EVALUATION OF THE GENETIC GAIN IN UPLAND COTTON DURING THE TWENTIETH CENTURY

A Thesis

by

BRIAN MATTHEW SCHWARTZ

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

MASTER OF SCIENCE

December 2005

Major Subject: Plant Breeding

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Approved by:

Chair of Committee,	C. Wayne Smith
Committee Members,	Peggy M. Thaxton
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ABSTRACT

Evaluation of the Genetic Gain in Upland Cotton During the Twentieth Century. (December 2005)

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Chair of Advisory Committee: Dr. C. Wayne Smith

Genetic gain studies in the past have been used to evaluate the historical improvement of different traits and give insight into what magnitudes of gain might be possible in the future. Additionally, they have been carried out to defend the role of genetics during periods of stagnant or decreasing yield trends. This study was conducted over a 2-year period (2003 and 2004) and included nine current or obsolete cotton (*Gossypium hirsutum* L.) cultivars grown in 5 plant densities designed to evaluate varying levels of interplant competition. Plant densities were single plant culture with plants spaced 3m x 3m, 2m x 2m, 1m x 1m, 1m x 0.3m, and two commercial populations with plants spaced 1m x 0.1m. Results were analyzed for each trait to determine whether genetic gains are interrelated with tolerance to interplant competition or strictly under genetic control. The rates of genetic gain for lint yield were highest in the 1m x 0.1m, 1m x 0.3m, and 1m x 1m treatment with slopes of 8.7, 8.2, and 7.1 kg ha^{-1} yr^{-1} respectively. The slopes were each significantly smaller in the 2m x 2m and 3m x 3m spaced populations with gains of 3.6 and 1.5 kg ha^{-1} yr^{-1} respectively, implying that for lint yield, genetic gains have been made for

tolerance to interplant competition. Similarly, modern maize hybrids only out perform obsolete hybrids at higher plant densities. Genetic gain for lint yield, fiber length, fiber strength, and fiber micronaire made in the context of tolerance to interplant competition is due in large part to the excellent performance of Deltapine 491 (2002) at higher plant populations.

DEDICATION

This work is dedicated foremost to my loving wife Susan. Thank you for your unending support and kindness.

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INTRODUCTION

Genetic gains in yield, fiber quality, yield components, and morphological traits in upland cotton, *Gossypium hirsutum*, have been documented by numerous studies in the past forty years. The focus of these reports was to interpret the rate of gain year^{-1} and report on the genetic portion of the progress that has resulted from the work of breeders. Resistance or tolerances to biotic stress such as disease and insect pests and abiotic stresses like drought and heat have been paramount to the gains that have been accomplished. Equally important may have been the selection of cultivars that will thrive under higher plant populations. Under stressful conditions, yield can be improved only if the effects of increased interplant competition can be negated by the plants. Changes in agronomic practices throughout the previous century are accountable for the remainder of the progress seen on the farm.

Quantifying yield potential on an individual plant basis, defined as the yield that can be achieved only when a cultivar is adapted and non-stressed (Duvick and Cassman, 1999), of cotton was the major objective of this study. Determining the yield potential of cultivars released throughout the last 100 years will allow conclusions to be drawn on whether there has been true genetic gain for yield, fiber quality, boll components, and morphological traits on an individual plant basis, or if cultivars have been developed to be productive in spite of increasing levels of interplant competition.

This thesis follows the style and format of Crop Science.

Research in cotton concerning plant population densities to date have not included densities that were designed to eliminate interplant competition altogether. This project is modeled after an experiment designed by Duvick and Cassman (1999) in which maize hybrids representing the eras of 1930 through 1990 were evaluated in three plant density treatments. Interestingly, the authors found that at low plant densities, the yield potential of all corn hybrids over time was essentially the same. At higher plant densities, it was evident that only newer hybrids were reaching their per unit land area yield potential, probably through improvements in stress tolerance (Tollenaar and Wu, 1999; Tollenaar et al., 1997). Similar results of increased productivity in modern cotton cultivars have been documented when comparing cultivars representing different eras at plant densities common to current production practices (Bayles et al., 2005; Bridge and Meredith, 1983; Culp and Green, 1992). The objective of this study was to evaluate genetic gain in yield and quality parameters among 9 cotton cultivars developed for production agriculture in specific eras over the last 100 years when grown with and without interplant competition at College Station, Texas.

LITERATURE CITED

The details of the emergence of upland cotton, *Gossypium hirsutum*, through an unlikely hybridization of New and Old world species to form an allotetraploid may never be apparent, but its impact on agriculture in the United States is clear. Upland cotton is well adapted to conditions in the Cotton Belt and has sustained the economic wellbeing of farm and fashion alike through many generations. Archeological evidence supports the theory that upland cotton was present long before man could have had any role in its beginnings (Smith and MacNeish, 1964).

Historical records document the use of cotton fiber for homespun clothing in early America in both the Hopi Indian and early European societies (Ramey, 1966). Over the next several hundred years, genotypes brought into the United States from all over the world were allowed to mix, hybridize, and become better adapted to conditions across the South (Brown, 1927). During this developmental period, cotton yield trends showed no increase. Numerous factors may have contributed to this including a lack of understanding of the principles of maintaining genetic gains and plant stress induced by both biotic and abiotic pressure. Niles (1982) upholds that 3 distinct events in the early history of cotton improvement were crucial to the path breeders followed. The first being intensive selection for photoperiod adaptation between early colonial times and the mid-1800’s. Second was the introduction of superior Mexican germplasm around 1806, followed lastly by the influx of the boll weevil at the turn of the 19th century. Together this series of events shaped the path for the development of the few cultivars that can be traced in the lineage of most modern genotypes. This bottleneck in the genetic base of upland cotton has been the topic of much discussion and some recent research (Bowman and Gutierrez, 2003; Van Esbroeck and Bowman, 1998; Van Esbroeck et al., 1999).

Breeding History

More productive and modern upland cotton types were sparked by the intentional introduction, mixing, and hybridization of a Mexican biotype, sometimes referred to as Burling’s introduction, with the then common American cultivars Georgia Green Seed and Creole Black Seed. This Mexican introduction was early maturing, boll rot resistant, and produced large open bolls that facilitated hand picking. Its lint yield, staple, and texture were more desirable than those of either the Georgia Green Seed or Creole Black cultivars. Combined with the wide adaptability found in Georgia Green and Creole, this new hybridized cultivar met the needs of farmers looking to produce higher quality fiber in upland growing conditions. As the 1806 and later introductions of the same biotype from Mexico became distributed across the cotton producing areas of the United States in the early 1800’s, men such as Henry W. Vick began selecting superior plants out of their fields and advancing this seed separately through mass selection, a process successfully used by corn and wheat growers in the North. Vick observed faster gains applying this methodology rather than selecting only on the basis of a seed’s outward appearance. Soon thereafter he released the cultivar 100 Seed, which altogether performed in a manner far superior to other cultivars of the day. 100 Seed was frequently sold under a number of other names (Moore, 1956). Martin Philips was certainly not the first to originate the idea of cross pollination in the cotton flower, but possibly the first to widely publish the concept in his article “Hybrid Cotton” in the winter of 1851 (Philips, 1851). Through the dissemination of information to the general public, common farmers were now armed with the knowledge and material to become breeders themselves.

When analyzing the background of modern cultivars, Ramey (1966) was able to identify 17 obsolete cultivars frequently occurring in their pedigrees. These sources, although marketed as pure-line cultivars, were often non-uniform and possessed more genetic variability than one might expect. Bohemian, Jackson Round Boll, Mebane Triumph, and Texas Stormproof were big boll Western types. Cleveland, Cook Improved, and Russell were big boll Eastern types. Tennessee Green Seed and Trice were early maturing cultivars. Dixie, Cleveland, Cook, and Toole all can be identified as sources of Fusarium wilt resistance. Sunflower and Polk contributed longer staple length. Lastly, the Acala and Kekchi introductions from Mexico were pivotal in the development of cultivars suited for the desert Southwest and the cooler temperatures in the High Plains, respectively.

By the 1930’s enough cotton seed had been grown, sold, and resold under various cultivar names in countless counties and states, that a factual record of which cultivar was what had become confounded. In 1930, a committee of cotton breeders and agronomists appointed by the Southern Agricultural Workers Association surveyed and reviewed all of the cultivars grown in production, characterized them, and assigned 31 as standard commercial cultivars. They were: Acala-5, Acala-8, New Boykin, Cleveland-5, Cleveland-884, Piedmont Cleveland, Wannamaker Cleveland, Cook 307-6, Delfos, Delta & Pine Land-8, Delta & Pine Land-10, Deltatype Webber, Dixie-Triumph, Dixie-14, Express-121, Lightning Express, Half-and-Half, Kasch, Lone Star, Mebane, Missdel, Station Miller, Mexican Big Boll, Oklahoma Triumph-44, Pima, Rowden, Arkansas Rowden-40, Toole, Stoneville, Trice, and Wilds. This list completed, the American Society of Agronomy and the Southern Agricultural Workers Association then required evidence of an improvement over or distinction from current standard commercial cultivars before any new cultivar could be recognized (Brown, 1938).

The years of 1936 through 1960 were marked with increased yields recorded throughout the country. Miller (1977) acknowledged some portion of these gains were due to higher yielding cultivars, but credits the wave of the technological advances in production to the steady rise in yield during this era. These improvements included commercial fertilizers, irrigation, skip-row culture, mechanization, and the introduction of many effective pesticides and herbicides.

Technological advances were not limited to the agricultural sector during this time period. The introduction of man-made fibers in the 1940’s initiated the subsequent competition for markets that had once been controlled by the cotton industry. Fiber quality again needed to be improved. One of the most significant breakthroughs in this sector of research came from J. O. Beasley at Texas A&M University. He developed an unprecedented "triple hybrid" from a cross between *G. thurberi*, *G. arboreum*, and *G. hirsutum*. The hybrid, once backcrossed to *G. hirsutum* for several generations, reduced the linkage associated between high lint yield and low fiber strength (Percival et al., 1999). As processes of scientific breeding expanded and the availability of seed from elite cultivars increased, researchers were better able control gene exchange (Brown and Ware, 1958). The problems of inadvertent seed mixing and inferior pollen flow from nearby fields that had once plagued breeders shifted to issues of improper choice of parental material, poorly defined long-term objectives, and the struggle to effectively differentiate material that had desirable genetics.

Cotton breeding during the past 45 years has taken many avenues. There have been shifts in the needs of the textile industry and ever-changing environmental challenges. Selection of individual plants and progeny rows following hybridization in varying forms of the pedigree breeding method was shown to result in greater improvements than when a breeder solely selected within older cultivars for gains (Feaster and Turcotte, 1970). Efforts to steadily increase production yields using the pedigree method often were hindered by simultaneous selection for apparently negatively correlated quality traits. To rectify this, Meredith and Bridge (1971) suggested that modifications to the conventional methods of cotton breeding were necessary. These modifications included, among others, random intermating, recurrent selection, and backcrossing. Miller and Rawlings (1967a) recommended that up to 4 cycles of random intermating should precede selfing to facilitate the breakup of linkage blocks associated with poor yield and quality. Both intermating and backcrossing have been shown to be successful in obtaining desirable genetic recombinations required for the basic success of a breeding program (Meredith, 1977).

Evans (1980) attributed 4 areas in which breeders have made gain to increased yields and quality in the past. They were (1) adaptation to local environments, (2) resistance to pests, (3) selection for higher yield potential under favorable conditions, and (4) suitability to continually changing agronomic and management practices. The variety of cultivars available for producers has increased due to breeder efforts to develop cultivars specifically adapted to certain regions. Resources and effort have been applied to local cultivar testing to identify specific markets to target for sales.

Pima and sea island cottons, *G. barbadense*, are not suited for production in the majority of the Cotton Belt. Breeders have long recognized the potential for introgressing their fiber quality into upland cotton. The work done at the New Mexico AES and the Pee Dee Experiment Station to advance material out of the segregating generations following the initial hybridization of the two species has been rigorous. After extensive crossing and backcrossing, followed by selection towards the adapted recurrent upland parent, breeders at the New Mexico AES and the USDA breeding program at Florence, SC have released numerous germplasm. The Acala cultivars have shown improvement in fiber quality, supposedly through *G. baradense* gene introgression into upland phenotypes. Staten (1971) argued that it was evident when assessing the fiber quality and overall appearance of these upland releases that significant *G. barbadense* introgression had occurred.

Interplant Competition

Isolation environments occur when “plants are spaced so widely apart as to exclude any plant-to-plant interference with the equal use of growth resources” (Fasoula and Fasoula, 1997). Competition among plants with each other and with weeds for space, light, carbon dioxide, water, and nutrients must be removed to achieve this state. Quisenberry et al. (1980) suggested that selection for increased lint yield has been more effective in locations not limited by the environment or competition.

Research in cotton concerning plant populations to date have not included densities that were designed to eliminate interplant competition. The vast majority of past studies have concentrated on finding the optimum number of plants ha^{-1} for increasing yield in commercial situations (Bridge et al., 1973; Fowler and Ray, 1977; Hawkins and Peacock, 1970; Smith et al., 1979). Tisdale (1928) experimented with different numbers of plants $hill^{-1}$ and plant spacings within the drill. He reported smaller bolls on plants as crowding increased.

Bridge et al. (1973) found that as plant populations decreased, significantly larger lint percentages, bolls, and seeds were observed. They found no consistent effects of plant population on fiber properties. Smith et al. (1979) attributed later maturity to low stand density and a reduction in lint percent and boll size to high stand density. Significantly greater fiber elongation found in the higher plant density culture was the only fiber property affected by plant population. Fowler and Ray (1977) reported the number of nodes to first fruiting increased with higher populations whereas reductions in plant height, stem diameter, number of branches, boll size, seeds boll^{-1}, seed index, and lint percent were noted in lower populations. Greater yields plant^{-1} are possible in lower plant densities through fruit initiation and retention. Cotton exhibits some plasticity in its response to different population densities and environments. Total seedcotton yield ha^{-1} can remain unaffected under varying levels of interplant competition through compensation in fruit retention and distribution patterns on the plant (Bednarz et al., 2000; Jones and Wells, 1998; Jost and Cothren, 2000).

Genetic Contributions to Yield

Genetic improvement studies have provided valuable insight into the gains made through cotton breeding during the past. When analyzing yield performance, two methods have been proposed to separate genetic and environmental effects. The first utilizes yield results from advanced strain tests through the years that included comparisons to a few common check entries.

Check cultivars then are used as an environmental index from which the results of each location and year can be adjusted. Genetic progress then is calculated in one of four statistical methods (Meredith and Bridge, 1984). The use of obsolete cultivars to represent the genetic potential of their era was validated by Meredith and Culp (1979) who reported no major changes in the characteristics of a cultivar through generations of seed increase. The maintenance of these cultivars has not been affected by inbreeding depression, seed contamination, reselection within a cultivar, and accumulation of seed carrying pathogens. The second method offers a comparison of yield performance between obsolete and modern cultivars tested together in the same environment. Both allow researchers to quantify genetic gain and explain past trends.

Environmental conditions, agronomic practices, and genetic modification by breeders all have at one time or another either received the credit or blame for increases, plateaus, or decreases seen in yield. A special session was held in 1977 at the Beltwide Cotton Production-Mechanization Conference to address potential causes in the previous 15 years for the plateau and decline of lint yields across the country. Meredith and Brown (1984) reinforced that drawing conclusions based only on the statistical correlation of 2 factors is often unwarranted because it does not necessarily imply a cause and effect relationship. After thorough evaluation, Meredith (1982) reasoned that a continuous decline over this long length of time covering such a broad area could not be attributed to weather alone. Unknown adverse effects of changes in cotton production practices, including insect and weed control through chemicals, soil compaction, water-related issues, and loss of soil organic matter and nutrients were most likely responsible for the reduction in lint yields and not the inherent yielding ability of cultivars (Bridge and Meredith, 1983). Reports of genetic advance in lint yield from 1939 to 1979 were reported in the California Acala seed stocks. However, these gains were not reflected in commercial production after 1960 suggesting increased environmental constraints (Bassett and Hyer, 1985). Miller (1977) agreed that newer cultivars were not responsible for decreasing yield trends and suggested that modern cultivars had the genetic potential to yield 2 to 17% more than those of 1965. He acknowledged that good breeding programs are needed to release material that can react stably during stress conditions.

The rate of genetic gain (kg ha^{-1} yr^{-1}) as observed in head to head comparisons of commercially grown obsolete and modern cultivars has been calculated in many studies (Table 1). Estimates of rate changes range from 1.5 to 10.5 kg ha^{-1} yr^{-1}. These results are contingent on the time period represented by the cultivars, the material selected to represent eras, and the environment in which they were tested.

Generally, yield gains were credited to the ability of modern cultivars to support more bolls $plant^{-1}$ and consistently generate higher lint percentages. Other underlying components of cultivars displaying increased yield potential were smaller bolls, smaller seed, earlier maturity, and higher micronaire values

(Bridge and Meredith, 1983; Bridge et al., 1971; Culp and Green, 1992; Hoskinson and Stewart, 1977; Meredith et al., 1997; Moser and Percy, 1999). Moser and Percy (1999) speculated that trends for increasing fiber micronaire and length indicate that weight fiber^{-1} is likely more responsible for the greater lint seed^{-1} in newer cultivars than number of fibers seed^{-1}. Bayles et al. (2005) reported on the genetic gain of “stripper type” cotton adapted to the Plains in Oklahoma. Results from this study credit larger bolls and seeds to the yield improvements observed in the most modern cultivars. Also important were lock tenacity and disease resistance. Outcomes contrary to those of “picker type” studies indicate that the requirements of this production system are truly different.

Cotton cultivars included in yield trials during the mid 1930’s were again evaluated in the late 1960’s under drastically different cultural systems to assess their yield response. Review of these results indicated that the ability to produce more bolls m^{-2} as the use of fertilizers, insecticides, herbicides, and irrigation became the norm must have been a factor in the selection of germplasm (Ramey, 1972). Turner et al. (1976) concluded that a smaller portion of the gains in yield can be credited to the reduction of seeds boll^{-1} and the increase of lint seed^{-1}. Bridge (1990) stated that efforts to breed host plant resistance and earliness into modern cultivars allow greater tolerance of, and escape from insect pressure. Yield gains were linked also to harvest flexibility and the avoidance of poor late season weather trends made possible by short season cotton. In a series of publications, Wells and Meredith (1984a; 1984b; 1984c) reported on the physiological differences between obsolete and modern cultivars, such as an earlier, more complete transitions from vegetative to reproductive dry matter partitioning which resulted in a greater amount of boll development occurring when leaf area and mass are at a maximum. Recent cultivars also partitioned more dry matter into reproductive structures without increasing total dry matter. They generally produce a greater number of smaller bolls with a higher lint percentage prior to the shedding of fruit that is common later in the season. Meredith and Wells (1989) suggested that by introducing variability for the reproductive to vegetative ratio, genetic advances in yield are possible. At some point logic suggests that further reduction in leaves and/or stems will no longer support increased lint yields. The improved photosynthetic capacity and stomatal conductance under water stress conditions of modern over obsolete Pima cultivars has been measured. The yield potential of these modern cultivars has risen as the number of bolls that can be supported under stress increases (Faver et al., 1997).

MATERIALS AND METHODS

Nine cultivars, 1 modern and 8 obsolete, were planted into 5 discrete plant density treatments. Each cultivar was selected for evaluation on the basis of adaptation to growing conditions in College Station, TX at their respective dates of release and the proximity of their year of development or release to the beginning of each decade, from 1900 through 2000 (Table 2).

In 2003 and 2004, the genotypes were grown in 5 plant densities designed to evaluate varying levels of interplant competition. Plant densities were single plant culture with plants spaced 3m x 3m, 2m x 2m, 1m x 1m, 1m x 0.3m, and two commercial populations with plants spaced 1m x 0.1m. Plots were single rows, 12m long. Within each planting density, genotypes were grown in a randomized complete block with 4 replications. Other than plant density, all cultural practices were normal for College Station, TX, including furrow irrigation. Genotypes were compared within and among each spacing treatment to estimate genetic gain for: lint yield, lint percent, boll size, seeds boll^{-1}, seed index, fiber length, fiber bundle strength, fiber maturity (measured as micronaire), fiber length uniformity, fiber elongation, plant height, node of first fruiting limb, and number of main stem fruiting nodes.

Seed for all genotypes in the 3m x 3m, 2m x 2m, 1m x 1m, and 1m x 0.3m spacing treatments was hand planted, 3 seeds hill^{-1}, and thinned to 1 plant hill^{-1} 2 weeks after emergence. Seed for all genotypes in the commercial populations were machine planted with an experimental plot planter. The experiments were monitored weekly and weeds removed as needed. Records of general plant health were kept throughout the growing seasons. Five mature bolls were taken randomly from each plant in the 3m x 3m, 2m x 2m, 1m x 1m, and 1m x 0.3m spacing prior to application of defoliant. Of the two commercial populations, one was harvested mechanically and 50 mature bolls were randomly taken from each plot row for every genotype in the second commercial population. Defoliant was applied to each spacing treatment only when the latest maturing cultivar had reached the 60% open boll stage to ensure the genetic potential of each plant. Plants in the 3m x 3m, 2m x 2m, 1m x 1m, and 1m x 0.3m spacing treatments that developed under equal levels of interplant competition were hand harvested as individual samples. Each plot row in the selected commercial population was harvested with a modified one-row plot cotton picker. Harvest weights were recorded and grab samples were saved from each plot. Morphological traits, including plant height, node of first fruiting limb, and number of main stem fruiting nodes were recorded in the 3m x 3m, 2m x 2m, 1m x 1m, and 1m x 0.3m spacing treatments in 2003 and 2004. They were only recorded in the commercial population in 2004.

Measurement of Lint Yield, Fiber Properties, and Yield Components

Each individual plant from the 3m x 3m, 2m x 2m, 1m x 1m, and 1m x 0.3m spacing treatments was ginned on an eight-saw laboratory gin. Lint yield plant^{-1} was recorded and lint percent was calculated. Lint yield plant^{-1} was converted to lint yield ha^{-1} using the number of plants area^{-1} specific to each spacing treatment. A random 40g fiber sample from each plant was forwarded to the Texas Tech International Textile Research Center for High Volume Instrument (HVI) fiber analysis. From the 5-boll samples several yield components were recorded including: boll size as the weight of seedcotton boll^{-1}, seeds boll^{-1}, and seed index as the weight of 100 fuzzy seed. Total lint yield plant^{-1} was calculated as lint yield plant^{-1} plus the lint weight from each 5-boll sample.

Each grab and 50-boll sample from the commercial spacing treatments was ginned on an eight-saw laboratory gin. Lint yield plot^{-1} was calculated using the gin turnout from its corresponding grab sample. Lint yield plot^{-1} was converted to lint yield ha^{-1}. Fiber quality and yield components were both determined from the 50-boll sample. A random 40g fiber sample was forwarded to the Texas Tech International Textile Research Center for High Volume Instrument (HVI) fiber analysis. Lint percent, boll size as the weight of seedcotton boll^{-1}, seeds boll^{-1}, and seed index as the weight of 100 fuzzy seed were recorded.

Statistical Analysis

Before analysis, those plants noted to have potential problems during the experiment were compared to outliers in the dataset. If justified by records, those data were removed. For all traits, plot means and not individual plant data were used for analysis. A Bartlett's test for homogeneity of variances was performed for each trait, testing the equality of variance between cultivars in each plant spacing treatment. Homogeneity of variances among each trait's rate of genetic gain slopes over the 5 plant spacing treatments were tested also. When conditions of homogeneity of variances were not met, the following data transformations were applied to the dataset and tested by Bartlett's: x^2, x^3, x^{-1}, x^{-2}, x^{-3}, $x^{1/2}$, $x^{-1/2}$, log(x), ln(x), and e^x. If a transformed data set corrected the homogeneity of variance, it was used in the analysis of variance. If no transformation succeeded, the original dataset was used.

An analysis of variance was performed on each of the measured traits, in each spacing treatment. The General Linear Models (GLM) procedure in SAS® using the appropriate error terms and assuming a mixed model with "genotypes" and "years" considered as fixed variables and "replications" considered as a random variable was chosen for the analysis. If the genotype x year interaction was not significant, means over both years were utilized. If significant, analyses were conducted separately for each year. Where the main effect, genotype, was found to be significant, a Waller-Duncan *k*-ratio LSD was used to separate treatment means.

Linear regression analyses were performed for each trait to obtain the corresponding rate of genetic gain slope in each replication for all 5 plant spacing treatments. An analysis of variance was performed on the rates of genetic gain slopes of each of the measured traits, across all spacing treatments. The General Linear Models (GLM) procedure in SAS® using the appropriate error terms and assuming a mixed model with "spacing" and "years" considered as fixed variables and “replications” considered as a random variable was chosen for the analysis. If the spacing x year interaction was not significant, means over both years were utilized. If significant, analyses were conducted separately for each year. Where the main effect, spacing, was found to be significant, a Waller-Duncan *k*-ratio LSD was used to separate treatment means.

RESULTS AND DISCUSSION

Lint Yield

Combined analyses for lint yield over the 2 years detected significant genotype x year interactions in the 2m x 2m, 1m x 1m, and 1m x 0.1m plant spacings (Table 3). These 3 plant spacings were analyzed again separately for each individual year. The means for lint yield in the 2 remaining plant spacings were combined over years. Differences among genotypes were significant for all plant spacing treatments. Deltapine 491 (2002) consistently yielded the highest in all planting densities. Generally, Lone Star (1905), Half-and-Half (1910), Deltatype Webber (1922), and Rowden 41B (1930) all performed similarly in each plant spacing treatment. Likewise, Deltapine 14 (1941), Stoneville 213 (1962), Deltapine 55 (1974), and Stoneville 506 (1982) had near equal yields in every spacing treatment (Table 4).

Rates of genetic gain varied for lint yield across all plant spacings and no spacing x year interactions were noted (Table 5). The rates of genetic gain were highest in the 1m x 0.1m, 1m x 0.3m, and 1m x 1m treatment with slopes of 8.7, 8.2, and 7.1 kg ha^{-1} yr^{-1} respectively (Table 6). The rate of gain, i.e. slopes, were each smaller (P = 0.05) in the 2m x 2m and 3m x 3m spaced populations with gains of only 3.6 and 1.5 kg ha^{-1} yr^{-1} respectively (Fig. 1). Higher rates of genetic gain under conditions of greater interplant competition are a result of increased lint yields in the more recently released cultivars, particularly Deltapine 491 (2002). This implies that for this trait, genetic gains have been made for tolerance to interplant competition. Similarly, modern maize hybrids only out perform obsolete hybrids at higher plant densities (Duvick and Cassman, 1999).

Another way to analyze the progress made by the cotton industry is to look at historic yield data over an extended time period. Unfortunately yearly national, state, and even county yield averages of all cultivars tested may not be representative of an individual location, much less an experiment managed to provide the best growing environment possible. The conclusion was reached that an average of the top 5 yielding entries from yearly commercial cultivar tests conducted on the Texas A&M University Research Farm would best represent the most adapted material of their time and make for an interesting comparison (Fig. 2). Historic data are presented where records could be found (TAES, 1913-2002). A decrease at the rate of 3.9 kg ha^{-1} yr^{-1} was reported in the time period from 1913 through 1926. A similar decrease of 3.10 kg ha^{-1} yr^{-1} was observed for the years 1904 through 1922 by Bridge and Meredith (1983). For the time period of 1937 through 1956, non-irrigated commercial cultivar tests showed yields increasing at a rate of 4.3 kg ha^{-1} yr^{-1}. Irrigated tests conducted from 1957 through 2002 illustrated similar increases of 4.1 kg ha^{-1} yr^{-1}. These increases are half of that found in the commercial spaced population reported herein. Larger increases in realized yield are observed as a direct result of the performance of recently released cultivars when obsolete and modern cultivars are grown together in an environment of high input and with interplant competition. This reinforces the inherent ability of modern genotypes to excel under such conditions.

Lint Percent

Significant genotype x year interactions in the combined analysis were detected for lint percent in the 1m x 1m and 1m x 0.1m plant spacings (Table 7). The 1m x 0.1m plant spacing was analyzed again separately for each year, but the significance ($P = 0.0462$) of the interaction in the 1m x 1m treatment was ignored for presentation purposes since the p-value rounded to the minimum significance level. The means for lint percent in the remaining 4 plant spacings were combined over years. Differences among genotypes were significant for all plant spacing treatments. Lint percent of cultivars released before Deltapine 14 (1941) ranged from 26% to 34% and 37% to 40% after its release. However, the exceptions Half-and-Half (1910) and Deltapine 491 (2002) were noted for their high lint percentages relative to their years of release averaging 38% and 43% respectively across all planting densities (Table 8).

When comparing the rates of genetic gain for lint percent across all plant spacings, no spacing x year interaction was noted (Table 9). The rates of genetic gain were highest in the 1m x 0.3m and 1m x 1m treatments with slopes of 0.11 % yr^{-1} (Table 10). The slope was significantly smaller in the commercial spaced population at 0.08 % yr^{-1} as illustrated in Fig. 3. Generally, gains in this trait are best characterized by the performance of Deltapine 491 (2002) as compared to the other 8 genotypes. An attempt to decipher the meaning of each calculated slope as it pertains to tolerance of interplant competition across the plant spacing treatments is less informative.

Trends of increasing lint percent have been reported throughout the literature and have been used in part to explain expanding lint yields (Bridge et al., 1971; Culp and Green, 1992; Hoskinson and Stewart, 1977; Miller and Rawlings, 1967b; Miller et al., 1958; Moser and Percy, 1999; Wells and Meredith, 1984c). In contrast, Bridge and Meredith (1983) concluded that lint percent had not changed in cultivars released after Deltapine 14 (1941). Both of these conclusions appear to be supported by the data from this study.

Boll Size

Analyses for boll size over the 2 years detected significant genotype x year interactions in the 3m x 3m and 1m x 1m plant spacings (Table 11). Both plant spacings were analyzed again separately for each individual year. The means for boll size in the remaining 3 plant spacings were combined over years. Differences among genotypes occurred in all plant spacing treatments. Across all planting densities, Rowden 41B (1930) and Lone Star (1905) generally produced larger (P = 0.05) bolls than the other cultivars evaluated. Cultivars released in the later half of the century tended to have smaller bolls (Table 12). These results are consistent with those of Bridge and Meredith (1983).

Variation for the boll size slopes among spacing treatments was not significant (Table 9) and the rates of genetic change were all -0.01 g yr^{-1} (Table 10). Boll size appears to be controlled genetically and not influenced by interplant competition as illustrated in Fig. 4. These data support the hypothesis that increased yields under varying levels of plant stress are not due to larger boll size, but likely to increased boll retention as support by Culp and Green (1992), Harrell and Culp (1976), Hoskinson and Stewart (1977), Miller et al. (1958), Moser and Percy (1999), Ramey (1972), Turner et al. (1976), and Wells and Meredith (1984c).

Published trends of decreasing boll size have been numerous, particularly in research completed during the 1960s and 1970s (Bridge and Meredith, 1983; Bridge et al., 1971; Culp and Green, 1992; Hoskinson and Stewart, 1977; Miller and Rawlings, 1967b; Wells and Meredith, 1984c). Culp and Harrell (1975) surmised that plants growing with a larger number of medium to small sized bolls would recover more rapidly from stress and produce greater yields. Conversely, Bayles et al. (2005) found that under stripper-cotton production systems, the more modern cultivars have larger bolls.

Seeds Boll^{-1}

For seeds boll^{-1}, genotype x year interactions were significant in the 3m x 3m, 2m x 2m, and 1m x 1m plant spacings (Table 13). Thus, genotypic means were separated within years while means for seeds boll^{-1} in the 2 remaining plant spacings were combined over years. Differences among genotypes were significant for all plant spacing treatments. In most cases and across all planting densities, Lone Star (1905), Half-and-Half (1910), and Rowden 41B (1930) produced more seeds boll^{-1} (Table 14). Others have also documented a reduction in the number of seeds boll^{-1} as the century has progressed (Miller and Rawlings, 1967b; Moser and Percy, 1999; Turner et al., 1976).

A spacing x year interaction was observed when analyzing the rates of genetic gain for seeds boll^{-1} across all plant spacings (Table 9). Small but significant differences among plant spacings were noted in the rates of genetic gain within years for seeds boll^{-1} (Table 10). The rates of genetic change were inconsistent between years for the 3m x 3m and 2m x 2m spacing treatments. In 2003, these slopes showed the least change in seeds boll^{-1} over the century, but both had the highest rates of decrease of all tests in 2004 at -0.05 seeds yr^{-1}. Because of an inconsistency in years and the lack of stronger trends (Fig. 5), only general conclusions are justified. There has been a slight decrease in the number of seeds boll^{-1} in cultivars released during the last 100 years. Therefore, increased yields in upland cotton are not a result of the extra lint that would be associated with a greater number of seeds per fruiting structure.

Seed Index

Significant genotype x year interactions were detected for seed index in the 1m x 1m and 1m x 0.3m plant spacings (Table 15), thus mandating mean separation within years. Seed index means in the remaining 3 plant spacings were combined over years. Differences among genotypes were significant for all plant spacing treatments. Across all planting densities, Rowden 41B (1930) and Deltatype Webber (1922) produced the largest seeds at approximately

13 g (100 seed)$^{-1}$. Deltapine 491 (2002), Deltapine 55 (1974), and Deltapine 14 (1941) tended to have the smallest seeds among the genotypes evaluated (Table 16).

When comparing the rates of genetic gain for seed index across all plant spacings, a spacing x year interaction was detected (Table 9). While variation among spacings was not significant, genotypic differences were significant when years were considered individually (Table 10). The rates of genetic change were similar in all but the 1m x 0.3m plant density in 2003 which was lower than the other 9 calculated slopes that ranged from -0.023 to -0.032 g (100 seed)$^{-1}$ year^{-1}. Slopes representing changes in this trait over time were not meaningfully different at any level of interplant competition. The general trend has been a decrease in seed size over the last century (Fig. 6). Consequently, the increased yields observed in upland cotton recently are not a result of the extra lint that could be produced by seeds with larger surface areas.

Several other studies have shown trends of the most recent cultivars having progressively smaller seeds (Bridge et al., 1971; Hoskinson and Stewart, 1977; Miller and Rawlings, 1967b; Moser and Percy, 1999). Alternatively, Bayles et al. (2005) found that the more modern, stripper-type cultivars have heavier seeds.

Fiber Length

Significant genotype x year interactions were not found for the 1m x 0.1m plant spacing in the analyses for fiber length (Table 17). The remaining 4 plant spacings were analyzed again separately for each individual year. Means for fiber length in the 1m x 0.1m plant spacing were combined over years. Differences among genotypes were significant for all plant spacing treatments. Across all planting densities, Deltapine 491 (2002) consistently had the longest upper half mean (UHM) fiber length, and Lone Star (1905) had fiber with HVI UHM lengths equaling those of cultivars released in the 1970s and 1980s (Table 18). This suggests that good fiber length genes or alleles were present in the early 20th century, and that breeders were unable or unmotivated to integrate them into material which possessed other traits deemed more important. Many studies conducted to evaluate genetic gains reported that there was little to no improvement of fiber length at their respective times (Bridge and Meredith, 1983; Bridge et al., 1971; Culp and Green, 1992; Hoskinson and Stewart, 1977; Miller and Rawlings, 1967b; Wells and Meredith, 1984c), and a few experiments have detected genetic improvement for this trait (Bayles et al., 2005; Turner et al., 1976). UHM lengths generally improved with the release of new cultivars after and including Deltapine 14 (1941).

Rates of genetic gain for fiber length were evaluated across all plant spacings and no spacing x year interactions were noted (Table 19). Variation among spacings were significant and the slope means were separated (Table 20). The rate of genetic gain was highest in the 1m x 0.1m treatment with a slope of 0.048 mm yr^{-1}. The slopes were significantly smaller in the other 4 populations. As shown in Fig. 7, increased fiber lengths in the more recently released cultivars under the most intense levels of interplant competition resulted in a higher rate of genetic gain. This implies that for this trait, genetic gains have been made for tolerance to interplant competition.

Fiber Strength

For fiber strength, genotype x year interactions were significant for all plant spacings (Table 21). Differences among genotypes were significant for all plant spacing treatments within each year. Across all planting densities, Deltapine 491 (2002) and Deltatype Webber (1922) consistently produced strong fibers (Table 22). This implies that fiber strength genes present in the 1920s were not easily integrated into genotypes with other, more valuable traits. It is more likely due to the lack of economic incentives before the advent of open-end spinning in the 1970s. However, increases in fiber strength over time has been reported in the literature (Bayles et al., 2005; Culp and Green, 1992; Turner et al., 1976), while a lack of progress has been observed by Bridge and Meredith (1983), Bridge et al. (1971), Miller and Rawlings (1967b), and Wells and Meredith (1984c).

A spacing x year interaction was not observed when analyzing the rates of genetic gain for fiber strength across the plant spacings studied (Table 19). Variation among spacings was significant and thus slope means were separated (Table 20). The rate of genetic gain was the highest in the 1m x 0.1m treatment with a slope of 0.39 kN m kg^{-1} yr^{-1}. All slopes except that in the 3m x 3m spacing of 0.30 kN m kg^{-1} yr^{-1} were smaller ($P = 0.05$). As depicted in Fig. 8, increased UHM fiber strength in Deltapine 55 (1974) and Deltapine 491 (2002) under the most intense levels of interplant competition resulted in a higher rate of genetic gain. The slope in the 3m x 3m spacing treatment aside, these results indicate that genetic gains have been made for tolerance to interplant competition in this trait.

Fiber Micronaire

Significant genotype x year interactions were detected for micronaire in the 2m x 2m, 1m x 1m and 1m x 0.1m plant spacings (Table 23). These 3 plant spacings were analyzed again separately for each individual year, while the means across years for fiber micronaire in the 2 remaining plant spacings were separated (Table 24). Micronaire was not a selection criteria in the oldest 5 cultivars as supported by the somewhat erratic distribution of readings through Deltapine 14's release in 1941. In cultivars released from the 1960s to the present, micronaire readings vary from 4.3 to 5.1 across all planting densities. This stabilization is a result of breeding to avoid penalties imposed on cotton sold with micronaire readings above 4.9 or below 3.5. Several researcher reports during the 1960s and 1970s observed consistent improvements in fiber micronaire (Bridge et al., 1971; Miller and Rawlings, 1967b; Turner et al., 1976; Wells and Meredith, 1984c), while in most recent accounts, increasing fiber micronaire trends appear to have leveled (Bayles et al., 2005; Bridge and Meredith, 1983; Culp and Green, 1992; Hoskinson and Stewart, 1977).

When comparing the rates of genetic gain for fiber micronaire across all plant spacings, a spacing x year interaction was not present (Table 19). However, variation between spacings was significant and the slope means were separated (Table 20). The rates of genetic gain were influenced by the readings from cultivars released before micronaire was used as a selection tool and illustrated in Fig. 9, but any rate of genetic gain is better estimated using only the cultivars released after 1960 as seen in Fig. 10. With these cultivars, slopes calculated from the 3m x 3m and 1m x 0.1m plant spacings were -0.001 and 0.010 units $year^{-1}$ respectively. These findings show that the more recently developed cultivars, Stoneville 506 (1982) and Deltapine 491 (2002), develop higher micronaire under elevated levels of interplant competition than when grown in lower plant populations. These results imply that for this trait, genetic gains have been made for tolerance to interplant competition. This contradicts the view some plant breeders have that plant competition results in the shading of developing leaves and bolls, which in turn lowers micronaire. Furthermore, micronaire is an estimation of fiber weight per unit length. By selecting for genotypes with higher micronaire values, breeders are advancing material that contributes to the higher yields seen in the recent past (Meredith, 2003). These gains over time may be irrelevant as micronaire is influenced by the environment and is purposefully selected only to be maintained between 3.5 and 4.9.

Fiber Uniformity Index

The plant spacings were analyzed separately for each individual year since the analysis of variance indicated a significant genotype x year interaction for all plant densities in this study (Table 25). Differences among genotypes were significant for all plant spacing treatments. Across all planting densities, Stoneville 506 (1982) exhibited high fiber length uniformity, and Half-and-Half (1910) always demonstrated the least uniformity of fiber lengths (Table 26). With the exception of Half-and-Half (1910), all cultivars produced fiber length uniformities acceptable within current market parameters

As with the other traits where there has been little to no effort to maximize or minimize parameters, but only maintain them within market driven ranges, estimates of gains may be meaningless. Never-the-less, rates of genetic gain for fiber uniformity index were evaluated across all plant spacings and a spacing x year interaction was noted (Table 19). Variation among spacings was not significant in the combined analysis, but differences were significant when years were analyzed individually (Table 20). The rates of genetic gain were exaggerated by non-uniform fiber length readings in Half-and-Half (1910) as shown in Fig. 11. The rates of genetic change are better estimated without Half-and-Half in the dataset (Fig. 12). The slopes calculated from the 3m x 3m and 1m x 0.1m plant spacings were 0.004 and 0.006 % year^{-1} respectively. Both estimates are essentially zero, which implies that there has neither been genetic gain for tolerance to interplant competition nor simple genetic improvement for this trait during the last century. Similarly, trends of genetic change in this trait over time were not found previously by Bayles et al. (2005) nor Hoskinson and Stewart (1977).

Fiber Elongation

Differences among genotypes were significant for all plant spacing treatments within each year (Table 27). Across all planting densities and years, Half-and-Half (1910) and Lone Star (1905) consistently produced fibers with the greatest extension before breaking (Table 28). Cultivars released after 1960, particularly Deltapine 491 (2002), produced fibers with lower elongation measurements.

Variation across fiber elongation slopes and spacing treatments was not significant although year affected ($P = 0.05$) elongation values (Table 19). The rates of genetic change were not different and ranged from -0.02 to -0.03 % yr^{-1} (Table 20). Fiber elongation appears to be genetically controlled and not influenced by interplant competition as illustrated in Fig. 13. There has been a steady decrease in fiber elongation over the last 100 years which may be in some way associated with increasing fiber strengths and lengths. Bridge et al. (1971) reported random distributions of fiber elongation as related to year of cultivar release, but suspected that this trait is directly dependent on the breeding program and thus genetic background or breeder bias.

Plant Height

Significant genotype x year interactions in the combined analyses were detected for plant height in the 2m x 2m and 1m x 1m plant spacings (Table 29), thus these 2 plant spacings were analyzed again separately for each individual year. The means for plant height in the 3m x 3m and 1m x 0.3m plant spacings were averaged over years. Data for plant height in the 1m x 0.1m plant spacing were only recorded in 2004. Genotypes also varied (P = 0.05) in plant height at this density in 2004 (Table 30). Although there is not an apparent trend towards shorter plants over the century as expected, Lone Star (1905) was the tallest cultivar followed by Rowden 41B (1930) (Tables 31 and 32). Cultivars released after Rowden 41B (1930) tended to be shorter in the 3m x 3m, 2m x 2m, and 1m x 1m spacing treatments (Tables 31) until the release of Deltapine 491 (2002). The other obvious trend in these data is that plant height appears to decrease at plant densities < 1m x 1m.

When comparing the rates of genetic gain for plant height across all plant spacings, a spacing x year interaction was not present (Table 33). Variation between spacings was significant at the P = 0.10 level, and these slope means were separated (Table 34). The rates of genetic change ranged from -0.25 to -0.09 cm yr^{-1} in the 3m x 3m and 1m x 0.1m plant spacings respectively. These results indicate that when competition for light, water, and nutrients is low, older cultivars tend to devote more energy into vegetative growth than newer cultivars.

Hoskinson and Stewart (1977) reported that obsolete cultivars developed taller plant structures at maturity than more modern cultivars.

Node of First Fruiting Limb

Combined analyses for the node of first fruiting limb over the 2 years detected significant genotype x year interactions in the 3m x 3m and 1m x 0.3m plant spacings (Table 35). These 2 plant spacings were analyzed again separately for each individual year. The means across years for node of first fruiting limb were separated in the 2m x 2m and 1m x 1m plant spacings. Data for node of first fruiting limb in the 1m x 0.1m plant spacing were only recorded in 2004. Genotypes were different (P = 0.05) from each other in this planting density (Table 30). The majority of first fruiting limbs were initiated between the 5^{th} and 8^{th} node in all plant spacings (Tables 36 and 32). While genotypes within each spacing varied (P = 0.05), the average NFFL was the same (P = 0.05) for Lone Star (1905) and Deltapine 491 (2002) suggesting no clear direction in movement of this trait.

Variation for the node of first fruiting limb slopes between spacing treatments was not significant (Table 33). Thus the rates of genetic change were not different, but the rate of changes ranged from -0.001 through 0.004 nodes yr^{-1} (Table 34). The node of first fruiting limb appears be genetically controlled and not influenced by interplant competition. Although breeders have selected for lower NFFL (Smith, 2005), these data verify that across these cultivars there has been no change for the past 100 years. One interesting point is that interplant competition did not result in an average NFFL difference from that found in the 3m x 3m spacing. This evidence supports the observation that there has not been a deliberate sustained breeding effort to alter this morphological trait.

Main Stem Fruiting Nodes

For the number of main stem fruiting nodes, genotype x year interactions in the combined analyses were not significant in the 3m x 3m, 2m x 2m, 1m x 1m, and 1m x 0.3m plant spacings (Table 37). Data were combined over years in these plant spacings. Differences among genotypes were significant in these 4 spacing treatments. Data for the number of main stem fruiting nodes in the 1m x 0.1m plant spacing were only recorded in 2004. Genotypes also varied (P = 0.05) in this planting density (Table 30). Older cultivars tended to have more MSFN, thus later maturity, than more recently developed cultivars, although there were no clear trends across all plant densities (Tables 38 and 32).

Variation for the number of main stem fruiting nodes slopes between spacing treatments was not significant (Table 33), and thus was non-existent across the century (Table 34).

SUMMARY AND CONCLUSIONS

Genetic gain studies have been utilized to determine the magnitude and timeframe of progress made by breeders for different traits. This study was implemented to evaluate how the improvements have been achieved. Every result and conclusion was ultimately influenced by the appropriate selection of cultivars to represent time eras. While inferences are limited to this study, most conclusions support those described by similar studies and reported in the literature.

The progression of each trait over the last century can be classified in 1 of 4 categories: genetic gains made for tolerance to interplant competition, under genetic control and not affected by interplant competition, no gain, and not well quantified by this study. Cotton breeders can in turn use the knowledge of how each trait has responded to varying levels of interplant competition to design appropriate individual plant nurseries for evaluation and selection. When the response of a plant character is directly influenced by plant population, the highest rates of gain may be obtained through individual plant selections made at higher plant densities than commonly used. For traits under genetic control it would be appropriate to make selections in nurseries with plants more widely spaced to facilitate other visual observations.

Lint yield, fiber length, fiber strength, fiber micronaire, and plant height all show evidence of genetic gain made in the context of tolerance to interplant competition. Concerning these traits, the excellent performance of Deltapine

491 (2002) at higher plant populations is largely responsible for the observed gains in all but plant height. Boll size, seed index, fiber elongation, and the number of main stem fruiting nodes appear to be less influenced by plant population. Fiber uniformity index and the node of first fruiting limb have not been altered by means of selection over time and were not affected by different plant density treatments. Generalizations regarding lint percent and seeds boll^{-1} should not be made as they both reacted inconsistently within the study. Of the 13 traits in upland cotton reported on herein, only lint yield, lint percent, boll size, fiber length, fiber strength, fiber micronaire, and plant height are commonly used as selection criteria. Interestingly, of these only lint percent and boll size were not characterized as having been bred for tolerance to interplant competition.

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APPENDIX A

TABLES

Table 1. Reported genetic gain determined through comparison of commercially grown obsolete and modern upland cotton cultivars in the same tests.

Time span of cultivar release†	Rate of Gain (kg ha^{-1} yr^{-1})	Number of cultivars	Reference
1945-1978	10.5	9	Culp and Green (1992)
1922-1962	10.2	13	Bridge et al. (1971); Bridge and Meredith (1983)
1910-1979	9.5	17	Bridge and Meredith (1983)
1937-1965	9.0	8	Meredith et al. (1997)
1939-1979	9.0	9	Bassett and Hyer (1985)
1937-1974	7.2	6	Hoskinson and Stewart (1977); Culp and Green (1992)
1905-1978	6.8	12	Wells and Meredith (1984c); Meredith et al. (1997)
1937-1993	6.1	16	Meredith et al. (1997)
1918-1982	5.6	12	Bayles et al. (2005)
1938-1993	5.3	38	Meredith (2002)
1983-1999	3.9	23	Meredith (2002)
1918-1982	3.7	12	Bayles et al. (2005)
1984-1993	1.5	8	Meredith et al. (1997)

† Approximate range of years cultivars in the tests were released.

Table 2. Upland cotton cultivars used to estimate genetic gain throughout the 20th century.†

Cultivar	Year of release‡	Breeder	Origin	Description
Lone Star	1905	D.A. Saunders	Jackson	big boll size medium staple adapted to Texas production
Half-and-Half	1910	H.H. Summerour	Cook	medium boll size short staple high lint percent adapted to poor land
Deltatype Webber	1922	D.R. Coker	Webber 82	big boll size medium staple short upright branches
Rowden 41B	1930	J.O. Ware	Rowden 40	big boll size stormproof adapted to Texas production
Deltapine 14	1941	E.C. Ewing	Deltapine 10	medium boll size medium staple widely adaptable
Stoneville 213	1962	C.W. Manning	Stoneville 7	early maturity resistant to Verticillium wilt widely adaptable
Deltapine 55	1974	E.C. Ewing	Deltapine 16 Stoneville 7A	stormproof tolerant of Verticillium wilt tolerant of Fusarium wilt
Stoneville 506	1982	C.W. Manning	Stoneville 7 Stoneville X1834	early maturity short plant stature resistant to Verticillium wilt resistant to Fusarium wilt widely adaptable
Deltapine 491	2002	D.L. Keim	Deltapine 5415 Deltapine 2156	larger boll size long staple widely adaptable

† Information compiled from many sources (Bridge and Meredith, 1983; Brown, 1936; Brown and Ware, 1958; Calhoun et al., 1997; Jones, 2005; Keim et al., 2002; Ware, 1951; Wells and Meredith, 1984c).
‡ Approximate year cultivar was released.

Table 3. Mean squares for lint yield of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	7969	131112*	1775	27582	13
Error A	6	4609	10950	51707	158397	189303
Geno	8	29740**	155747**	661931**	777724**	797050**
Geno x Year	8	1052	8419*	27862**	40740	93892**
Error B	48	1034	3132	9106	28613	10815

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 4. Mean lint yield of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Lint yield							
	Year of	3m x 3m	2m x 2m		1m x 1m		1m x 0.3m	1m x 0.1m	
Cultivar	release	Both years	2003	2004	2003	2004	Both years	2003	2004
		kg ha^{-1}							
Deltapine 491	2002	334a†	807a	599a	1446a	1329a	1694a	1649a	1322a
Stoneville 506	1982	217b	484bc	375bc	890b	788c	1155b	1132c	1080bc
Deltapine 55	1974	239b	519b	425b	981b	1039b	1270b	1314b	962c
Stoneville 213	1962	222b	475bc	396bc	884b	968b	1245b	1080cd	1177ab
Deltapine 14	1941	231b	450c	363bc	982b	833c	1146b	990d	1073bc
Rowden 41B	1930	163c	279e	314cd	565cd	546d	856c	598e	792d
Deltatype Webber	1922	128d	269e	205e	454d	400e	675d	631e	666d
Half & Half	1910	161c	307e	264de	539cd	768c	842c	357f	648d
Lone Star	1905	170c	381d	263de	649c	631d	842c	691e	729d
Test Mean		207	441	356	821	811	1081	938	939
% CV		15.5	9.9	18.6	11.3	12.1	15.7	9.7	12.3

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 5. Mean squares for rates of genetic gain for lint yield of upland cotton grown in five plant spacings at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares
Year	1	0.9892**
Error A	6	0.0109
Spacing	4	4.3226**
Spacing x Year	4	0.0610
Error B	24	0.0565

** Significant at the 0.01 level of probability.

Table 6. Means for the rates of genetic gain for lint yield of upland cotton grown in five plant spacings at College Station, TX in 2003 and 2004.

	Lint yield
Spacing treatment	Both years
	kg ha^{-1} yr^{-1}
1m x 0.1m	8.7a†
1m x 0.3m	8.2a
1m x 1m	7.1a
2m x 2m	3.6b
3m x 3m	1.5c
Test Mean	5.8
% CV	15.2

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 7. Mean squares for lint percent of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	136.66**	4.32	10.92*	5.26	2.39
Error A	6	1.77	2.78	0.99	2.41	1.26
Geno	8	160.85**	188.23**	257.66**	233.03**	168.00**
Geno x Year	8	3.07	0.88	2.97*	2.50	1.64**
Error B	48	1.57	0.69	1.37	1.81	0.42

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 8. Means for lint percent of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Lint percent					
	Year of	3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m	
Cultivar	release	Both years	Both years	Both years	Both years	2003	2004
		%					
Deltapine 491	2002	41.8a†	42.6a	45.8a	44.7a	43.5a	41.3a
Stoneville 506	1982	34.9c	36.4d	36.2c	36.6d	35.8d	36.3e
Deltapine 55	1974	36.8b	38.8b	39.5b	38.4bc	38.3b	38.0c
Stoneville 213	1962	35.2c	36.6d	37.2c	36.7d	37.1c	37.0de
Deltapine 14	1941	37.5b	37.8c	40.0b	38.9b	39.0b	37.6cd
Rowden 41B	1930	29.8e	30.6f	30.8e	30.7f	30.9f	31.0g
Deltatype Webber	1922	26.4f	26.3g	26.0f	26.0g	27.5g	27.3h
Half & Half	1910	35.6c	37.8c	37.2c	37.5cd	38.4b	39.0b
Lone Star	1905	32.4d	33.1e	33.8d	32.6e	33.1e	32.9f
Test Mean		34.5	35.6	36.3	35.8	36.0	35.6
% CV		3.6	2.3	3.2	3.8	1.8	1.8

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 9. Mean squares for rates of genetic gain for lint percent, boll size, seeds boll^{-1}, and seed index of upland cotton grown in five plant spacings at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares			
		Lint percent	Boll size	Seeds boll^{-1}	Seed index
Year	1	0.0144	0.1280	0.441	0.2436*
Error A	6	0.1843	0.1991	0.115	0.0373
Spacing	4	1.3353**	0.1159	0.090	0.0354
Spacing x Year	4	0.5346	0.1581	0.389**	0.4896**
Error B	24	0.2323	0.0714	0.052	0.0877

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 10. Mean rates of genetic gain for lint percent, boll size, seeds boll^{-1}, and seed index of upland cotton grown in five plant spacings at College Station, TX in 2003 and 2004.

	Lint percent	Boll size	Seeds boll^{-1}		Seed index	
Spacing treatment	Both years	Both years	2003	2004	2003	2004
	% yr^{-1}	g yr^{-1}	seeds yr^{-1}		g yr^{-1}	
1m x 0.1m	0.08b†	-0.01a	-0.04b	-0.04ab	-0.029b	-0.024a
1m x 0.3m	0.11a	-0.01a	-0.03ab	-0.03a	-0.009a	-0.032b
1m x 1m	0.11a	-0.01a	-0.03ab	-0.02a	-0.023ab	-0.028ab
2m x 2m	0.09b	-0.01a	-0.01a	-0.05b	-0.028b	-0.027ab
3m x 3m	0.08b	-0.01a	-0.02a	-0.05b	-0.027b	-0.029ab
Test Mean	0.09	-0.01	-0.02	-0.04	-0.023	-0.028
% CV	16.1	26.9	66.5	53.2	54.4	39.5

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 11. Mean squares for boll size of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	0.3575	3.0665**	1.2098	0.0117	0.0123
Error A	6	0.0637	0.0822	0.2265	0.4199	0.8539
Geno	8	2.8647**	2.5702**	2.6424**	2.8964**	3.7298**
Geno x Year	8	0.2566**	0.1256	0.2377**	0.1580	0.1462
Error B	48	0.0815	0.0740	0.0727	0.0806	0.0781

** Significant at the 0.01 level of probability.

Table 12. Means for boll size of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Cultivar	Year of release	Boll size: 3m x 3m 2003	3m x 3m 2004	2m x 2m Both years	1m x 1m 2003	1m x 1m 2004	1m x 0.3m Both years	1m x 0.1m Both years
		g seedcotton						
Deltapine 491	2002	5.9cd†	5.6c	5.8de	6.0cd	5.6def	5.2ef	5.1cde
Stoneville 506	1982	5.5e	6.0b	5.5f	5.2e	5.5ef	5.0g	5.0de
Deltapine 55	1974	6.1c	5.7bc	5.8d	5.8d	5.6de	5.3de	5.0e
Stoneville 213	1962	6.3c	6.0b	5.9d	5.8d	5.9cd	5.3def	5.2cd
Deltapine 14	1941	5.7de	5.6c	5.6ef	5.8d	5.3f	5.1fg	4.6f
Rowden 41B	1930	7.6a	7.2a	7.2a	7.6a	6.9a	6.8a	6.5a
Deltatype Webber	1922	6.0cd	5.7bc	5.8d	6.1bcd	5.5ef	5.5cd	5.6b
Half & Half	1910	6.2c	6.0b	6.2c	6.4bc	6.0c	5.7c	5.4bc
Lone Star	1905	6.7b	7.1a	6.7b	6.5b	6.5b	6.2b	6.6a
Test Mean		6.2	6.1	6.1	6.1	5.9	5.6	5.4
% CV		4.5	4.7	4.5	5.0	3.8	8.3	5.1

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 13. Mean squares for seeds boll^{-1} of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	34.3**	51.9**	92.8**	42.9*	37.7
Error A	6	1.2	1.6	2.8	5.3	6.3
Geno	8	33.7**	23.0**	26.7**	24.8**	30.3**
Geno x Year	8	11.9**	7.7**	6.5**	0.9	2.3
Error B	48	2.5	1.2	2.2	1.6	1.8

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 14. Means for seeds boll^{-1} of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Seeds boll^{-1}							
	Year of	3m x 3m		2m x 2m		1m x 1m		1m x 0.3m	1m x 0.1m
Cultivar	release	2003	2004	2003	2004	2003	2004	Both years	Both years
		seeds							
Deltapine 491	2002	33.7bc†	30.1e	35.0a	28.7g	34.9bc	30.8d	31.3de	30.6cd
Stoneville 506	1982	30.5d	30.8de	30.5d	29.2fg	29.5d	29.0e	28.6f	28.7e
Deltapine 55	1974	35.4ab	32.3cd	34.6ab	31.3de	32.9bc	31.9cd	32.3cd	30.3cd
Stoneville 213	1962	34.8abc	32.4cd	33.0bc	32.0d	33.1bc	32.0bcd	31.5de	30.9c
Deltapine 14	1941	32.7cd	30.7de	32.6c	32.2cd	34.3bc	31.4cd	31.9cd	30.5cd
Rowden 41B	1930	35.9ab	34.5b	34.9a	33.2bc	35.4ab	33.3ab	33.5ab	32.2b
Deltatype Webber	1922	31.1d	30.1e	30.8d	30.3ef	32.3c	28.8e	30.3e	29.5de
Half & Half	1910	36.8a	33.5bc	34.4ab	34.0ab	37.8a	32.5bc	34.6a	33.8a
Lone Star	1905	33.9bc	38.2a	35.3a	34.8a	33.9bc	34.0a	32.8bc	34.6a
Test Mean		33.9	32.5	33.5	31.8	33.8	31.5	31.9	31.2
% CV		5.1	4.4	3.7	2.9	5.4	3.2	3.9	4.3

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 15. Mean squares for seed index of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	8.6423**	2.8490	2.6816*	1.0208	6.2717
Error A	6	0.1257	0.5284	0.4369	1.1257	1.6001
Geno	8	22.3892**	24.1307**	17.7622**	15.6492**	25.5438**
Geno x Year	8	0.1392	0.2065	1.3327**	1.7584**	0.2345
Error B	48	0.1391	0.1647	0.4412	0.3164	0.1259

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 16. Means for seed index of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Seed index						
	Year of	3m x 3m	2m x 2m	1m x 1m		1m x 0.3m		1m x 0.1m
Cultivar	release	Both years	Both years	2003	2004	2003	2004	Both years
		g						
Deltapine 491	2002	8.7g†	8.6f	9.3d	8.9ef	10.6bcd	8.9f	9.2fg
Stoneville 506	1982	10.8d	10.4c	11.2b	10.7c	10.9bc	10.4c	10.7c
Deltapine 55	1974	9.1f	9.4e	9.8cd	9.2e	10.2cd	9.3ef	9.6e
Stoneville 213	1962	10.2e	10.2cd	10.8bc	10.3cd	10.5bcd	10.0d	10.2d
Deltapine 14	1941	9.1f	8.8f	10.6bc	8.7f	10.2cd	9.3ef	9.0g
Rowden 41B	1930	13.4a	13.3a	12.9a	13.4a	12.6a	13.2a	13.4a
Deltatype Webber	1922	13.0b	13.2a	12.8a	13.7a	12.6a	13.5a	13.3a
Half & Half	1910	10.2e	9.9d	10.9bc	10.1d	9.7d	9.6de	9.4ef
Lone Star	1905	11.3c	11.2b	11.5b	11.3b	11.4b	12.4b	12.4b
Test Mean		10.7	10.5	11.1	10.7	11.0	10.7	10.8
% CV		3.5	3.9	7.8	3.3	6.6	3.1	3.3

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 17. Mean squares for fiber length of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	5.8790**	10.3129**	1.0904	0.5551	0.3584
Error A	6	0.1971	0.1894	0.5645	1.5362	2.6900
Geno	8	48.3781**	46.0723**	48.8934**	43.0927**	50.3749**
Geno x Year	8	0.4734**	0.2766**	0.3202*	0.6887**	0.2133
Error B	48	0.1418	0.0485	0.1261	0.1340	0.2108

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 18. Means for fiber length of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Fiber length								
	Year of	3m x 3m		2m x 2m		1m x 1m		1m x 0.3m		1m x 0.1m
Cultivar	release	2003	2004	2003	2004	2003	2004	2003	2004	Both Years
		mm								
Deltapine 491	2002	29.8a†	28.7a	29.5a	29.0a	29.0a	28.9a	29.4a	28.9a	29.8a
Stoneville 506	1982	28.8bc	28.8a	29.0b	28.3b	28.6ab	28.4b	28.1c	28.3b	28.5b
Deltapine 55	1974	28.4cd	27.9b	28.4c	27.9c	28.2bc	27.9c	28.1c	27.7cd	28.1c
Stoneville 213	1962	28.2de	26.8d	28.0d	27.0e	28.0c	27.4de	27.6d	26.5e	27.8cd
Deltapine 14	1941	27.9e	27.4c	27.9d	27.1e	27.7cd	27.4e	27.4d	27.6d	27.6d
Rowden 41B	1930	26.1g	25.7e	26.3e	25.9g	25.6e	25.6g	25.5e	25.9f	25.7f
Deltatype Webber	1922	27.1f	26.8d	27.8d	26.7f	27.3d	26.9f	27.3d	26.8e	26.9e
Half & Half	1910	21.1h	21.1f	21.4f	21.0h	20.6f	21.2h	21.0f	21.7g	21.1g
Lone Star	1905	28.9b	27.9bc	29.2b	27.7d	28.6ab	27.8cd	28.9b	28.1bc	28.1c
Test Mean		27.4	26.8	27.5	26.7	27.1	26.8	27.0	26.8	27.1
% CV		1.3	1.5	1.0	0.6	1.5	1.1	1.2	1.5	1.7

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 19. Mean squares for rates of genetic gain for fiber length, fiber strength, fiber micronaire, fiber uniformity index, and fiber elongation of upland cotton grown in five plant spacings at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		Length	Strength	Micronaire	Uniformity index	Elongation
Year	1	0.01	40.4734**	0.0101	8.6100**	28.6303**
Error A	6	36.73	0.3405	0.0353	0.1712	0.3234
Spacing	4	117.70**	3.3589**	0.1629**	0.0544	0.2586
Spacing x Year	4	29.30	0.6009	0.0503	4.1183**	0.2218
Error B	24	11.96	0.6900	0.0352	0.2369	0.2197

** Significant at the 0.01 level of probability.

Table 20. Mean rates of genetic gain for fiber length, fiber strength, fiber micronaire, fiber uniformity index, and fiber elongation of upland cotton grown in five plant spacings at College Station, TX in 2003 and 2004.

	Length	Strength	Micronaire	Uniformity index		Elongation
Spacing treatment	Both years	Both years	Both years	2003	2004	Both years
	mm yr^{-1}	kN m kg^{-1} yr^{-1}	units yr^{-1}	% yr^{-1}		% yr^{-1}
1m x 0.1m	0.048a†	0.39a	0.008bc	0.01b	0.03a	-0.02a
1m x 0.3m	0.038c	0.23b	0.010ab	0.02a	0.01b	-0.03a
1m x 1m	0.043b	0.26b	0.011a	0.03a	0.01b	-0.03a
2m x 2m	0.041b	0.24b	0.010ab	0.02a	0.01b	-0.03a
3m x 3m	0.043b	0.30ab	0.007c	0.03a	0.01b	-0.03a
Test Mean	0.043	0.28	0.009	0.02	0.01	-0.03
% CV	8.1	29.4	20.7	22.6	33.7	17.2

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 21. Mean squares for fiber strength of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	4042**	3234**	1626**	1536**	2247**
Error A	6	121	25	48	43	158
Geno	8	2733**	2556**	2617**	2973**	3621**
Geno x Year	8	131**	166**	346**	303**	242*
Error B	48	40	26	43	32	90

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 22. Means for fiber strength of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Fiber strength									
	Year of	3m x 3m		2m x 2m		1m x 1m		1m x 0.3m		1m x 0.1m	
Cultivar	release	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
		kN m kg^{-1}									
Deltapine 491	2002	316.5a†	296.0a	307.4a	289.7b	307.1a	290.4b	312.9a	295.6b	316.9a	315.9a
Stoneville 506	1982	307.5b	295.5a	308.8a	284.7bc	303.6a	286.3bc	297.0c	286.1c	291.6b	293.6bc
Deltapine 55	1974	289.8c	274.8bc	293.1b	274.4e	289.7bc	275.4de	291.5cd	272.6d	286.0b	300.4b
Stoneville 213	1962	290.4c	265.6cd	285.4c	264.6f	290.1bc	267.9ef	289.0d	261.2e	273.0c	282.5cde
Deltapine 14	1941	286.4c	262.0d	285.2c	265.8f	283.6c	264.5f	280.0e	271.8d	265.1c	278.4de
Rowden 41B	1930	292.6c	271.8bc	291.7bc	278.3de	291.0bc	277.9cd	286.6de	276.2d	266.1c	275.9e
Deltatype Webber	1922	305.3b	296.5a	303.8a	300.3a	294.5b	303.4a	304.9b	307.0a	294.8b	321.8a
Half & Half	1910	246.8d	243.5e	241.3d	243.9g	231.7d	247.6g	233.6f	248.2f	247.5d	245.0f
Lone Star	1905	286.7c	281.4b	287.8bc	282.1cd	288.7bc	281.1cd	291.7cd	285.4c	263.6c	291.6bcd
Test Mean		291.3	276.4	289.4	276.0	286.7	277.2	287.5	278.2	278.3	289.4
% CV		1.8	2.6	2.0	1.5	2.2	2.4	2.0	2.1	2.9	3.7

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 23. Mean squares for fiber micronaire of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	0.6871**	0.7771**	0.5891**	0.0059	1.2013**
Error A	6	0.0387	0.0495	0.0213	0.0782	0.0390
Geno	8	3.5383**	3.5215**	3.3800**	3.2089**	2.7100**
Geno x Year	8	0.0486	0.1003**	0.0781*	0.0403	0.1025**
Error B	48	0.0231	0.0298	0.0341	0.0393	0.0261

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 24. Mean micronaire values for nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Micronaire							
	Year of	3m x 3m	2m x 2m		1m x 1m		1m x 0.3m	1m x 0.1m	
Cultivar	release	Both years	2003	2004	2003	2004	Both years	2003	2004
		units							
Deltapine 491	2002	4.5c†	4.3c	4.9b	5.0a	4.9a	4.9a	5.1b	4.9b
Stoneville 506	1982	4.8b	4.7ab	5.0ab	4.8ab	4.6bc	4.7b	5.0bc	4.9b
Deltapine 55	1974	4.5c	4.5bc	4.6c	4.6c	4.4c	4.4c	4.9bcd	4.3c
Stoneville 213	1962	4.6c	4.5bc	4.6c	4.7bc	4.4bc	4.5c	4.8cd	4.5c
Deltapine 14	1941	4.3d	4.1d	3.9d	4.5c	3.9d	4.0d	4.5e	3.9d
Rowden 41B	1930	5.1a	4.8a	5.2a	4.9a	4.9a	5.1a	5.4a	5.2a
Deltatype Webber	1922	3.4e	3.4e	3.3e	3.3d	3.2e	3.3e	3.7f	3.7e
Half & Half	1910	5.0a	4.7ab	4.8bc	4.9a	4.7ab	4.7b	4.8d	4.9b
Lone Star	1905	3.2f	3.0f	3.3e	3.2d	3.3e	3.4e	3.8f	3.5e
Test Mean		4.4	4.2	4.4	4.4	4.3	4.3	4.7	4.4
% CV		3.5	4.3	3.8	3.3	5.1	4.6	3.5	3.6

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 25. Mean squares for fiber uniformity index of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	0.6890	4.9556*	7.4923**	1.0380	9.3889*
Error A	6	0.4250	0.4302	0.2462	1.0141	1.3688
Geno	8	14.3495**	15.2383**	13.4345**	15.9422**	12.3634**
Geno x Year	8	0.7695**	1.2599**	1.9070**	2.1317**	1.8811**
Error B	48	0.1794	0.1458	0.2116	0.1693	0.4287

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 26. Means for fiber uniformity index of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Fiber uniformity index									
	Year of	3m x 3m		2m x 2m		1m x 1m		1m x 0.3m		1m x 0.1m	
Cultivar	release	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
		%									
Deltapine 491	2002	83.1b†	81.9d	82.5e	81.8d	83.0bc	81.9bc	82.9ab	82.2bc	82.8bc	84.3a
Stoneville 506	1982	83.7a	83.5a	84.3a	83.1a	83.9a	82.5a	83.3a	83.0a	84.2a	83.3b
Deltapine 55	1974	83.0bc	82.6bc	83.5b	82.8ab	83.2ab	82.2abc	83.0ab	82.2bc	83.6ab	82.9bcd
Stoneville 213	1962	83.4ab	82.5bc	83.1cd	82.2bcd	83.4ab	81.8cd	83.1a	81.6cd	83.3b	82.0d
Deltapine 14	1941	82.5cd	82.0cd	82.7de	81.2e	83.0bc	81.4d	82.5bc	81.6d	82.5c	82.0d
Rowden 41B	1930	82.2d	82.6bc	82.6e	82.4bc	82.3c	82.3abc	81.9d	82.4b	83.5ab	82.3cd
Deltatype Webber	1922	82.1d	82.3cd	82.7de	82.1cd	82.4c	82.3ab	82.3cd	82.1bcd	83.6ab	82.6bcd
Half & Half	1910	78.5e	79.3e	78.2f	79.5f	78.1d	79.5e	77.4e	79.5e	80.6d	78.6e
Lone Star	1905	83.0bc	83.0ab	83.2bc	82.8ab	83.0bc	82.6a	83.3a	83.0a	83.4ab	83.1bc
Test Mean		82.4	82.2	82.5	82.0	82.5	81.8	82.2	81.9	83.1	82.3
% CV		0.5	0.5	0.4	0.5	0.6	0.5	0.5	0.5	0.7	0.8

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 27. Mean squares for fiber elongation of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares				
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	1m x 0.1m
Year	1	17.7895**	28.8003**	33.0993**	42.7817**	0.6181
Error A	6	0.1123	0.1055	0.0886	0.0524	0.404
Geno	8	6.0821**	7.6505**	7.0947**	6.3654**	7.9866**
Geno x Year	8	0.4284**	0.3739**	0.5582**	0.3777**	1.5832**
Error B	48	0.0796	0.0848	0.0971	0.0613	0.2905

** Significant at the 0.01 level of probability.

Table 28. Means for fiber elongation of nine obsolete and modern upland cotton cultivars grown in five plant density treatments at College Station, TX in 2003 and 2004.

		Fiber elongation									
	Year of	3m x 3m		2m x 2m		1m x 1m		1m x 0.3m		1m x 0.1m	
Cultivar	release	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
		%									
Deltapine 491	2002	5.1e†	4.8d	5.0g	4.2e	4.8d	4.5de	4.7f	4.2d	3.7e	4.6c
Stoneville 506	1982	5.3d	5.2bc	5.2f	4.7bcd	5.4c	4.5de	5.6e	4.6c	4.5d	5.4b
Deltapine 55	1974	5.6cd	5.0cd	5.6e	5.1b	5.7c	4.8c	6.1d	4.7c	4.6d	5.2bc
Stoneville 213	1962	5.7c	4.8d	5.9e	4.6d	5.7c	4.3e	6.2d	4.3d	4.8d	4.9bc
Deltapine 14	1941	6.4b	5.4b	6.5d	5.0b	6.5b	4.9c	7.0c	5.2b	5.6c	5.5b
Rowden 41B	1930	6.8b	5.2bc	6.8c	4.9bc	6.8b	4.9c	7.2c	5.0b	5.8c	5.1bc
Deltatype Webber	1922	6.7b	4.9cd	6.2d	4.6cd	6.6b	4.6cd	6.2d	4.6c	5.6c	5.0bc
Half & Half	1910	9.4a	7.1a	9.3a	7.3a	8.7a	7.5a	9.3a	6.2a	7.9a	6.9a
Lone Star	1905	8.8a	6.8a	8.5b	6.4a	8.0a	6.3b	8.0b	6.3a	6.5b	6.8a
Test Mean		6.6	5.4	6.6	5.2	6.5	5.1	6.7	5.0	5.4	5.5
% CV		4.6	5.4	3.2	6.0	4.9	5.6	4.9	3.9	7.5	10.2

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 29. Mean squares for plant height of nine obsolete and modern upland cotton cultivars grown in four plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares			
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m
Year	1	553	4581**	2238	10768**
Error A	6	144	124	376	174
Geno	8	1916**	1730**	759**	871**
Geno x Year	8	98	91**	106*	36
Error B	48	51	29	39	52

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 30. Mean squares for plant height, node of first fruiting limb (NFFL), and number of main stem fruiting nodes (MSFN) of nine obsolete and modern upland cotton cultivars grown in a 1m x 0.1m plant density treatment at College Station, TX in 2004.

Source	DF	Mean Squares		
		Plant height	NFFL	MSFN
Geno	8	181.8**	2.2186**	5.8061**
Rep	3	927.5**	0.1730	9.6489**
Error	24	27.2	0.3471	1.5039

** Significant at the 0.01 level of probability.

Table 31. Means for plant height of nine obsolete and modern upland cotton cultivars grown in four plant density treatments at College Station, TX in 2003 and 2004.

		Plant height					
	Year of	3m x 3m	2m x 2m		1m x 1m		1m x 0.3m
Cultivar	release	Both years	2003	2004	2003	2004	Both years
		cm					
Deltapine 491	2002	103cd†	116cd	100bc	111bcd	101bc	94b
Stoneville 506	1982	93e	101fg	88d	106de	84d	92b
Deltapine 55	1974	101cd	110de	93cd	99e	97c	93b
Stoneville 213	1962	98de	106ef	88d	108cde	94c	91b
Deltapine 14	1941	100de	103fg	94bcd	101e	97c	91b
Rowden 41B	1930	130b	137b	121a	117bc	108b	113a
Deltatype Webber	1922	108c	118c	100b	118b	97c	97b
Half & Half	1910	98de	99g	92d	103de	98c	95b
Lone Star	1905	138a	149a	119a	134a	119a	119a
Test Mean		108	115	99	111	100	98
% CV		6.6	4.2	5.9	6.1	5.6	7.3

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 32. Means for plant height, node of first fruiting limb (NFFL), and number of main stem fruiting nodes (MSFN) of nine obsolete and modern upland cotton cultivars grown in a 1m x 0.1m plant density treatment at College Station, TX in 2004.

		1m x 0.1m		
	Year of	2004		
Cultivar	release	Plant height	NFFL	MSFN
		cm	nodes	
Deltapine 491	2002	81d†	6.4ab	19.2b
Stoneville 506	1982	80d	5.9bcd	17.5b
Deltapine 55	1974	86cd	5.2de	18.5b
Stoneville 213	1962	90bc	6.6ab	19.4b
Deltapine 14	1941	89bc	5.3cde	18.4b
Rowden 41B	1930	94ab	4.9e	19.3b
Deltatype Webber	1922	80d	6.2bc	19.0b
Half & Half	1910	82cd	5.5cde	18.5b
Lone Star	1905	99a	7.2a	21.9a
Test Mean		87	5.9	19.1
% CV		6.0	10.0	6.4

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 33. Mean squares for rates of genetic gain for plant height, node of first fruiting limb (NFFL), and number of main stem fruiting nodes (MSFN) of upland cotton grown in five plant spacings at College Station, TX in 2003† and 2004.

Source	DF	Mean Squares		
		Plant height	NFFL	MSFN
Year	1	1.6049**	0.8242	0.1225
Error A	6	0.1801	0.3383	0.3955
Spacing	4	1.3459*	0.2912	0.3846
Spacing x Year	3	0.1807	0.2661	0.0534
Error B	21	0.4757	0.4351	0.2798

*,** Significant at the 0.10 and 0.05 levels of probability, respectively.

† Plant height, NFFL, and MSFN were not recorded in the 1m x 0.1m plant density treatment in 2003.

Table 34. Means for the rates of genetic gain for plant height, node of first fruiting limb (NFFL), and number of main stem fruiting nodes (MSFN) of upland cotton grown in five plant spacings at College Station, TX in 2003† and 2004.

	Plant height	NFFL	MSFN
Spacing treatment	Both years	Both years	Both years
	cm yr^{-1}	nodes yr^{-1}	nodes yr^{-1}
1m x 0.1m	-0.09a‡	-0.001a	-0.02a
1m x 0.3m	-0.18abc	0.001a	-0.02a
1m x 1m	-0.16ab	0.004a	-0.03a
2m x 2m	-0.19bc	-0.001a	-0.02a
3m x 3m	-0.25c	0.001a	-0.04a
Test Mean	-0.18	0.001	-0.03
% CV	37.8	669.4	63.1

† Plant height, NFFL, and MSFN were not recorded in the 1m x 0.1m plant density treatment in 2003.

‡ Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 35. Mean squares for node of first fruiting limb of nine obsolete and modern upland cotton cultivars grown in four plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares			
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m
Year	1	0.1750	10.6623**	12.1496**	1.2667*
Error A	6	0.2844	0.5605	0.5116	0.2066
Geno	8	1.3147**	1.3768**	1.2255**	2.1223**
Geno x Year	8	0.5608*	0.3316	0.5499	0.6512**
Error B	48	0.2619	0.2439	0.3135	0.1930

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 36. Means for node of first fruiting limb of nine obsolete and modern upland cotton cultivars grown in four plant density treatments at College Station, TX in 2003 and 2004.

		Node of first fruiting limb				
	Year of	3m x 3m	2m x 2m	1m x 1m	1m x 0.3m	
Cultivar	release	Both years	Both years	Both years	2003	2004
		nodes				
Deltapine 491	2002	6.4a†	6.8a	6.8a	6.7a	7.3a
Stoneville 506	1982	5.5cd	5.9c	6.4abc	5.9bc	5.7de
Deltapine 55	1974	5.7bcd	5.8c	6.0cd	6.4ab	5.7de
Stoneville 213	1962	6.0abc	6.6a	6.6ab	6.8a	6.1cd
Deltapine 14	1941	6.2ab	6.6a	6.3abc	7.0a	6.0de
Rowden 41B	1930	5.9bc	5.8c	6.2bc	6.0bc	5.5e
Deltatype Webber	1922	6.2ab	6.5ab	6.5abc	6.8a	6.6bc
Half & Half	1910	5.3d	6.1bc	5.5d	5.4c	6.1cde
Lone Star	1905	6.5a	6.8a	6.6ab	7.0a	6.9ab
Test Mean		6.0	6.3	6.3	6.4	6.2
% CV		8.6	7.8	8.9	6.9	7.1

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

Table 37. Mean squares for number of main stem fruiting nodes of nine obsolete and modern upland cotton cultivars grown in four plant density treatments at College Station, TX in 2003 and 2004.

Source	DF	Mean Squares			
		3m x 3m	2m x 2m	1m x 1m	1m x 0.3m
Year	1	6.213	131.104**	7.996	143.228**
Error A	6	6.707	7.634	7.741	3.709
Geno	8	22.880**	40.003**	17.818**	15.359**
Geno x Year	8	4.166	5.459	1.504	3.330
Error B	48	2.660	3.327	1.543	2.578

** Significant at the 0.01 level of probability.

Table 38. Means for number of main stem fruiting nodes of nine obsolete and modern upland cotton cultivars grown in four plant density treatments at College Station, TX in 2003 and 2004.

		Number of main stem fruiting nodes			
	Year of	3m x 3m	2m x 2m	1m x 1m	1m x 0.3m
Cultivar	release	Both years	Both years	Both years	Both years
		nodes			
Deltapine 491	2002	23.9bc†	23.1bc	24.0bcd	22.2ab
Stoneville 506	1982	23.0c	21.4cd	20.5f	19.8d
Deltapine 55	1974	24.7b	23.9b	21.9e	20.5cd
Stoneville 213	1962	24.9b	22.0cd	23.3cd	19.9d
Deltapine 14	1941	24.6b	21.3d	23.0de	20.5cd
Rowden 41B	1930	27.6a	26.8a	23.0de	23.1ab
Deltatype Webber	1922	27.3a	26.0a	24.8ab	22.7ab
Half & Half	1910	24.8b	21.2d	24.4abc	21.7bc
Lone Star	1905	27.5a	26.0a	25.3a	23.3a
Test Mean		25.4	23.5	23.3	21.5
% CV		6.4	7.8	5.3	7.5

† Means within a column followed by the same letter are not different at K=100 (approximates p=0.05) according to Waller-Duncan LSD.

APPENDIX B

FIGURES

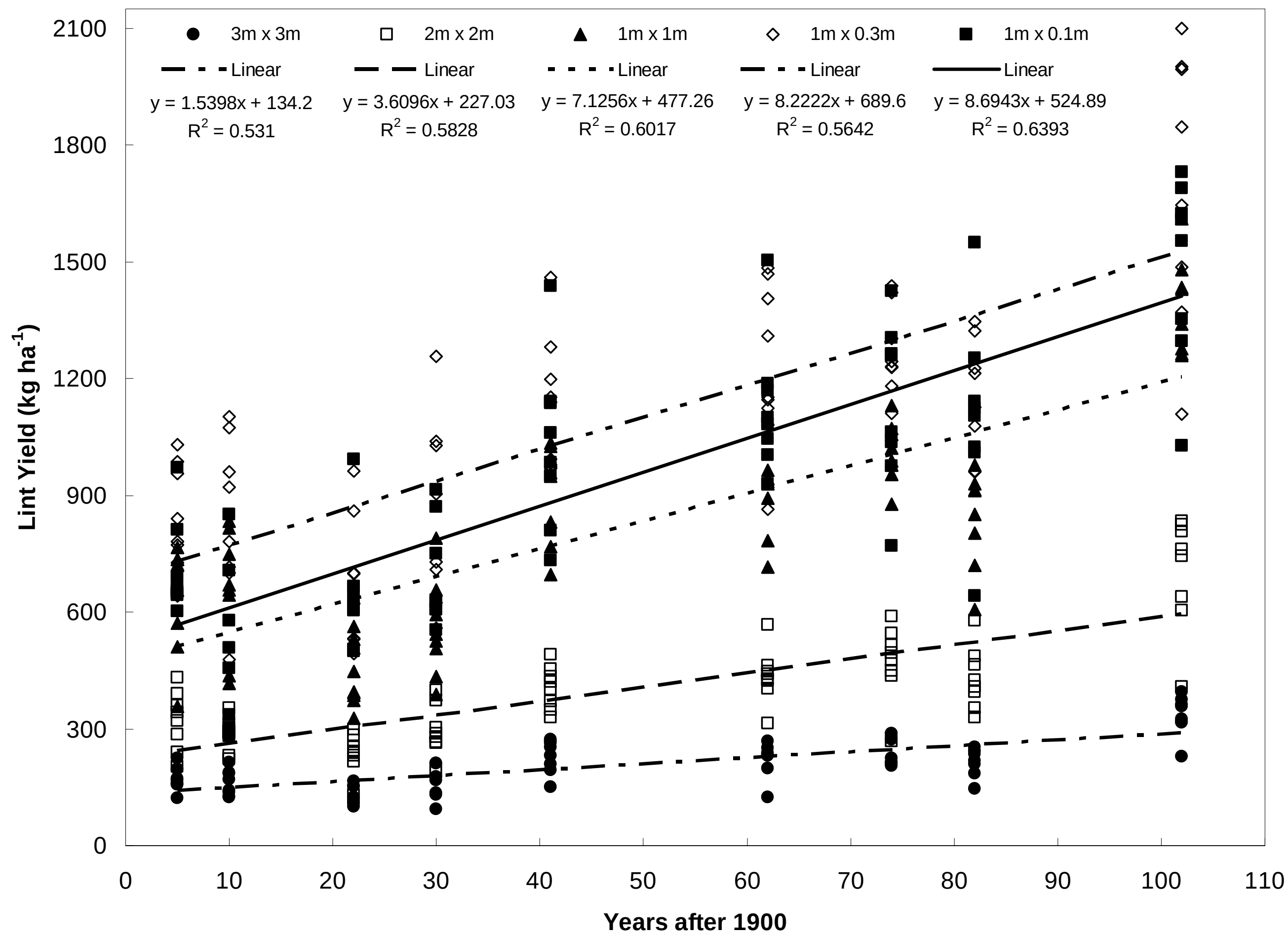

Fig. 1. Rates of genetic gain for lint yield of upland cotton as estimated using 9 twentieth century cultivars grown in five plant densities at College Station, TX in 2003 and 2004.

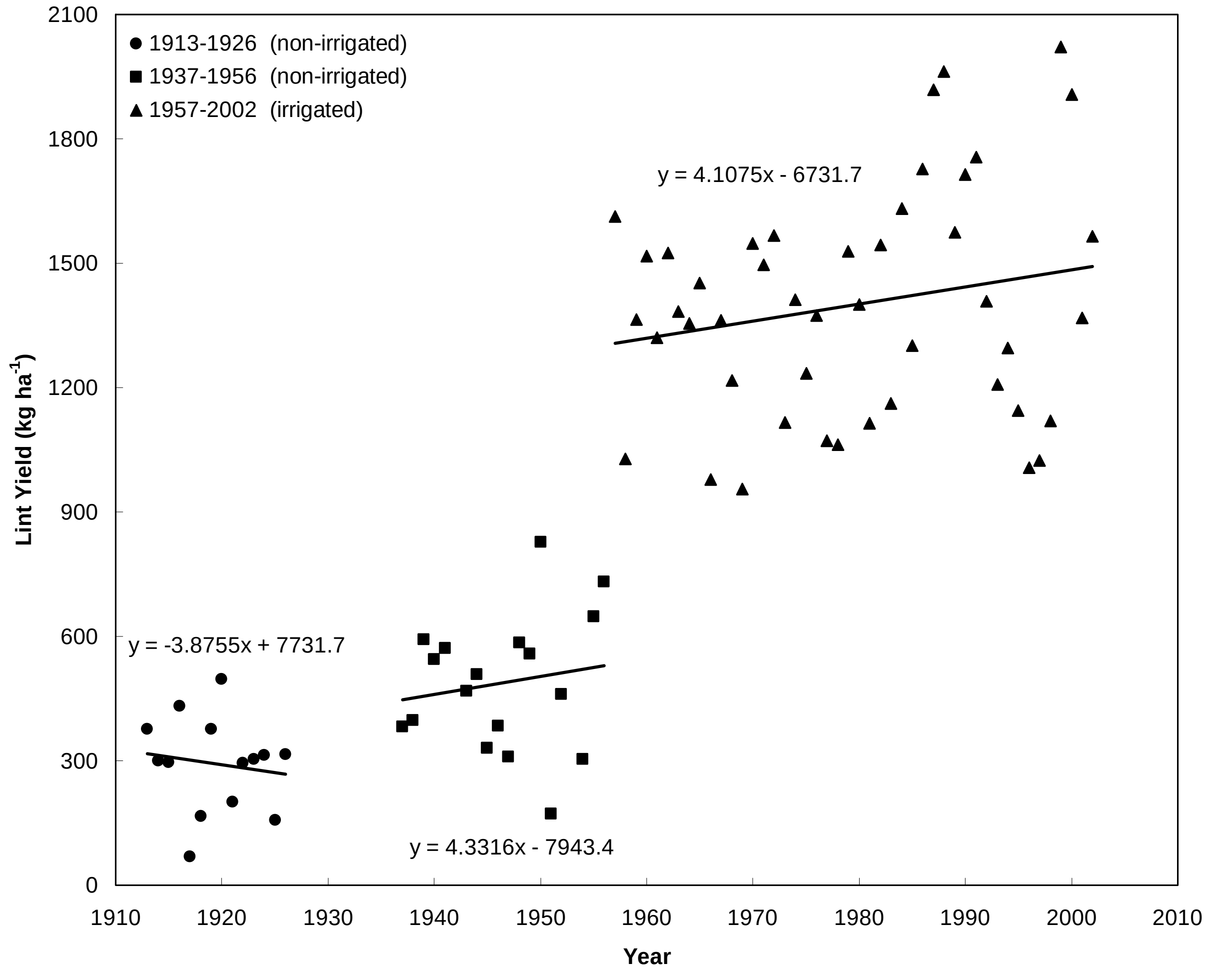

Fig. 2. Trends over time of the top 5 yielding upland cotton cultivars in commercial cultivar trials conducted at the Texas A&M Research Farm, 1913-2002.

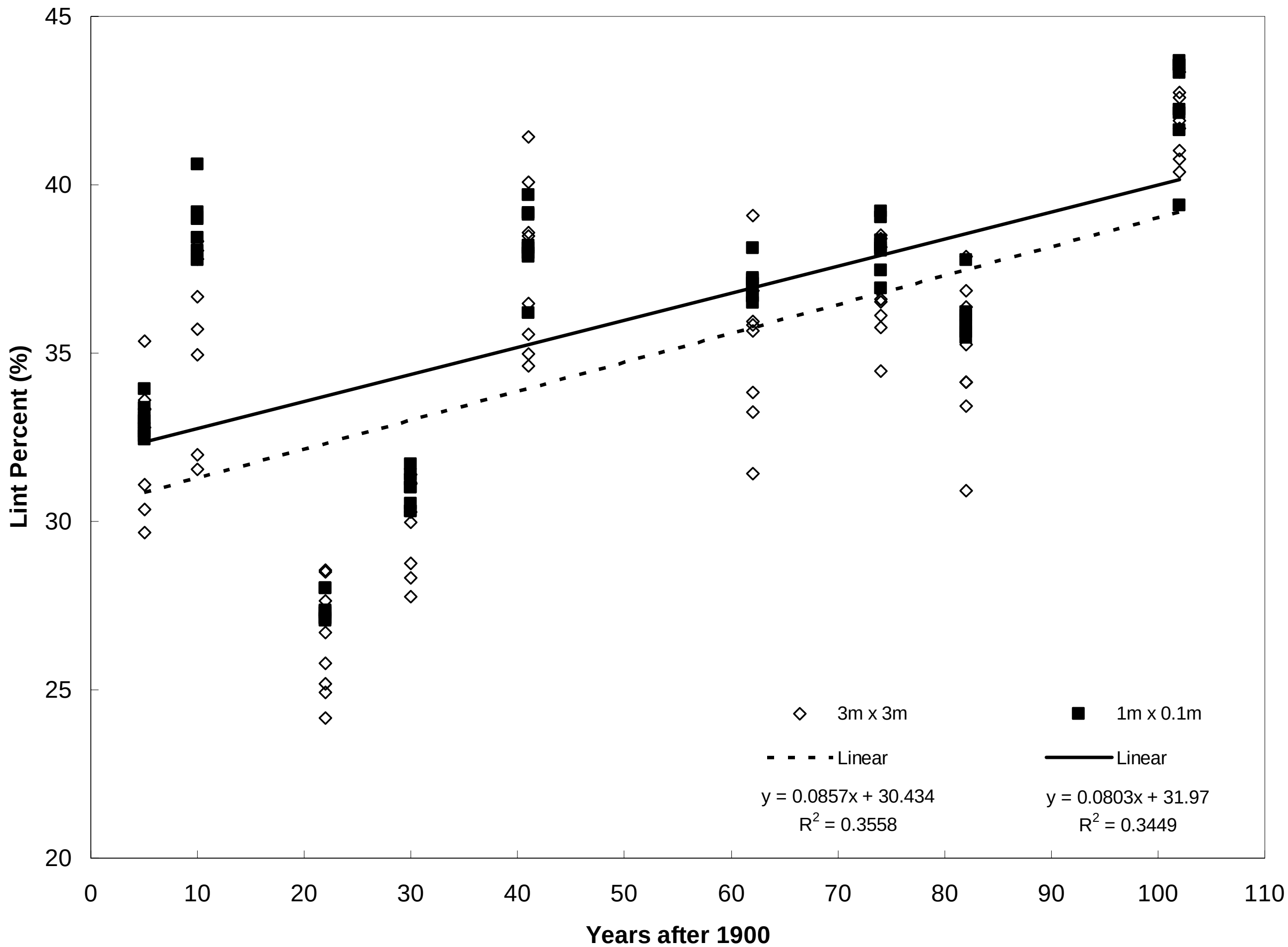

Fig. 3. Rates of genetic gain for lint percent of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

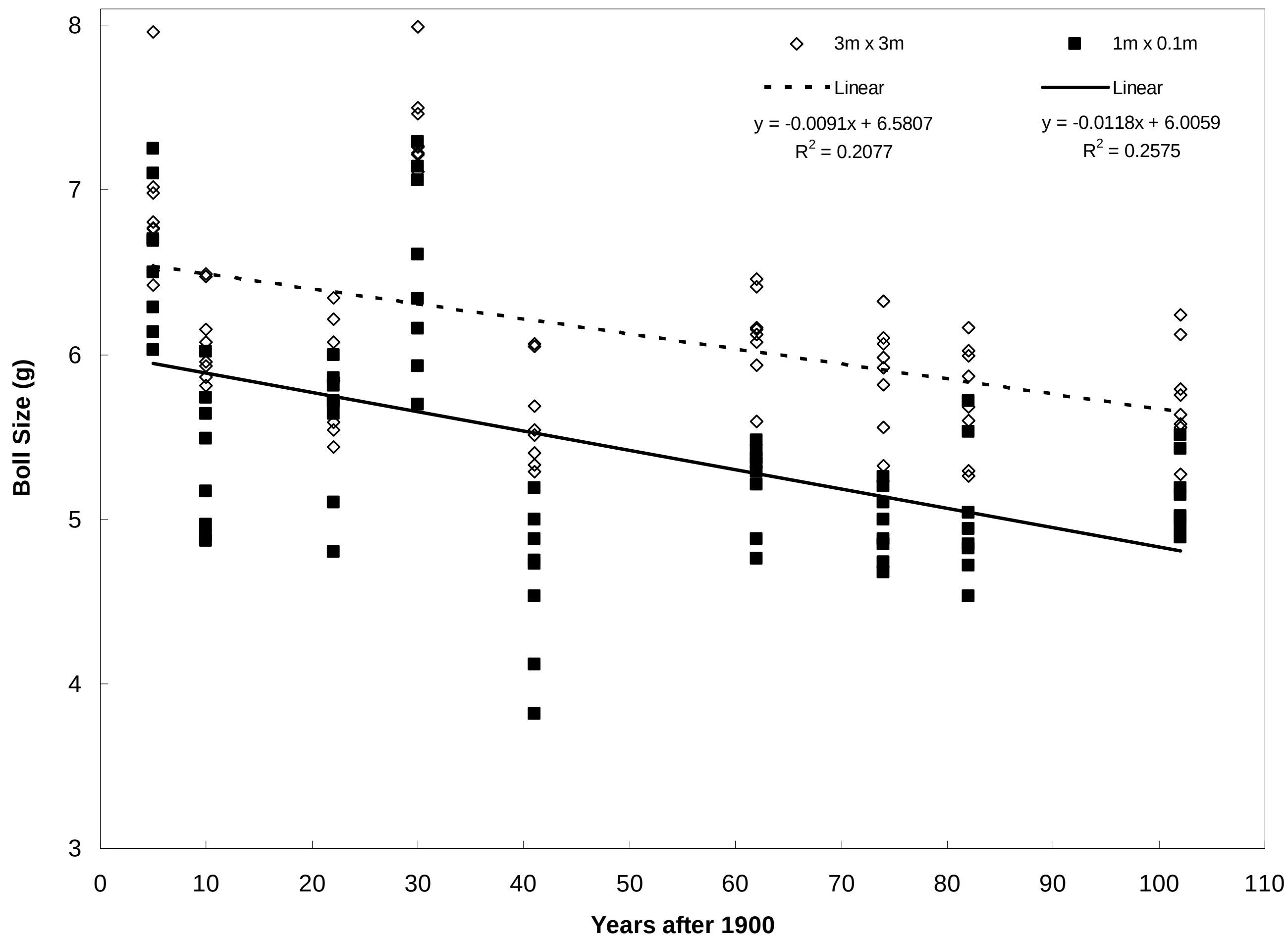

Fig. 4. Rates of genetic gain for boll size of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

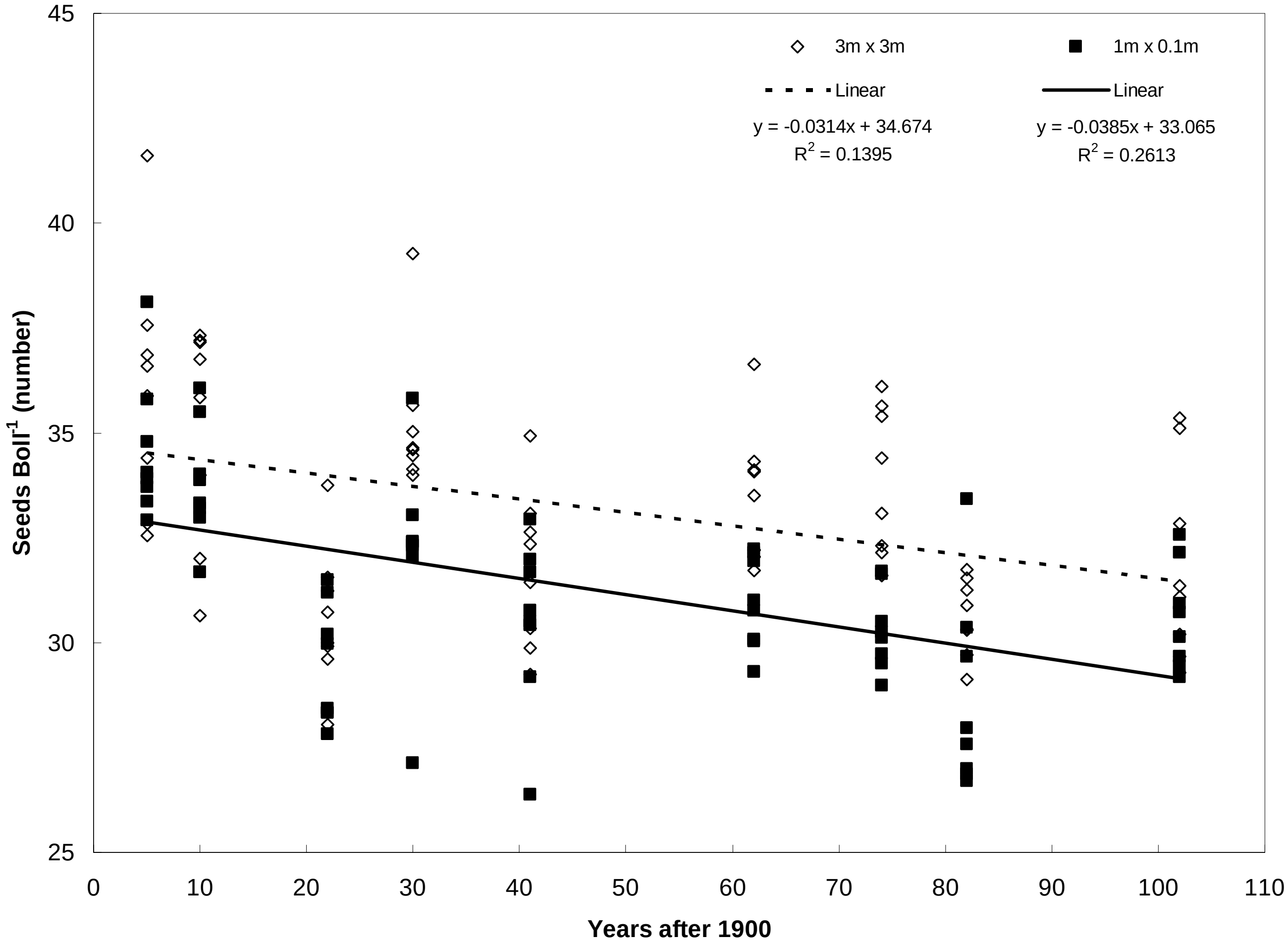

Fig. 5. Rates of genetic gain for seeds boll^{-1} of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

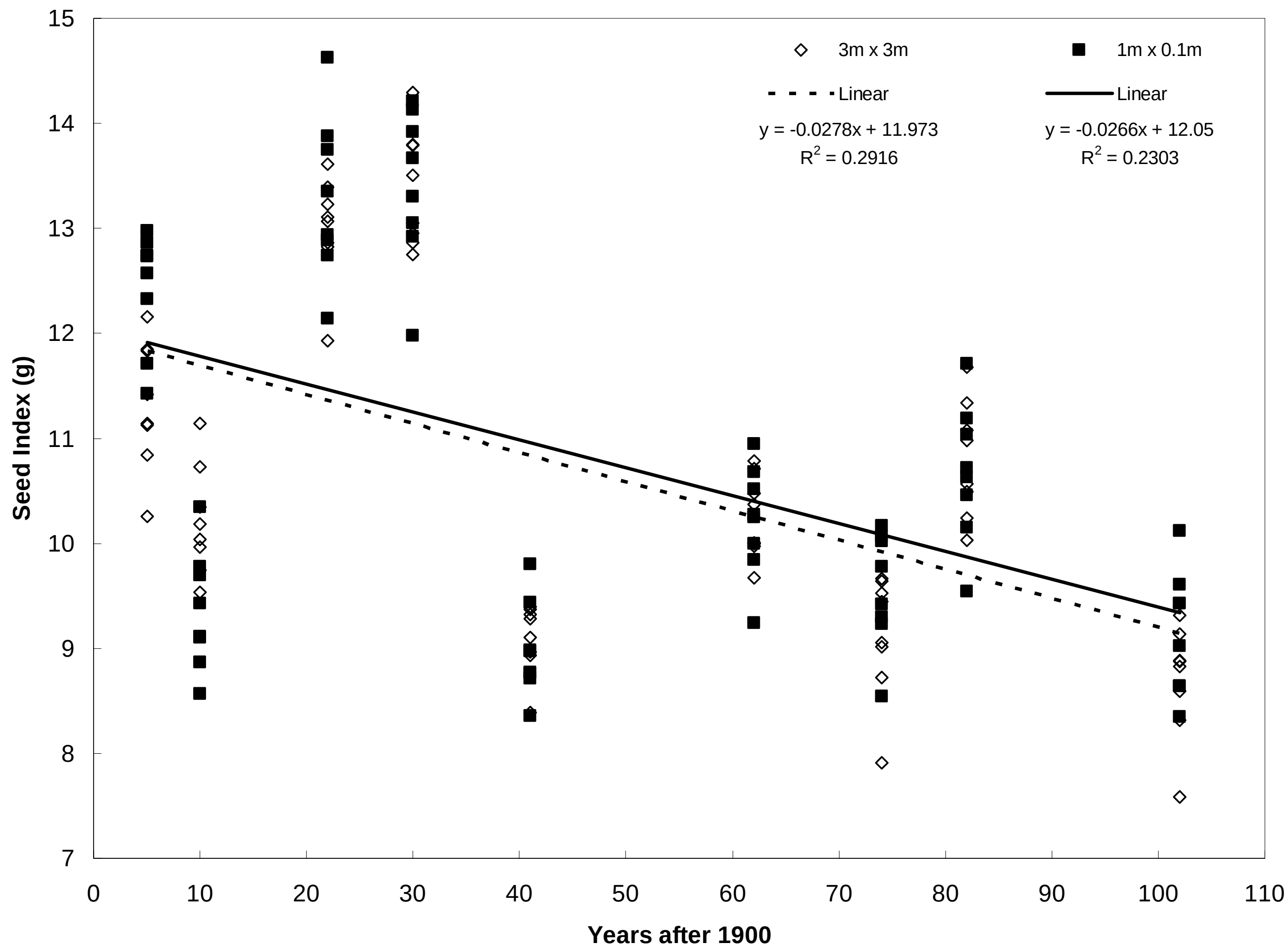

Fig. 6. Rates of genetic gain for seed index of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

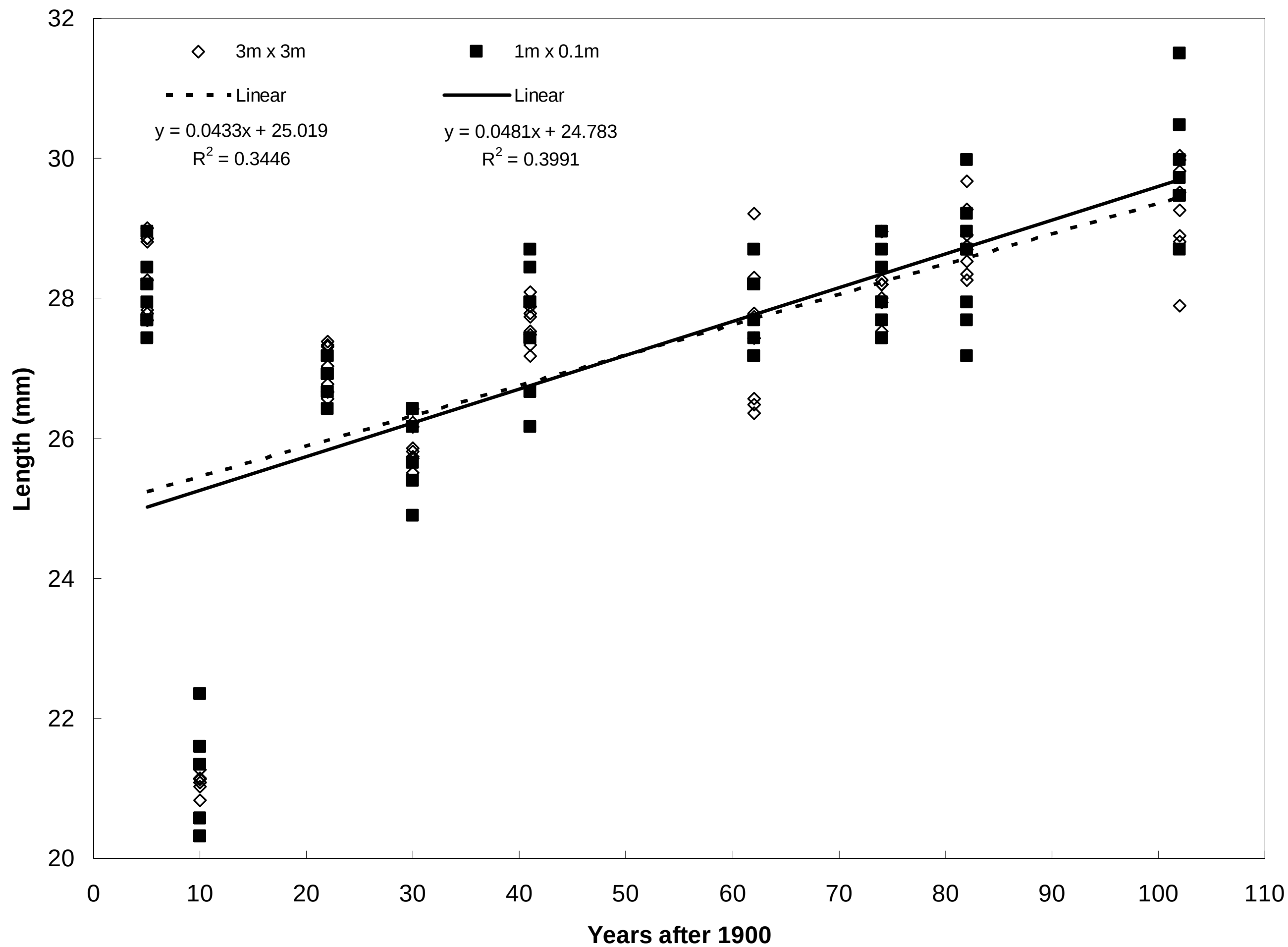

Fig. 7. Rates of genetic gain for fiber length of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

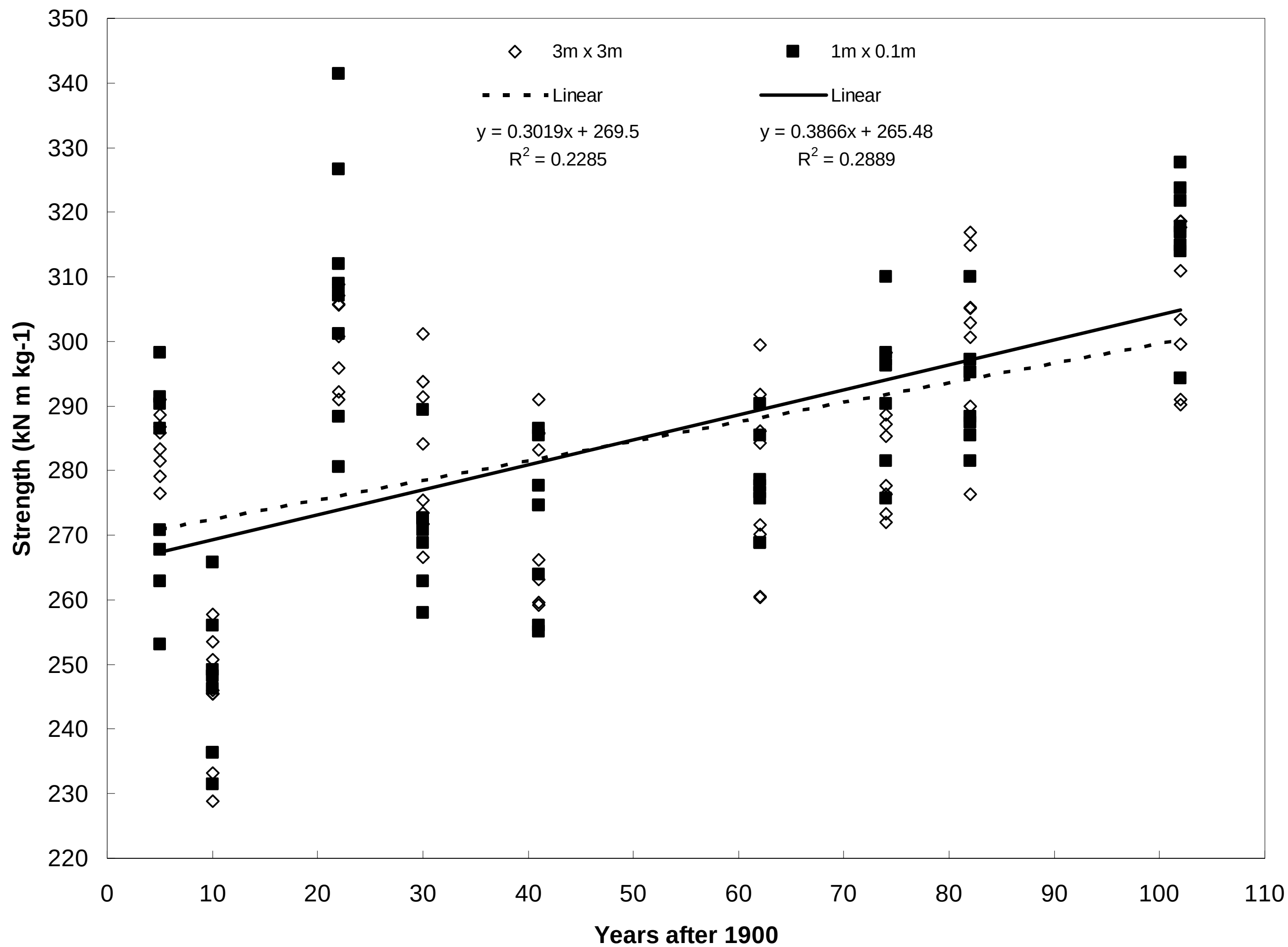

Fig. 8. Rates of genetic gain for fiber strength of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

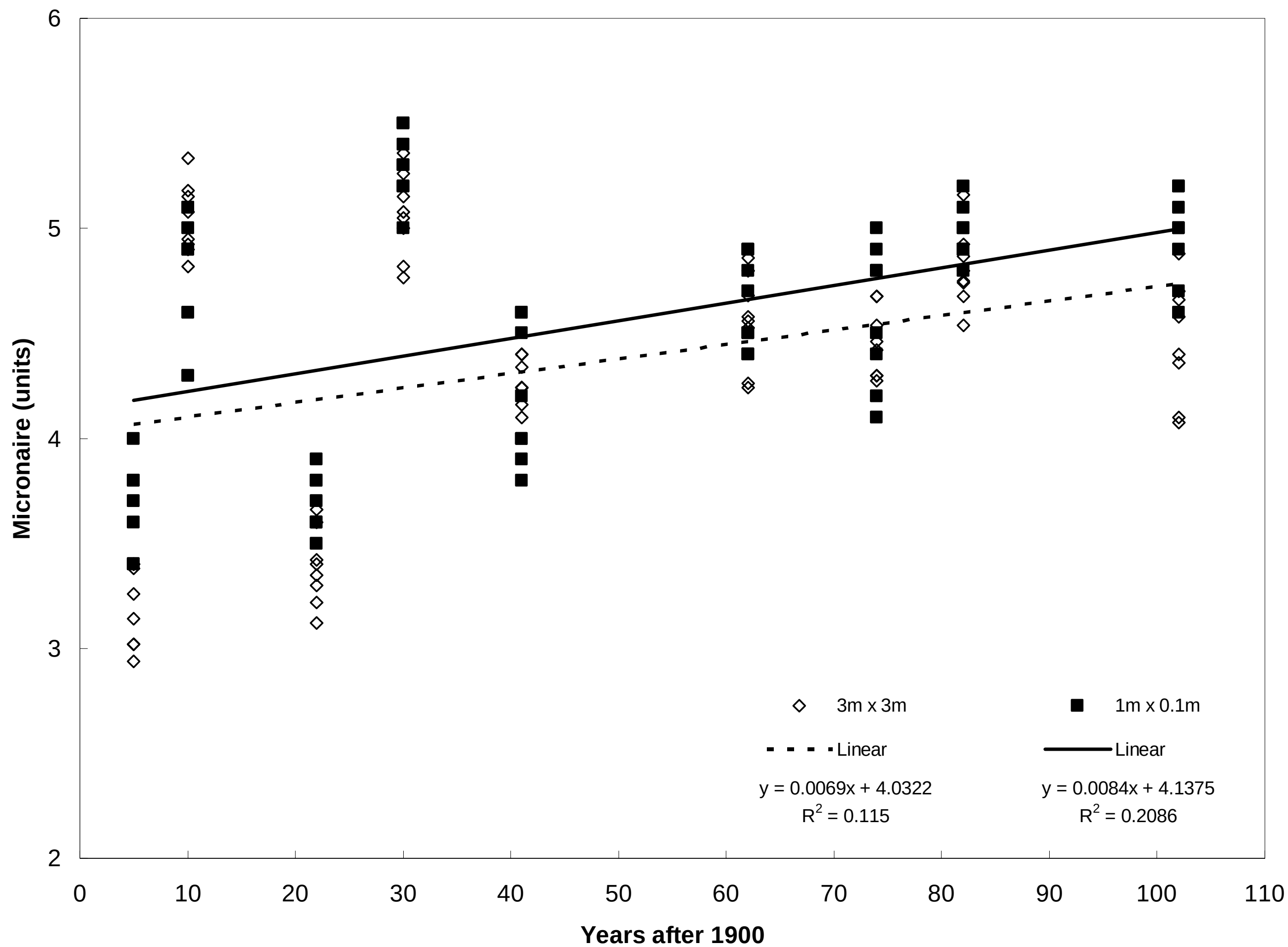

Fig. 9. Rates of genetic gain for fiber micronaire of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

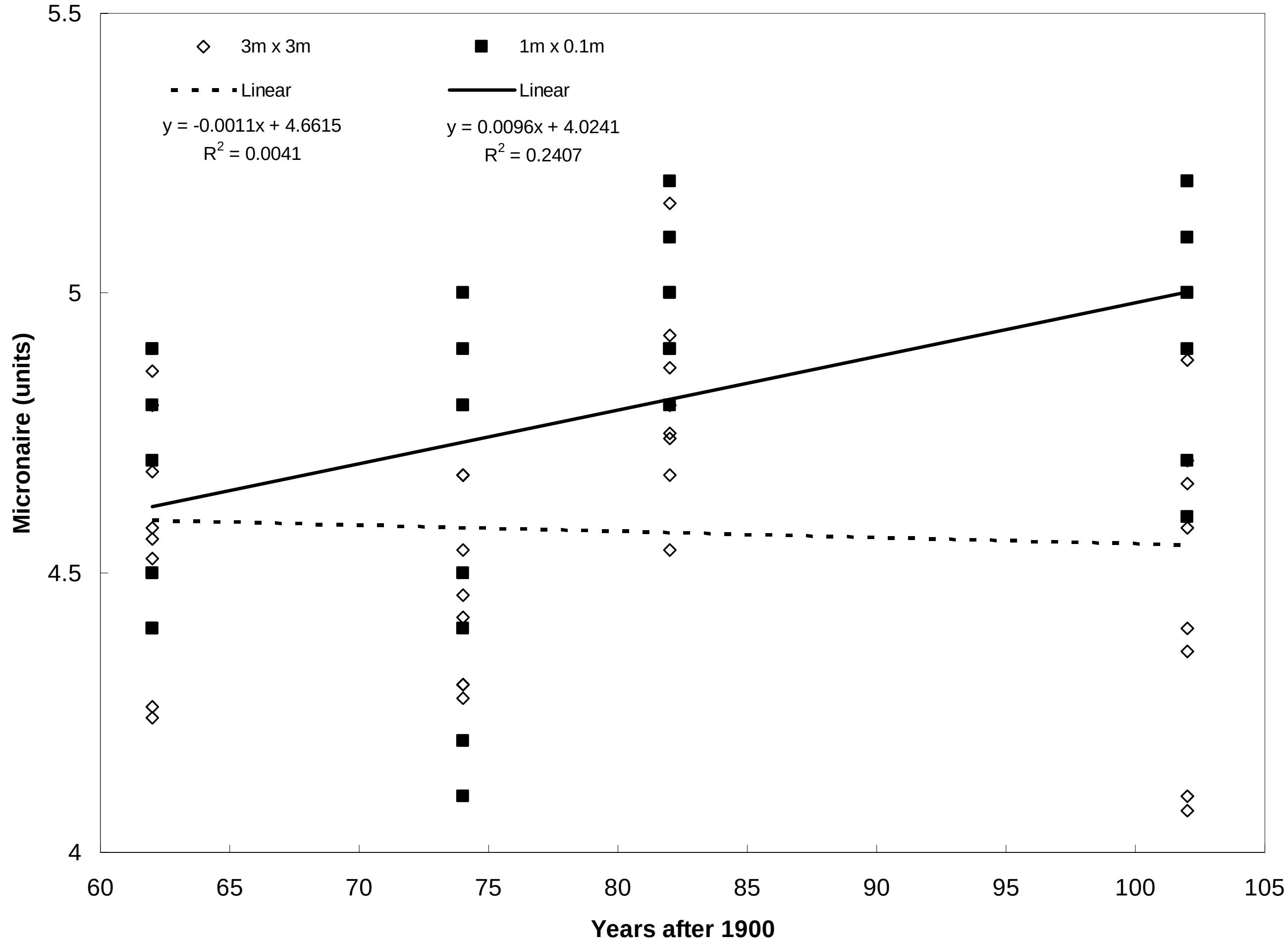

Fig. 10. Rates of genetic gain for fiber micronaire of upland cotton as estimated using 4 cultivars representing the last 40 years and grown in two plant densities at College Station, TX in 2003 and 2004.

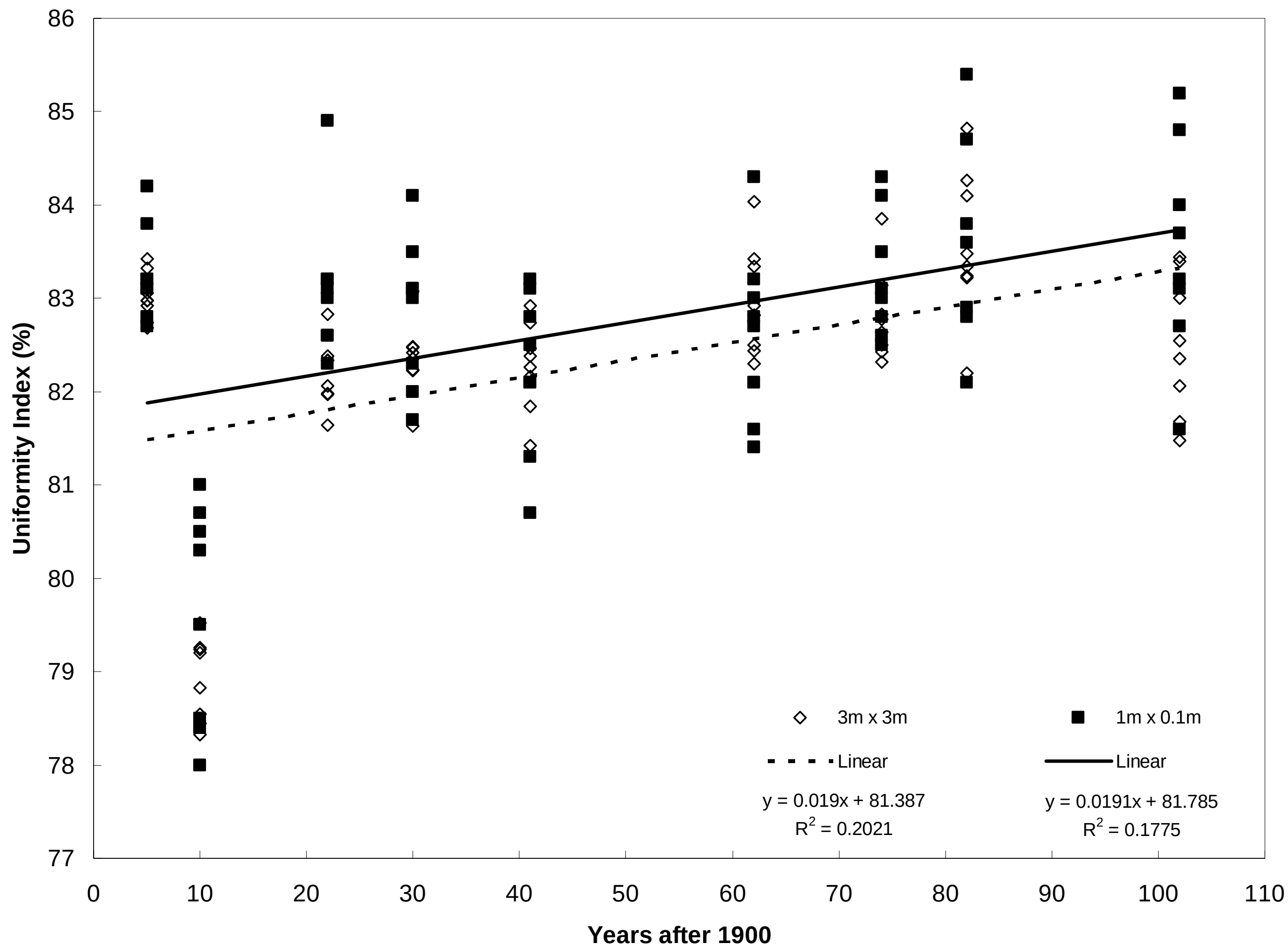

Fig. 11. Rates of genetic gain for fiber uniformity index of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

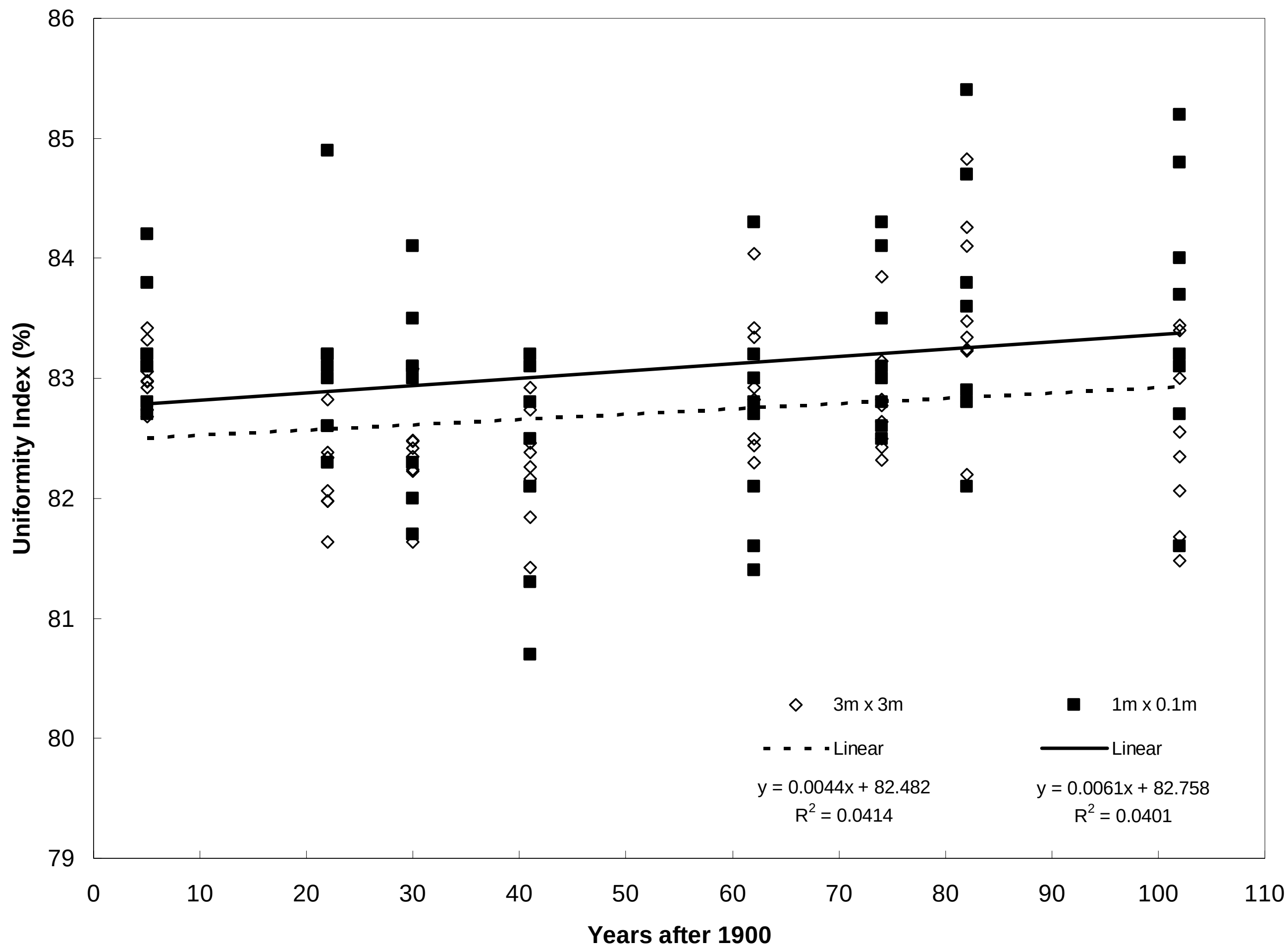

Fig. 12. Rates of genetic gain for fiber uniformity index of upland cotton grown in two plant densities at College Station, TX in 2003 and 2004 as estimated when the cultivar Half-and-Half (1910) is removed from the analysis.

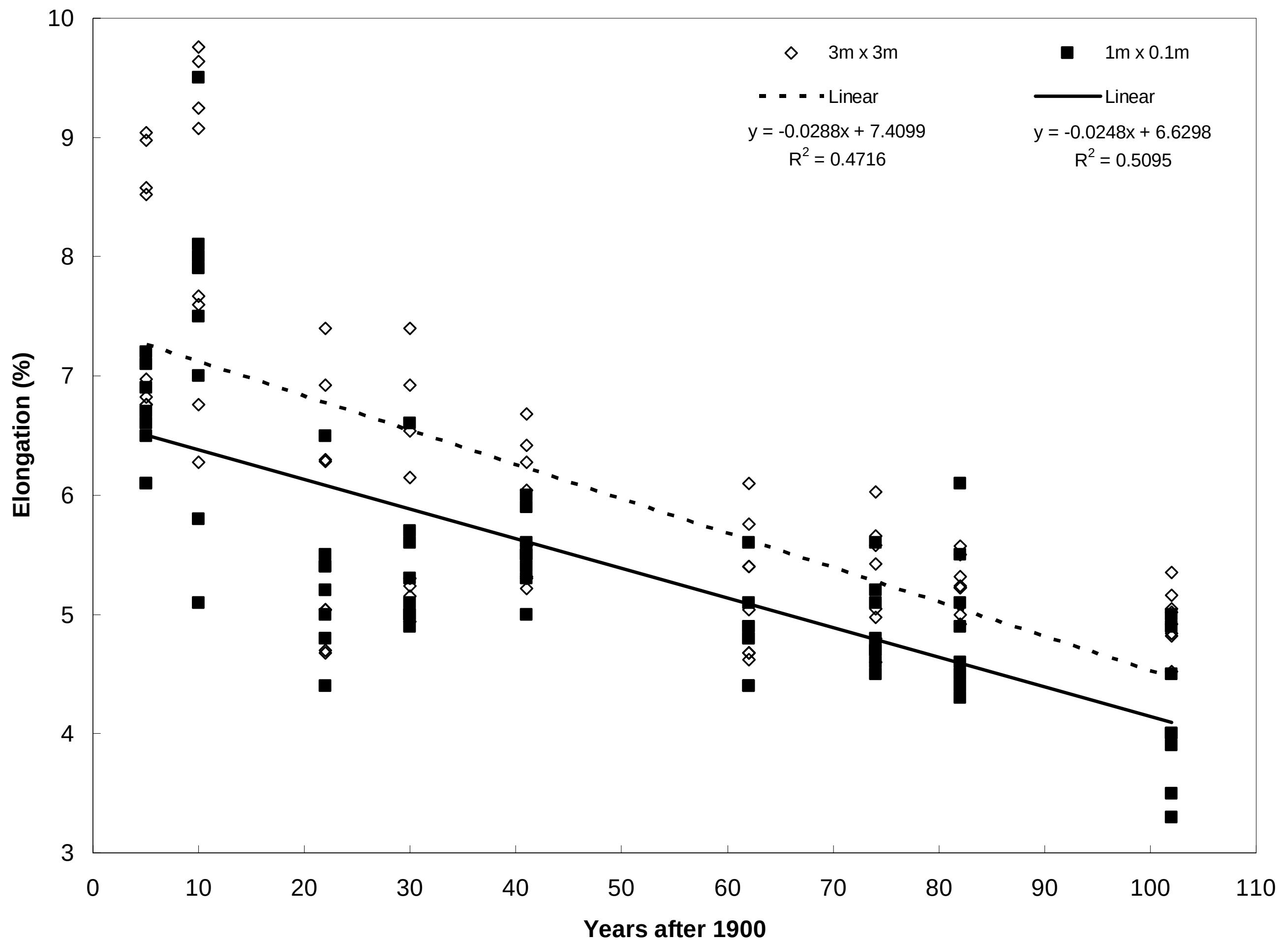

Fig. 13. Rates of genetic gain for fiber elongation of upland cotton as estimated using 9 twentieth century cultivars grown in two plant densities at College Station, TX in 2003 and 2004.

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