individual years.
‡Nitrogen fertilizer rate, kg N ha^{-1}.

Micronaire

Cotton with micronaire measuring within a range from 3.5 to 4.9 is not assigned a discount. Micronaires from 3.7 to 4.2 bring a premium. In 2001, the overall mean for micronaire was 4.5. Neither nitrogen nor row spacing effects were significant, and all nitrogen and row spacing means were within the higher range of values resulting in no premiums or discounts (Table 17). Micronaire again averaged 4.5 across all treatments in 2002. In this year, however, there were significant nitrogen effects. Mean micronaire values were 4.6, 4.6, 4.4, and 4.4 for the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, respectively. The mean of the 50-kg N ha^{-1} rate was significantly higher than the means of the 101- and 151-kg N ha^{-1} rates. Row spacing effects on micronaire were not significant in 2002. As in 2001, means for both nitrogen and row spacing factors were within a no premium or discount range (Table 18).

When combined over 2001 and 2002, year effects on micronaire were not significant. However, micronaire showed significant nitrogen effects in the combined analysis. Means were 4.6, 4.6, 4.4, and 4.4 for the respective 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, with the means of the two lower nitrogen rates significantly greater than those of the two higher nitrogen rates (Table 19).

Fiber Length

In HVI fiber quality analysis, which was performed in this study, lengths are measured in hundredths of an inch. Fiber lengths of 1.05 to 1.07 inches are considered equivalent to 1 1/16 inches, i.e. a staple length of 34 (Cotton Incorporated and Textile World staff, 2001). The base fiber length for which no premium or discount is assigned is 34, at a color grade of 41 and leaf grade of 4. In 2001, the overall mean length was 1.09. By nitrogen rate, fiber length averaged 1.11, 1.10, 1.09, and 1.08 for the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments respectively, with all differences significant except for those between 0- and 50- and between 50-and 101-kg N ha^{-1}. Row spacing effects on fiber length were not significant in 2001. All means for both row spacing and nitrogen were greater than the base fiber length (Table 17).

Fiber length averaged 1.10 across all treatments in 2002 (Table 18). Nitrogen effects were again significant, although in contrast to 2001, higher nitrogen increased fiber length. For the respective 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, mean fiber lengths were 1.08, 1.09, 1.11, and 1.12, with the means of the lower two nitrogen treatments significantly less than those of the higher. Row spacing effects on fiber length were not significant in 2002.

The yearly means for fiber length were not significantly different in analysis performed over years. Due to a significant year by nitrogen interaction on fiber length, treatment means are not discussed for the combined data.

Length Uniformity Index

Length uniformity index values of 80 to 82 percent result in no premiums or discounts, while uniformities of 83 percent or higher are assigned premiums. For the year 2001, the average uniformity was 83.5 percent across all treatments. All nitrogen and row spacing means were between 83 and 84 percent, with no significant differences between means for either factor (Table 17). In 2002 uniformity averaged 84.3 percent across all treatments. There were no significant differences among nitrogen or among row spacing means, all of which fell between 84 and 85 percent (Table 18).

In data combined over years, the length uniformity index was significantly higher in 2002 (84.3 percent), than in 2001 (83.5 percent) (Table 19). There was a significant year by nitrogen interaction on uniformity in data combined over 2001 and 2002, and for this reason the treatment effects are not reported as two year means.

Fiber Strength

Fiber strengths from 25.5 to 29.4 are assigned no discounts according to the CCC, and values of 29.5 or greater are given premiums. In 2001, the overall mean for fiber strength was 27.8. There were no significant differences in fiber strength by nitrogen. However, row spacing effects were significant. The mean strengths in the 19- and 38-cm spacings were 27.4 and 27.6, respectively, both of which were significantly less than the 76-cm mean of 28.3. All nitrogen and row spacing main effect means were within the range of fiber strengths assigned no premiums or discounts (Table 17). Averaged across all treatments, fiber strength was 29.2 in 2002. There were no significant nitrogen or row spacing effects on strength in 2002. No discounts would have been assigned for any main effect mean in 2002; one mean, that of the 76-cm row spacing, was 29.5 and would have brought a premium (Table 18).

Heterogeneity of variance prevented fiber strength data from being combined over 2001 and 2002.

Elongation

The average elongation in 2001 across all treatments was 6.4. Differences were not seen by nitrogen rate. Means of 6.5, 6.4, and 6.3 were found for the 19-, 38-, and 76-cm row spacings respectively, with the 19- and 76-cm means significantly different (Table 17). The overall mean elongation value in 2002 was 6.2. There were no significant responses to nitrogen or to row spacing (Table 18). Elongation data were not combined over years.

Reflectance (Rd), Yellowness (+b), and Color Grade

In 2001, the overall mean Rd was 72.3. There were no significant effects of nitrogen or row spacing on Rd (Table 17). Rd averaged 74.9 across all treatments in 2002, with no significant effects from nitrogen or row spacing (Table 18).

The average +b value across all treatments was 8.0 in 2001. Nitrogen means were 7.6, 7.9, 8.4, and 8.1 for the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, with the 0- and the 101-kg N ha^{-1} treatments significantly different (Table 17). There were no significant differences by row spacing. In 2002, the overall average +b value was 9.9. Nitrogen and row spacing effects were not significant (Table 18).

The base color grade is 41, as discussed above in the section on fiber length. In 2001, color grades associated with Rd and +b values ranged were strict low middling (41 or 42) for 29 of the plots, low middling (51 or 52) for 13 plots, and middling (31) for the remaining six plots. Six of the 48 plots were light spotted (42 and 52). Seventeen plots would have been discounted for color, given a staple length of 34 and leaf grade of 4.

In 2002, color grades were mostly middling (31 or 32), although 15 of the 48 plots were graded as strict middling (21 or 22). Thirty-two plots were light spotted (32 or 22), with the remainder graded as white (31 or 21). These 32 plots would have received a discount for color if staple length was 34 and the leaf grade was four.

Discussion

This study, in which cotton was hand picked, provides an opportunity to observe effects of the row spacing systems and nitrogen treatments on quality without the overriding influence of harvest method.

Quality was high for the cotton in all three years in most respects, with yearly means for most parameters above the ranges of values assigned discounts. The one exception to this was color grade, for which 32 and 17 plots would have received discounts in 2002 and 2001, respectively, had they been at base values for fiber length and leaf grade. Color was probably affected most affected by rainfall during harvest. In 2001, frequent precipitation during boll opening was experienced, resulting in a higher degree of moldy and hard locked bolls. Such field weathering has been found to reduce both Rd and +b values (Hake et al., 1996b), and the yearly means for both of these color parameters were lower in 2001 than in 2002. Values for uniformity and fiber strength were both lower in 2001, which also indicates field weathering (Hake et al., 1996b). There was much less rain during boll opening in 2002. Although reflectance was higher in 2002, yellowness was high enough to result in light spotted color for many samples.

Nitrogen effects were shown in certain quality parameters. Higher nitrogen rates tended to reduce micronaire. This can occur due to vigorous vegetative growth that shades leaves adjacent to bolls, reducing carbohydrate availability to those bolls (Hake et al., 1996b). A significant year by nitrogen interaction was seen for length, in which higher nitrogen significantly decreased fiber length in 2001, and significantly increased it in 2002. Fiber length tends to be optimized by stress-free growing conditions, including ample nutrients (Hake et al., 1996b). This is in accord with the response to nitrogen seen in 2002. The reason for reduced fiber length at higher nitrogen rates in 2001 is not known.

Row spacing effects on quality parameters were evident only in 2001, when decreased row spacing resulted in a significant reduction in fiber strength and significant increases in elongation. As for fiber length, producing cotton for high yield tends to optimize fiber strength (Hake et al., 1996b). This implies less stressful growing conditions, and although yields may be similar for UNR cotton, the stress on individual plants is increased. This may have been a factor in the reduction in fiber strength for UNR row spacings in 2001.

Quality parameters did not appear to be greatly affected by the treatments in this study. The effects of harvest method are probably of much greater consequence UNR cotton production.

Individual Leaf Area

Individual leaf area data were examined as separate analyses of variance for each measurement date. Treatment effects on leaf area are shown in Figures 1-6.

2000

All leaves in 2000 were tagged on 26 June or 27 June (estimated to have unfolded 26 June). Because of varying degrees of nitrogen deficiency, leaves were unfolding at different main stem nodes by nitrogen treatment. Therefore, unfolding leaves were tagged at the 9th, 10th, 11th, and 12th main stem nodes in the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, respectively. Leaf length was measured 15 times. As calculated from the leaf length, the largest mean leaf area averaged across all treatments was 86.2 cm^2 per leaf, achieved at 51 days after unfolding (DAU) in the last measurement made.

Nitrogen effects were significant for leaf area at all but the first measurement date in 2000. At each measurement other than the first, mean area of leaves was ordered from greatest to least as 151-, 101-, 50-, and 0-kg N ha^{-1} (Fig. 1). Means separated in the same pattern on the sixth measurement (14 DAU) and all measurements thereafter, with all differences significant except for that between the 50- and 101-kg ha^{-1} nitrogen rates. Row spacing effects were also significant at all but the first measurement date in 2000. At each measurement the leaf area was greatest in the 76- and least in the 19-cm row spacing. From the second measurement date (4 DAU) and on, for the 76-cm spacing

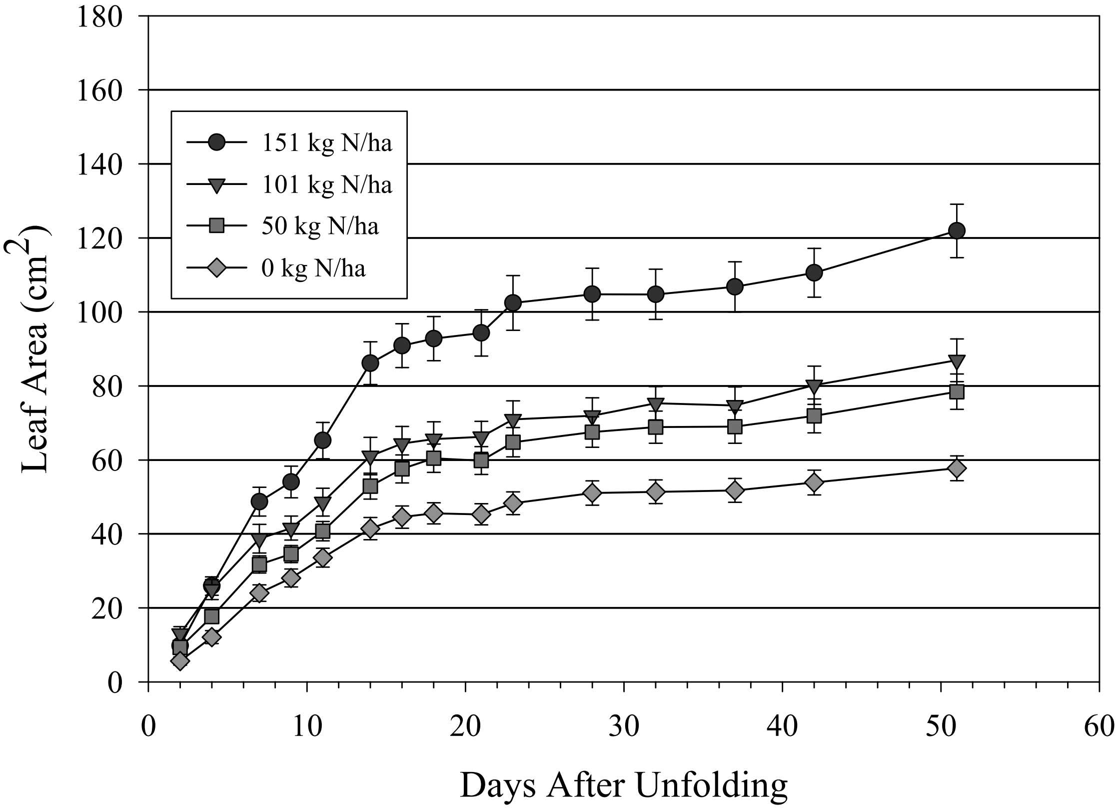

Fig. 1. 2000 leaf area expansion by nitrogen rate. Leaves measured in the respective nitrogen treatments were at the 9th, 10th, 11th, and 12th main stem nodes, respectively for the 0-, 50-, 101-, and 151-kg/ha treatments. Bars represent +/- the standard error of the mean.

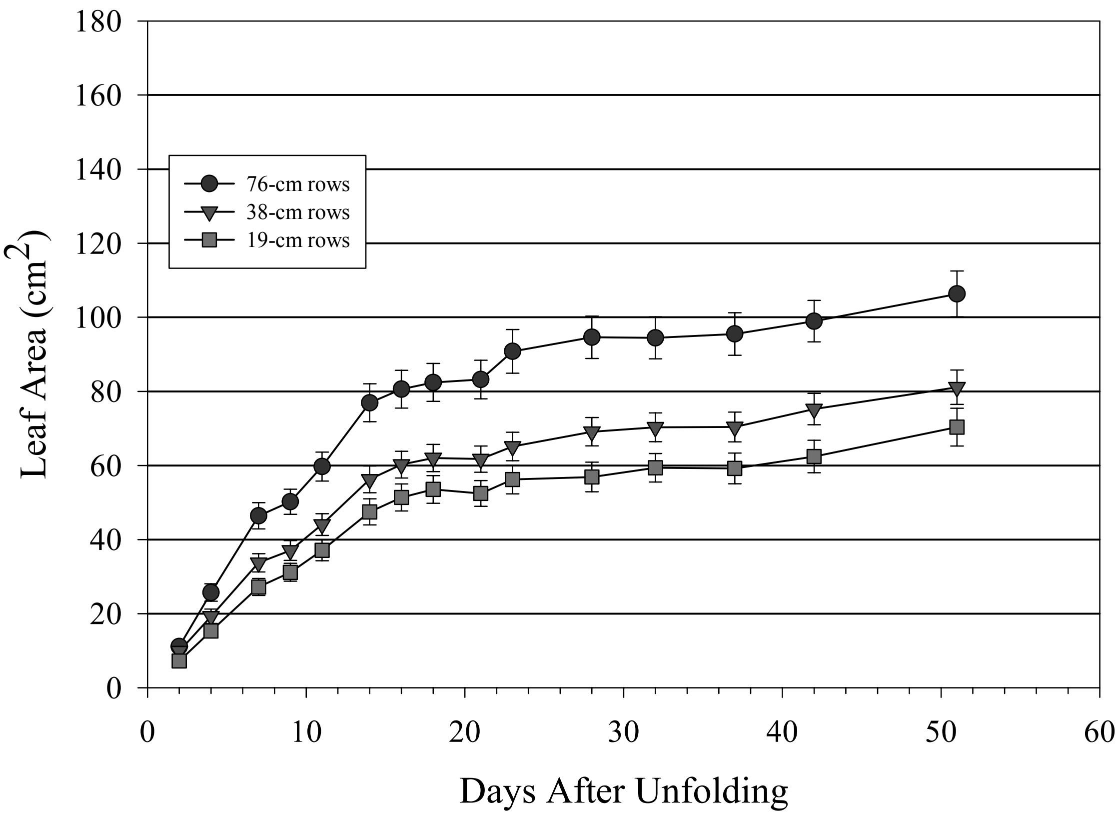

Fig. 2. 2000 leaf area expansion by row spacing. Each spacing includes 9th, 10th, 11th, and 12th main stem leaves. Bars represent +/- the standard error of the mean.

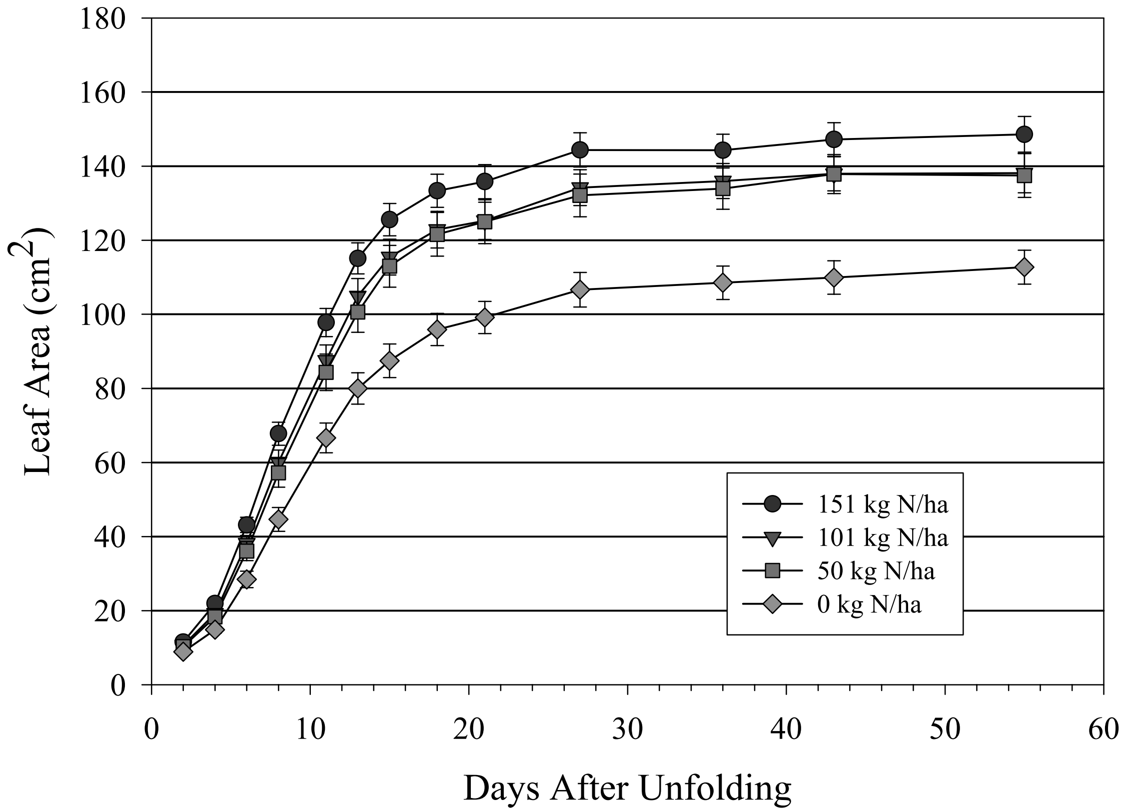

Fig. 3. 2001 tenth main stem leaf area expansion by nitrogen rate. Bars represent +/- the standard error of the mean.

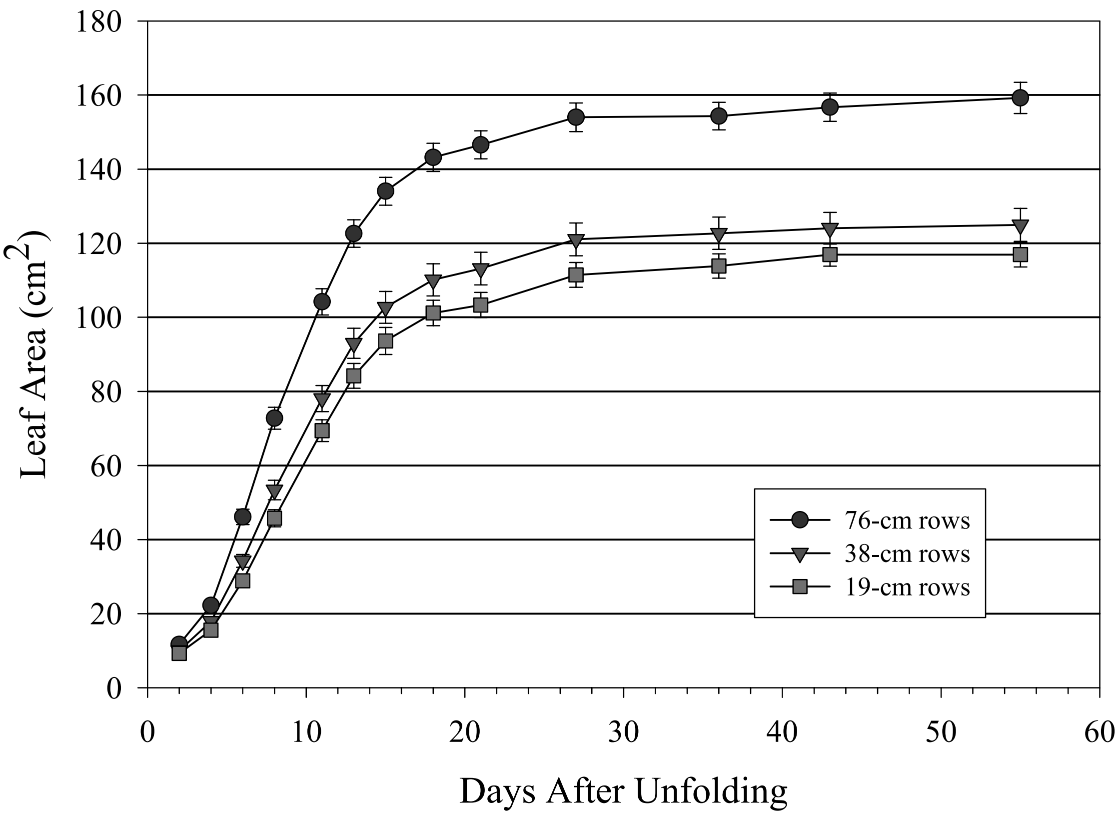

Fig. 4. 2001 tenth main stem leaf area expansion by row spacing. Bars represent +/- the standard error of the mean.

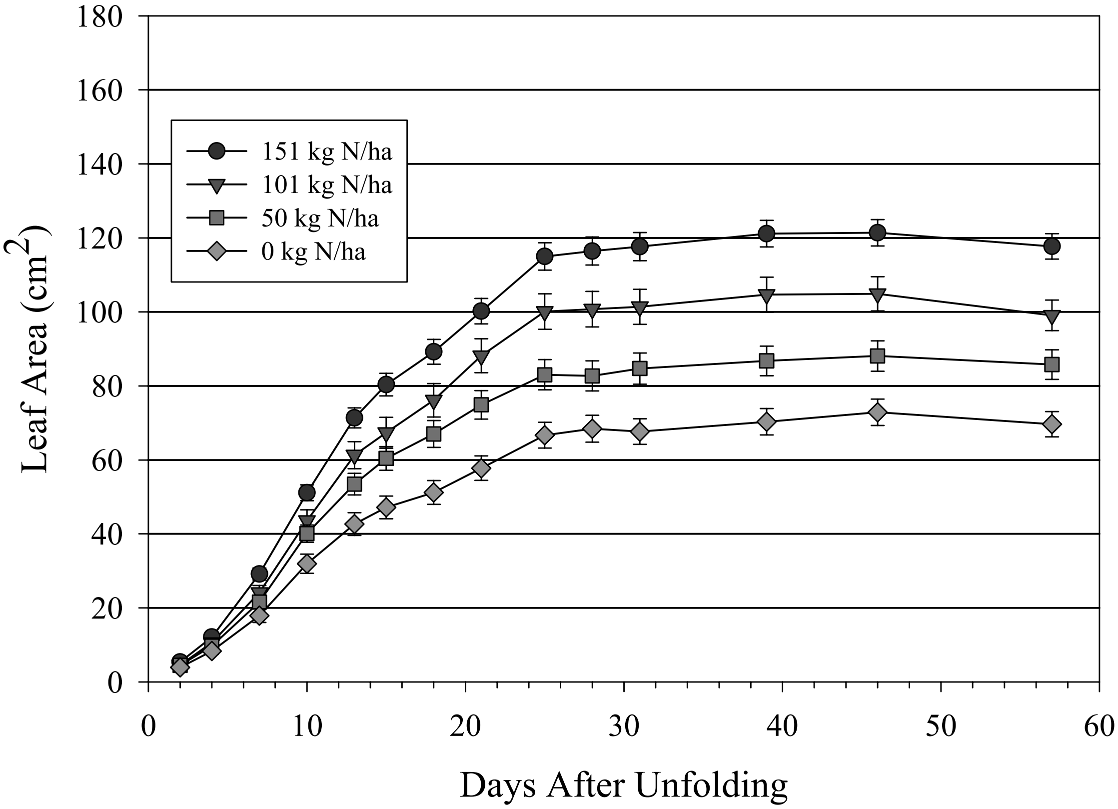

Fig. 5. 2002 tenth main stem leaf area expansion by nitrogen rate. Bars represent +/- the standard error of the mean.

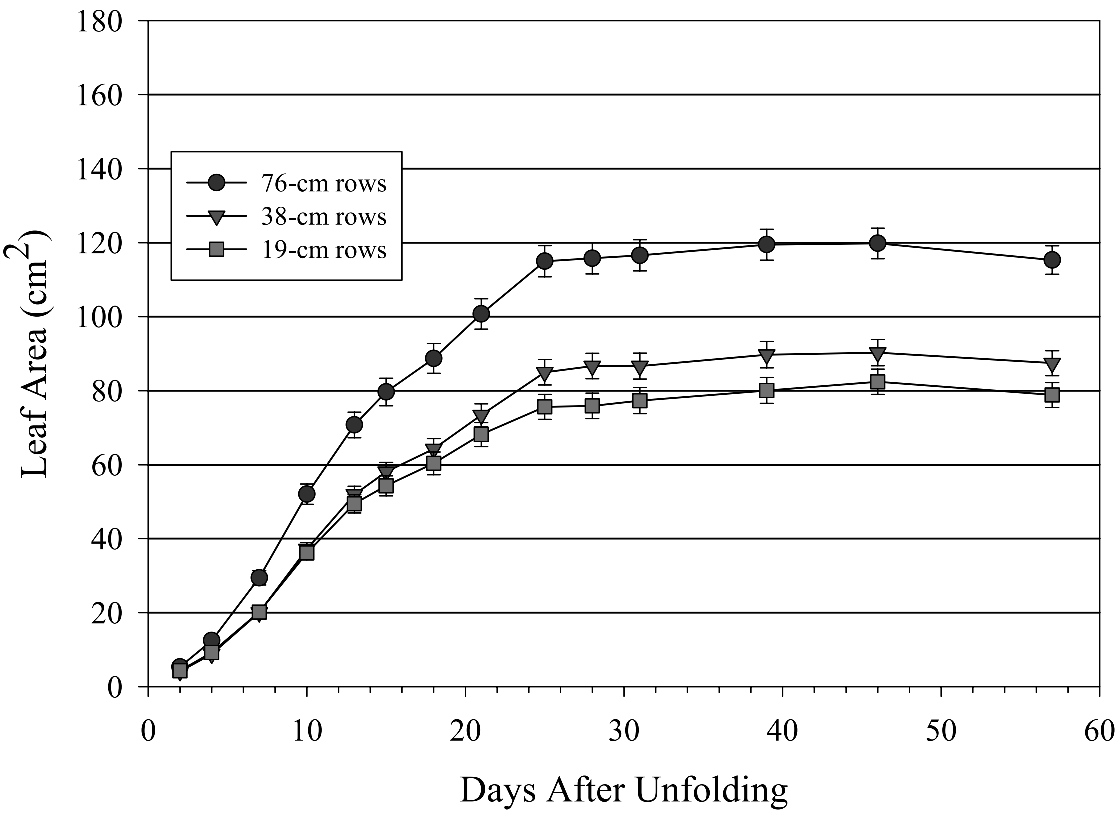

Fig. 6. 2002 tenth main stem leaf area expansion by row spacing. Bars represent +/- the standard error of the mean.

mean leaf area was significantly higher than that of the other spacings (Fig. 2). Among the measurement dates, a significant difference existed between the 19-and the 38-cm mean leaf area only at measurement 14 (42 DAU).

2001

Leaves in 2001 were tagged on 21 June. Differences in the node at which leaves were unfolding were slight, and therefore this date was selected so that all leaves could be tagged at node 10. The length of leaves was measured 13 times. Overall average leaf area was greatest at the last measurement (55 DAU), when it had a value of 133.4 cm^2 per leaf.

There were significant nitrogen effects at all measurement dates in 2001. Means were ordered according to nitrogen rate on each measurement, with the 151-kg N ha^{-1} mean the greatest and the 0 kg N ha^{-1} the least. The size of differences in leaf area was much less than was evident in 2000. The mean of the 0-kg N ha^{-1} nitrogen rate was significantly lower than all others on each date, while the means of the 50- and 101-kg ha^{-1} nitrogen rates were never significantly different (Fig. 3). On five measurement dates, the mean of the 151- did not significantly differ from that of the 101-kg N ha^{-1} treatments. Row spacing effects were significant at each measurement in 2001 as well. Similar to the first year of the study, the 76-cm leaf area mean was significantly greater than the other two spacings at each measurement, and there were never significant differences between the 19-and the 38-cm means (Fig. 4).

2002

Unfolding leaves were tagged on June 10 in 2002. As in 2001, the differences in the main stem node at which leaves were unfolding were minimal, and all tagged leaves were again at node 10. Measurements of leaf length were performed 14 times. Averaged across all treatments, a maximum area of 96.83 cm^2 per leaf was found at the 13^{th} measurement (46 DAU).

In 2002, nitrogen effects were significant at each measurement date, and means sorted in order of nitrogen rate, with the 151-kg N ha^{-1} rate being the greatest and the 0-kg N ha^{-1} the least (Fig. 5). For measurements 1 through 7, no adjacent means were significantly different. Beginning with measurement 8 (21 DAU) means began to be separated more completely, and on measurements 12 and 13 (39 and 46 DAU, respectively) all differences in leaf area were significant. Row spacing effects were also significant in 2002 at each measurement, and the 76-cm treatment mean was always the greatest while the 19-cm treatment was the least (Fig. 6). At the 10^{th}, 12^{th}, and 14^{th} measurements (28, 39, and 57 DAU, respectively), all spacing differences in leaf area were significant. On all other measurement dates, there were significant differences only between the 76-cm and each of the other row spacings.

Discussion

In the data on individual leaves, there appears to be a strong year effect. The greatest individual leaf areas occurred in 2001 for all treatments. Individual leaf size is diminished by to water stress (Krieg and Sung,1986). Differences in moisture availability (if present during leaf expansion) could therefore have played a role in the year effect. Leaves in dicots are sinks during their early growth (Taiz and Zeiger, 1998), and therefore the amount of leaf area on the rest of the plant could impact the expansion of the tagged leaf. A reduction in early boll load as may have occurred in 2001 (note the previously discussed reduced percentage of first position bolls) could have allowed additional carbon to be allocated into leaf expansion.

The area of individual leaves showed highly significant increases due to higher nitrogen levels in all years. Although leaves were tagged at different nodes in 2000, all were within the range of node 6 through 12, which were grouped as similar in size by Wullschleger and Oosterhuis (1992). Thus, the leaf areas in 2000 at the high nitrogen rates were probably larger due to the treatments, rather than the difference in main stem node.

Row spacing effects on individual leaf area were likewise highly significant in each year, with wider row spacings producing larger leaves. Differences in leaf area between leaves in 19- and 38-cm rows were small and only rarely significant. Differences in leaf area between the 76-cm and either reduced spacing were much larger and almost always significant.

Relationship of Yield Components and Plant Development to Total Lint Yield

Higher levels of nitrogen caused significant increases in lint yield each year. Each row spacing responded similarly to nitrogen additions as shown by the lack of row spacing by nitrogen interaction on lint yield in any year. Many of the yield components and measures of plant growth were also significantly affected by changes in nitrogen rate. Nitrogen effects were most apparent in 2000 and 2002. In 2001, nitrogen responses were generally smaller in magnitude and less likely to be significant for parameters other than lint yield. Row spacing by nitrogen interactions were significant in 2001 for total nodes and ginout, which were probably due to variation in the soil or insect pressure rather than differential responses of each row spacing to additions of nitrogen.

Because plant populations were constant across nitrogen rates, lint yield responses to nitrogen were due to changes in individual plant size and yield. In general, higher nitrogen rates caused taller plants with more nodes and a greater height to node ratio, although this response was inconsistent for total nodes in 2001. Increases in total nodes potentially provide plants with a greater number of fruiting sites, which is probably one of the reasons for nitrogen-induced yield increases. The number of bolls per plant increased with increasing nitrogen rate in 2001 and in 2002, although differences were significant only in 2002. Ginout was not affected by nitrogen rate, with the exception of 2001 when a significant nitrogen by row spacing interaction occurred, and probably was not a key factor in differences in yield by nitrogen rate. Boll seedcotton weight was significantly increased by higher nitrogen for first position bolls at nodes 6 through 10 in both 2000 and 2002, also contributing to yield increases. The size of individual leaves was increased at higher nitrogen rate as evidenced by responses of main stem leaves at nodes 9-12 in 2000 and at node 10 in 2001 and 2002. This may have contributed to larger bolls at the higher nitrogen rates, and thus indirectly to yield.

Row spacing effects on lint yield per hectare were not significant in any year. Increased populations in UNR spacings probably contributed to reduced size of individual plants, but also made it possible for yields to remain unchanged on a unit area basis.

Ultra-narrow row systems reduced plant height, total nodes, and height to node ratio. Reduced row spacings showed significant reductions in bolls per plant. On a per hectare basis, the estimated number of bolls was not affected by row spacing in 2001 or 2002, although there was a numeric increase in more narrow rows. Effects on boll distribution were for a higher percentage of bolls to be located at the first position and at lower nodes in reduced row spacings. This change in boll distribution may have been responsible for higher ginout at reduced row spacing. However, first position bolls at nodes 6 through 10 tended to be smaller in more narrow rows, which may have counteracted the effects of higher ginout on lint yield. Reduced individual leaf area was found in ultra-narrow rows. This factor could have been important in limiting boll size due to diminished local carbohydrate availability. Row spacing effects on quality were not significant for most parameters. All cotton was hand picked, however, which negated negative impacts of finger stripping on UNR cotton quality.

Each row spacing responded similarly to nitrogen fertilizer addition, as indicated by the lack of significant nitrogen by row spacing interaction in any year on lint yield in any year. This indicates that nitrogen fertilizer rates for UNR cotton probably do not need to be changed from those recommended for conventional row spacings in the area in which this cotton was produced.

Cumulative Seedcotton Harvest

Data discussed in this section includes both cumulative seedcotton harvest (CSH) data and the estimates of DAP to 60 percent seedcotton harvest that were derived from it. CSH data from 2000, 2001, and 2002 is listed in Tables 20, 21, and 22, respectively. DAP to 60 percent seedcotton harvest is listed in Table 23. CSH and DAP to 60 percent seedcotton harvest data are not combined over years.

Table 20. Cumulative seedcotton harvest (CSH) by picking date, 2000. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05)

	Days after planting (DAP)							
Mean	98	101	105†	108†	113	116†	123	143
	% total lint yield							
Nitrogen‡								
0	4.0b	10.4b			66.1c		91.0b	100.0a
50	9.1a	18.5a			76.0b		95.1a	100.0a
101	13.1a	25.3a			82.6a		96.9a	100.0a
151	12.6a	23.6a			82.5a		96.5a	100.0a
Row spacing (cm)								
19	10.7a	21.2a			78.0a		95.3a	100.0a
38	12.1a	23.4a			79.0a		95.6a	100.0a
76	6.2b	13.6b			73.8b		93.8b	100.0a

†Nitrogen and row spacing main effect means not listed due to significant nitrogen by row spacing interaction
‡Nitrogen fertilizer rate, kg N ha^{-1}

Table 21. Cumulative seedcotton harvest (CSH) by picking date, 2001. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

	Days after planting (DAP)		
Mean	97	119.5†	148.5‡
	--------------------------------------% total lint yield-------------------------------------		
Nitrogen§			
0	5.3c	84.8a	100.0a
50	11.1b	86.9a	100.0a
101	17.3a	89.1a	100.0a
151	14.2ab	88.2a	100.0a
Row spacing (cm)			
19	13.6a	90.1a	100.0a
38	12.3a	88.0a	100.0a
76	9.8a	83.2b	100.0a

†Harvest began 119 DAP and was completed 120 DAP
‡Harvest began 147 DAP and was completed 150 DAP
§Nitrogen fertilizer rate, kg N ha^{-1}

Table 22. Cumulative seedcotton harvest (CSH) by picking date, 2002. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05)

	Days after planting (DAP)						
Mean	103	110	113	117	120	127	142
	---% total lint yield---						
Nitrogen†							
0	9.2a	47.4a	64.5a	80.0a	87.2a	97.0a	100.0a
50	10.2a	45.7a	61.7ab	77.6ab	85.0ab	96.9a	100.0a
101	9.9a	40.0ab	55.0b	70.5bc	80.6bc	95.0ab	100.0a
151	5.4a	31.4b	45.6c	63.6c	75.9c	93.0b	100.0a
Row spacing (cm)							
19	9.5ab	46.7a	64.1a	79.2a	86.7a	97.0a	100.0a
38	10.3a	44.4a	59.3b	74.4b	82.9b	96.1a	100.0a
76	6.3b	32.3b	46.6c	65.2c	76.9c	93.2b	100.0a

†Nitrogen fertilizer rate, kg N ha^{-1}

Table 23. Days after planting (DAP) to 60 percent seedcotton harvest. Because estimates were made from main effect CSH means rather than individual plots, mean separations are not provided.

Mean	2000†	2001‡	2002
	---DAP---		
Year	108.1		113.7
Nitrogen§			
0			112.2
50			112.6
101			114.2
151			116.1
Row spacing (cm)			
19			112.3
38			113.1
76			115.8

†In 2000, nitrogen and row spacing main effect means not listed due to significant nitrogen by row spacing interaction on cumulative seedcotton harvest (CSH)
‡Estimates not made in 2001 due to the amount of time between pickings
§Nitrogen fertilizer rate, kg N ha^{-1}

2000

When averaged across all treatments in 2000, the field reached 60 percent seedcotton harvested at 108.1 days after planting (Table 23). There was a significant nitrogen by row spacing interaction on CSH at the third, fourth, and sixth harvest dates (Table 20). In this interaction, the row spacing effects at the two highest nitrogen rates differed from those at the two lowest. At 101- and at 151-kg N ha^{-1}, CSH means were greatest for 19-cm rows and least for 76-cm rows, and the differences between the greatest and least CSH were larger than at low nitrogen rates. At 0- and 50-kg N ha^{-1}, the 38-cm row spacing CSH mean was the greatest, and little difference existed between the 19- and 76-cm row spacings. The interaction at the fourth harvest (108 days after planting) is shown in Fig. 7.

For the first, second, fifth, and seventh harvest dates, the nitrogen by row spacing interaction was not significant. Nitrogen effects (as averaged over all row spacings) were

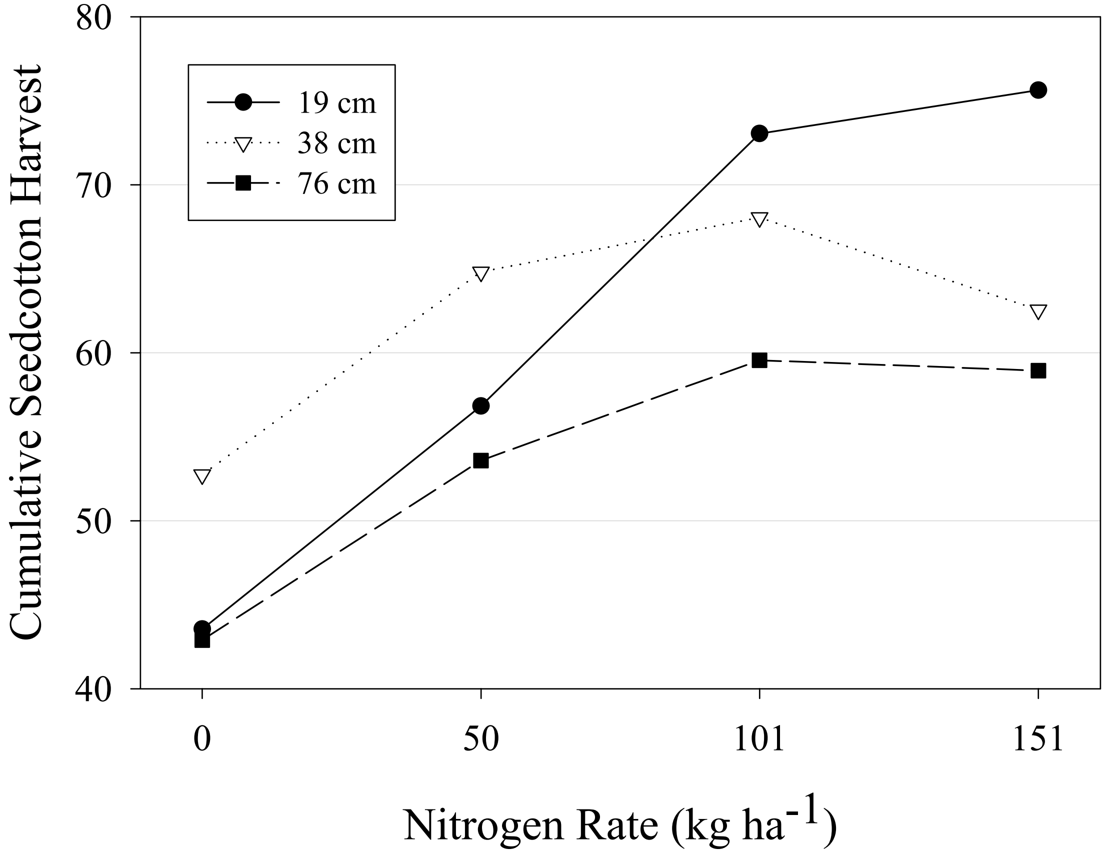

Fig. 7. Interaction between nitrogen rate and row spacing on CSH, fourth harvest (108 days after planting), 2000. Typical of all significant nitrogen by row spacing interactions in 2000.

significant at each of these harvests. Mean separations showed no significant differences between the 101- and the 151-kg N ha^{-1} treatments. The 0-kg N ha^{-1} treatment for CSH was significantly less than any other treatment mean at each harvest date (Table 20).

At the first, second, fifth, and seventh harvests, which did not show a significant nitrogen by row spacing interaction in 2000, row spacing effects (averaged over all nitrogen rates) on CSH were significant. In each case the 76-cm row mean was significantly less than the those of the narrower spacings, while differences between means of the 19- and 38-inch cm row spacings were not significant (Table 20).

Due to the significant nitrogen by row spacing interactions, row spacing means for days to 60 percent seedcotton harvest are reported separately by each nitrogen treatment. These data are listed in Table 24. At the 0-kg N ha^{-1} fertilizer rate, nitrogen treatments reached 60 percent seedcotton harvest at an estimated 112.0, 110.0, and 112.1 days after planting for the 19-, 38-, and 76-cm row spacings, respectively. Listed in the same order of row spacing, 60 percent seedcotton was reached at 109.0, 107.1, and 109.6 days after planting for the 50-kg N ha^{-1} treatment; 104.9, 106.3, and 108.2 days after planting for 101 kg N ha^{-1}; and 105.1, 107.6, and 108.3 days after planting for the 151-kg N ha^{-1} treatment.

Table 24. Days after planting (DAP) to 60 percent seedcotton harvest by treatment, 2000.

	Nitrogen Rate (kg N ha^{-1})			
Row spacing (cm)	0	50	101	151
	-DAP-			
19	112.0	109.0	104.9	105.1
38	110.0	107.1	106.3	107.6
76	112.1	109.6	108.2	108.3

2001

In 2001, estimates of 60 percent seedcotton harvest were not made because there were no harvests close to this stage. In the first and second harvests, the means for CSH across all treatments were 12.0 and 87.2 percent, respectively.

Nitrogen effects on CSH were significant at the first but not at the second harvest in 2001. Significant row spacing effects on CSH were present only at the second harvest, with the 76-cm mean being significantly lower than the 19- and 38-cm means (Table 21).

2002

Across all treatments, 60 percent seedcotton harvest was reached at 113.7 days after planting in 2002 (Table 23). Nitrogen effects on CSH were significant at the second through the sixth harvests. In each of these harvests, the 0 kg-N ha^{-1} treatment had (numerically) the greatest CSH mean while the 151-kg N ha^{-1} had the least. Varying patterns of mean separation were seen among the nitrogen rates (Table 22). Unlike previous years, no nitrogen by row spacing interactions were evident on CSH at any harvest date.

In 2002, row spacing effects were significant at the first through the sixth harvest dates. For harvests three, four, and five, all differences in mean CSH between row spacings were significant, with the 19-cm row spacing being highest for CSH and the

76-cm the lowest. At harvests two and six, the order of the treatments was the same, but differences were only significant between the 76-cm and the two more narrow spacings (Table 22).

In 2002, 60 percent seedcotton was reached at 112.2, 112.6, 114.2, and 116.1 days after planting for the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, respectively. The 19-, 38-, and 76-cm spacings reached 60 percent seedcotton harvest at 112.3, 113.1, and 115.8 days after planting, respectively, in 2002 (Table 23).

Discussion

Based on days after planting to 60 percent seedcotton harvest, the 2000 crop matured more than five days earlier than the 2002 crop. However, due to the initial stand failure in 2000, the study was replanted on May 15, two weeks later than the May 1 planting done in 2002. Therefore, the crop actually matured 8 to 9 days earlier in the calendar year in 2002 than in 2000.

Nitrogen effects on CSH tended to be significant in all years, although the interaction of nitrogen rate with row spacing was significant on several occasions in 2000. For harvest dates in which this interaction was not significant, the tendency averaged across all row spacings was for increases in CSH with higher nitrogen rate in 2000 and in 2001 (Tables 20 and 21). This implies that the crop was maturing earlier at higher nitrogen rates. Excessive nitrogen rates are often associated with delayed maturity, an apparent conflict with this data. However, none of the rates of nitrogen applied in this study would be considered excessive. The 0-kg N ha^{-1} and the 50-kg N ha^{-1} rates induced nitrogen deficiency symptoms to varying degrees in all years. In 2000, this may have led to later crop maturation as will be discussed below in the section on Specific Site Flowering Date. Differences in boll maturation period, also discussed below, may have been important in effects on CSH apparent in 2001.

Even in the interactions between nitrogen and row spacing in 2000, the tendency for each row spacing was for greater CSH as nitrogen rate was increased from 0 up through 101-kg N ha^{-1} (Fig. 7). Therefore, the overall trend discussed of reduced CSH at low nitrogen rates is valid despite some differences in the nature of the nitrogen response between row spacings.

In 2002, in contrast to the two previous years, higher nitrogen rates caused significant reductions in CSH at all but the first and last harvest dates (Table 22). As will be discussed below, the effects on earliness components that would lead to delayed maturity at low nitrogen rates were absent in 2002. Two earliness components, boll distribution and boll maturation period, showed effects in that year that led to increases in crop earliness at low nitrogen rates.

Row spacing effects on CSH were significant at most harvest dates in all three years. There was an interaction between row spacing and nitrogen rate at several harvest dates in 2000 and 2001, as discussed above. For any harvest without this interaction reductions in row spacing (averaged across all nitrogen rates) tended to increase CSH (Tables 20, 21 and 22). Unlike the effect of nitrogen, this response was consistent across all three years. This row spacing response has long been theorized for UNR cotton

(Lewis, 1971) and has been shown, although not consistently, in other studies such as that of Jost and Cothren, 2000.

When used to estimate differences in days to 60 percent seedcotton harvest, CSH differences did not translate into marked differences in earliness among the row spacing or nitrogen treatments. Maximum row spacing differences, which are of interest to producers seeking an earlier harvest, were 3.5 days as averaged across all nitrogen treatments in 2002, and 3.3 days for the nitrogen rate (101 kg N ha^{-1}) showing the greatest row spacing difference in 2000.

Boll Maturation Period

The boll maturation period, defined as the time from white flower to open boll for an individual fruit, is expressed here in heat units (dd60s) rather than days to minimize climatic differences for bolls set early vs. late. Boll maturation period data are reported in Table 25.

In 2000, the average boll maturation period across all treatments was 1126.9 dd60s. No significant effects were present by nitrogen rate, with all treatment means falling within approximately 10 dd60s of each other. Likewise, there were no significant effects of row spacing on the boll maturation period, and means were separated by less than 8 dd60s (Table 25).

The boll maturation period averaged across all treatments in 2001 was 1146.5 dd60s. Nitrogen effects were significant in this year. The boll maturation period means were 1168.7, 1152.5, 1137.9, and 1131.0 for the respective 0-, 50-, 101-, and 151-kg N ha^{-1} treatments. The 0-kg N ha^{-1} mean was significantly greater than that of the 101- and 151-kg N ha^{-1} means. Row spacing effects on boll maturation period were not significant (Table 25).

In 2002, the field as a whole averaged 1074.8 dd60s for boll maturation period. By nitrogen rate, means were 1057.6, 1068.7, 1076.0, and 1089.7 dd60s for bolls in the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, respectively, with the 151-kg N ha^{-1} mean being significantly greater than all others, and the 90- significantly greater than the 0-kg N ha^{-1} mean. Row spacing effects on boll maturation period were not significant in 2002 (Table 25).

Table 25. Individual boll maturation period, measured in 1 m of row per plot. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Mean†	2000	2001	2002
	---dd60s---		
Year	1126.9	1146.5	1074.8
Nitrogen‡			
0	1124.8a	1168.7a	1057.6c
50	1131.7a	1152.5ab	1068.7bc
101	1129.7a	1137.9b	1076.0b
151	1121.6a	1131.0b	1089.7a
Row spacing (cm)			
19	1133.3a	1134.2a	1082.9a
38	1126.0a	1149.5a	1074.5a
76	1125.6a	1148.9a	1072.7a

†Means are reported in dd60s to minimize climatic influences on results, since bolls were set at various times in the season

‡Nitrogen fertilizer rate, kg N ha^{-1}

Discussion

Averaged across all treatments, the yearly mean boll maturation period was lower in 2002 than it was in the two previous years. This could be an artifact from the way that heat units are expressed. Heat units (dd60s) were calculated by averaging the daily maximum and minimum temperature and then subtracting a base temperature of 60. Moderate temperatures in 2002 potentially caused reduced heat unit accumulation, but "true" heat units could have been similar between years since cotton probably does not hasten development due to extremely high temperatures (Witten and Cothren, 2003).

Nitrogen effects on boll maturation period were inconsistent from year to year. In 2000, no significant effects were seen on boll maturation period. In 2001, the boll maturation period was longer with low nitrogen rates, while in 2002 the boll maturation period was extended with high nitrogen rates. The reasons for the change in direction of this effect are unknown. Gerik et al. (1998) reported data showing essentially no response of boll maturation period to nitrogen deficiency in a greenhouse study.

The boll maturation effects may have played a role in the earliness of maturity of the entire crop. In 2001, indications from the first and second harvests were that lower nitrogen had delayed crop maturity, which corresponds to increased boll maturation period at the 0-kg N ha^{-1} rate in that year. Likewise in 2002, days to 60 percent seedcotton were increased at higher nitrogen rates, indicating later maturity, and corresponding increases in boll maturation period were seen at these rates.

Specific Site Flowering Date

Analysis of variance was performed on the date of bloom of fruit at a specific site, node 8 position 1 (node 8 position 1). Fruit set was common at this site in all treatments, allowing a reasonable sample size. Being one of the first sites to bloom, it also provides an indication of the time that fruiting commenced in each treatment. This measure includes only the date of bloom of harvested bolls. Data on date of bloom at node 8 position 1 is included in Table 26.

Flowers at node 8 position 1 opened an average of 58.4 DAP in 2000. By nitrogen rate, the mean flowering dates were 62.1, 58.9, 56.6, and 56.6 DAP for the 0-, 50-, 101-, and 151-kg N ha^{-1} treatments, respectively, with the 0-kg N ha^{-1} mean being significantly greater than that of any other nitrogen rate. There were no significant differences by row spacing (Table 26).

In 2001, the mean date of bloom for node 8 position 1 across all treatments was 58.3 DAP. There were no significant effects by nitrogen or by row spacing on this measure (Table 26).

The mean date of bloom for node 8 position 1 across all treatments in 2002 was 64.4 DAP. Responses to nitrogen and row spacing were not significant (Table 26).

Table 26. Days after planting (DAP) to first position white bloom at main stem node eight. Means within a single column and factor are not significantly different if followed by the same letter (Duncan, 0.05).

Mean	2000	2001	2002
	--	DAP	--
Year	58.4	58.3	64.4
Nitrogen†			
0	62.1a	58.9a	65.8a
50	58.9b	57.7a	64.3a
101	56.6b	58.2a	63.6a
151	56.6b	58.6a	64.3a
Row spacing (cm)			
19	59.3a	59.0a	65.2a
38	58.4a	57.8a	63.3a
76	58.1a	58.3a	64.9a

†Nitrogen fertilizer rate, kg N ha^{-1}

Discussion

There was an increase in days after planting to flower opening at node 8 position 1 in 2002. Nitrogen effects were shown only in 2000, with the lowest nitrogen rate significantly delaying bloom at node 8 position 1 (Table 26). This delay is probably related to the nitrogen deficiency evident very early in the season in that year. The delay in bloom probably originated from slower node addition since, as discussed previously, lower nitrogen rates resulted in significant reductions in total nodes across all treatments only in 2000 (Table 26). As mentioned earlier, nitrogen deficiency causes reductions in plant growth (Taiz and Zeiger, 1998).

The results on date of bloom at node 8 position 1 are helpful in explaining the delayed crop maturity at low nitrogen rates in 2000. Plants were delayed in blooming at node 8 position 1, and potentially at nodes 7 or 6, in the zero nitrogen rate. This may indicate a later initiation of fruiting at low nitrogen, contributing to later maturity.

Row spacing effects were not significant on date of bloom at node 8 position 1 in any year. A numeric trend toward delayed bloom at node 8 position 1 as row spacing was reduced did exist in 2000 (Table 26). Total nodes were significantly reduced in 2000 and in 2002 by more narrow row spacing (Table 7). Therefore, reductions in the rate of node addition probably occurred sometime after the date of bloom of node 8 position 1. This could include earlier cutout as was found by Cawley et al. (1999). It could also include differences in late season growth.

The lack of significant effects on date of bloom at node 8 position 1 by row spacing is important because it may indicate a similar time for initiation of fruiting for each row spacing. Earliness of maturity is in theory an advantage of UNR cotton, and these data indicate that it is probably not counteracted by delays in early season node addition or initiation of fruiting.

Boll Distribution—Earliness Effects

Another important contributor to the time of maturation is boll distribution. Bolls set on branches at higher main stem nodes or on distal positions on those branches were set later than proximal bolls at lower main stem nodes. Data of this type has been discussed above in terms of impact on lint yield. However, its implications for earliness will be discussed here.

When averaged across row spacings, nitrogen means for percent bolls at position 1 (including all nodes) were 65 percent or greater. Across all nitrogen rates, means for percent bolls at position 1 were greater than 60 percent for each row spacing, with the exception of the 76-cm rows in 2001, which had 54 percent first position bolls. Similar percentages of bolls (including all positions) were located within N6-10 (Table 9). Since most bolls were in these areas of the plant, discussion of factor effects on percent first position bolls and the percent bolls at N6-10 provides a good basis for understanding the overall boll distribution effects on earliness in this study.

Discussion

The yearly mean for percent of bolls at position 1 was lower in 2001 than in 2002 (Table 9). All else being equal, this would have caused later maturity in 2001, although days to 60 percent seedcotton harvest was not calculated for this year. The overall percent of bolls at nodes 6-10 was similar across all years.

Lower nitrogen rates caused trends of greater percent first position bolls and greater percent total bolls at N6-10 in most cases (no trend by nitrogen was apparent for percent first position bolls in 2001). This tendency would cause the cotton at lower nitrogen rates to mature earlier if other earliness components were equivalent. However, differences by nitrogen were significant in only one instance, for N6-10 in 2002. Thus, the nitrogen effects on earliness through boll distribution may have been minimal. In 2000, later maturity was found for the lower nitrogen rates, implying that the numerically higher percentages of first position and N6-10 bolls found in that year were not influential enough to counteract the delaying effects of other components. However, the significant nitrogen effects on boll distribution in 2002 are in accord with the earlier maturity of the low nitrogen treatments in that year.

Row spacing effects on boll distribution were significant for percent first position bolls and for percent bolls at N6-10 in each year. The effect of reductions in row spacing was to increase both of these percentages, which would contribute to earliness in the more narrow rows. This may have played an important role in the small earliness increases seen with reduced row spacings in both 2000 and 2002.

Relationship of Earliness Components to Earliness of Seedcotton Harvest

Small earliness differences were brought about by the nitrogen and row spacing treatments. The interaction of these factors was also important in 2000. The nitrogen effects on earliness were unusual in that they were inconsistent over years. Low nitrogen resulted in delayed maturity in 2000, and probably in 2001 as well. However, the reduced nitrogen rates hastened maturity in 2002. Different earliness components contributed to the CSH responses to nitrogen in each year. Each year is discussed separately to differentiate the varying contributions of earliness components in each year.

2000

Reduced nitrogen caused decreases in the earliness of the crop in 2000 as evidenced by data on CSH. The earliness of the crop appeared to be most affected by a reduced rate of development in the low N treatments. Data collected on the date of bloom for bolls harvested at node 8 position 1 show that this fruiting site bloomed significantly later at the zero nitrogen rate than at the other nitrogen treatments. Because the eighth node is one of the lower fruiting nodes on a cotton plant, later first position bloom at this node may imply later initiation of flowering for the plant as a whole. Slower node addition was also evidenced empirically in 2000 by the necessity of tagging emerging main stem leaves at lower nodes in plots receiving reduced amounts of nitrogen.

Boll maturation period was not significantly affected by nitrogen rate in 2000, and probably had little impact on overall crop earliness. Boll distribution, in terms of percent first position bolls or in terms of percent of total bolls at nodes 6-10, was not significantly impacted by nitrogen in 2000. Although numeric trends that existed would have increased earliness in lower nitrogen treatments, this was apparently counteracted by the delayed crop development.

Reductions in row spacing increased crop earliness in 2000. In this case the most important factor appeared to be the boll distribution. As row spacing was decreased, significant increases were seen in percent first position bolls at reduced row spacings and in percent of total bolls at nodes 6-10, which probably allowed the crop to reach 60 percent seedcotton harvest more quickly. Effects of row spacing on boll maturation period and on the date of bloom at node 8 position 1 were not significant, and did not contribute to increased earliness with more narrow rows in 2000.

2001

Although a good assessment of days to 60 percent seedcotton harvest could not be made in 2001, trends apparent in CSH appear to indicate similar treatment impacts on earliness to those seen in 2000, when low nitrogen rate reduced CSH, indicating delayed maturity. However, in 2001 the only earliness component significantly affected by nitrogen rate was boll maturation period. In this response, boll maturation period was significantly increased by reductions in nitrogen rate, contributing to any delayed maturity occurring in those treatments. Effects of reduced nitrogen rate on boll distribution were not significant in 2001. Likewise, there were no significant impacts of nitrogen rate on date of bloom at node 8 position 1.

As row spacing became more narrow, CSH was increased at the second harvest in 2001. There were no significant effects on boll maturation period or on date of bloom at node 8 position 1 that could contribute to this. However, the boll distribution was influenced by row spacing, with significant increases in percent first position bolls as well as percent of total bolls at N6-10 at reduced row spacings. Thus boll distribution was again the key factor in row spacing earliness differences.

2002

In 2002, lower nitrogen rates delayed crop maturity as indicated by CSH data. This is a contrast from the two previous years, and is reflected as well in the changed effects on earliness components. Unlike 2000, delayed crop development was not influential in earliness according to the indicators measured. There were no significant differences in the date of bloom at node 8 position 1 in 2002. In terms of other indicators, emerging leaves could be tagged at the 10^{th} main stem node in all treatments on the same day. Although there were fewer total nodes at low nitrogen rates in 2002, differences were not significant.

However, there were significant differences in the boll maturation period by nitrogen rate. In contrast to effects seen in 2001, reduced nitrogen rates caused decreases in boll maturation period. This contributed to increased earliness at low nitrogen rates. Likewise, boll distribution was significantly impacted by nitrogen rate in 2002 for the percent of bolls at N6-10. This was the only year in which this effect was significant, and the tendency for a larger percentage of total bolls to be within N6-10 in the low nitrogen treatment contributed to the increased earliness in those treatments as well.

Small earliness differences were again seen by row spacing in 2002. Reductions in row spacing increased earliness of harvest. Significant increases in first position bolls, and in percent of total bolls at N6-10, were seen with reduced row spacing. Neither boll maturation period nor date of first position bloom at node 8 effects were significant. Thus the most important earliness component of these three was probably the boll distribution.

CONCLUSIONS

One of the main objectives of this study was to compare the responses of UNR cotton and conventional row spacings to varying nitrogen fertilizer rate. Although many explanatory variables were examined, the two most important responses are yield and the earliness of maturity. Differences in earliness of maturity were minimal when compared by row spacing or by nitrogen rate. Although unusual earliness responses to nitrogen were evident in 2000 and 2001, row spacing responses were generally consistent across all years, showing small increases in earliness with UNR spacings. From an earliness standpoint, changes in nitrogen application rate for producers growing UNR cotton are probably unnecessary. The lack of significant nitrogen by row spacing interaction on lint yield confirms that the different row spacings do not require different nitrogen fertilizer rates.

Under the conditions of this study, earliness differences by row spacing were always less than four days, limiting the attractiveness of UNR cotton as a way to produce an earlier maturing crop. The compensating ability of cotton as a crop was evidenced in the consistency of overall lint yield response across row spacing systems despite changes in individual plant architecture and yield components. The lack of significant yield differences by row spacing shows that the decision of whether UNR cotton should be produced in place of the more common 76-cm rows will depend on economic consequences of other aspects of UNR cotton production.

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