77

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Dynamic Aspects of Heterosis in Interspecific Crosses of Cotton – A Plant Modelling Approach

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In accordance with our research grant agreement for this project, we
herewith submit 5 copies of the above indicated report.

Signatures:

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TABLE OF CONTENTS

	<u>Page</u>
Abstract	3
Objectives	4
Body of Report:	
A. Field experiments in Israel	4
B. Experiments with Interspecific hybrids in Mississippi	7
C. Experiments in New Mexico	40
Description of Cooperation	51
Evaluation of Research Achievements	52

The following graduate students contributed to this research : A. Ben-Porath, Y. Tal, S. Shoshan, and C.G.S. Valdes-Lozano, as well as Ms. Victoria B. Cosico, a post-doctorate fellow from the Philippines.

ABSTRACT

Several interspecific hybrids were tested in Israel under field conditions over three years. The results indicated a wide range in lint yields and in micronaire values. The hybrids yielded more than 'Pima S-5' (G. barbadense), but only in a few cases did they yield more than 'Acala SJ-2' (G. hirsutum). The quality of their fiber (length and strength) was very good. It was similar to the quality of 'Pima' varieties. These results indicated the necessity of finding more suitable combinations of breeding lines which may be used to create a high yielding hybrid. The results also revealed the sensitivity of these hybrids to variations in environmental conditions.

The interspecific hybrid 182 was compared with its parental varieties, 'Acala SJ-2' (G. hirsutum) and 'R-142' (G. barbadense), in the USDA-ARS SPAR units at Mississippi State, MS. There were two consecutive experiments under five temperature regimes. Germination of the hybrid was earlier than that of the parent varieties, especially under cool (suboptimal) temperatures. It was also observed that the seedlings of the hybrids were more vigorous and their vegetative growth rate (plant height, mainstem node number, and leaf number) was much faster than that of the parents at low temperatures. Fruiting was earlier in the hybrid than in the Acala parent. The SPAR experiments showed that the seedling vigor of the hybrid was due to its capacity for more rapid stem internode elongation and leaf expansion. The resulting ability to capture more light, rather than a superior leaf photosynthetic efficiency, explains the greater dry matter production and growth in the hybrid than in the parents.

The specific physiological process differences among the parents and the hybrids were identified and a data base characterizing the processes of vegetative growth and development and fruiting were obtained for use in simulation models.

OBJECTIVES

The objectives of this project were:

(a) To examine the growth, development and yield of some G. hirsutum x G. barbadense interspecific F₁ crosses, in comparison to commercial cultivars, in field tests and under controlled conditions.

(b) To define the changes that are needed to adapt a dynamic simulation model, by changing some of its parameters, so that it will be able to simulate these crosses.

(c) To determine the relative advantages of these crosses under different environmental conditions.

A. FIELD EXPERIMENTS IN ISRAEL.

A1. Materials and Methods.

All the hybrids included in the experiments were F1 plants obtained by crossing male-sterile Gossypium hirsutum A-lines with restorer G. barbadense R-lines. The F1 hybrids were designated by a code of three digits, in which the first two digits indicate the female parent (A-line) and the third digit indicates the male parent (R-line) used for creating this hybrid.

In the following list of A-lines, which we used, the first five were created in Israel by repeated backcrossing of commercial cultivars to the male sterile DES-HAMS-16, which was originally bred by the late Dr. Vesta Meyer (USDA, Stoneville, Miss.). It was based on the cytoplasm of G. harknessii. The other two lines were bred by Dr. D. D. Davis (Las Cruces, NM).

<u>A-line code</u>	<u>Origin</u>
16	Riverina Poplar (Australia)
17	Coker 310 (Southeastern USA)
18	Acala SJ-2 (California)
19	Acala B-8310 (New Mexico)
20	6 - M - 10 (Texas)
38	Line A-1-4
40	Line A-1-1

Three different R-lines were used, coded 2, 3, and 4. These were bred by Dr. D. D. Davis by backcrossing G. barbadense lines to the original DES-HAF lines of Dr. Vesta Meyer, and selecting for male fertility restoration. They were coded as R142, R143, and R144, respectively.

Because of seed production difficulty, different hybrids were used in the various experiments. Irrigation and fertilizer applications were made according to recommended practice in Israel.

1981. There were three replicated field experiments: (1) Ein-Shemer (central coastal plain); (2) Ein-Hakhoresh (central coastal plain); (3) Mivhor (southern plain). All the experiments were planted at the beginning of April, in five replicates of a randomized block design. Experiments (1) and (2) were drip - irrigated and each plot consisted of two rows 10 m long. Experiment (3) was irrigated by sprinklers, and each plot was one row 20 m long. Hybrid 182 was compared to Pima S-5 in the first two experiments, whereas in the third one, hybrid 183 was compared to Pima S-5 and Acala SJ-2.

1982. There were three replicated experiments, designed as randomized blocks: (1) Mivhor (southern plain); (2) Horshim (central coastal plain); (3) Nahal-Oz (Negev). There were five replicates in experiment (1) and six in the others. Each plot consisted of one row 16 m long in experiment (1), and of one row 10 m long in the others. Experiments (1) and (2) were planted on 23 and 12 of April, respectively, and they were irrigated by sprinklers. The third experiment was planted on 16 April and was drip-irrigated. Ten hybrids and two check cultivars in (1), two hybrids and Acala SJ-2 in (2), and one hybrid and Acala SJ-2 in (3) were compared.

1983. Two hybrids and two check cultivars were included in an irrigation experiment conducted in Gal-On (southern plain). Each of them was treated by four different drip-irrigation regimes (with amounts of water ranging from 247 to 409 mm per season). Planting was on 13 April, in plots consisting of four rows 15 m long. There were five replicates in a randomized block design.

A2. Results and Discussion

The main results of these experiments are given in Table A1. In this table, letters following the results indicate statistical significance by the Student-Newman-Keuls multiple range test.

The results indicate a very wide range of lint yields among the hybrids. Some hybrids gave high yields in some experiments and low yields in others. The hybrids out-yielded Pima S-5 in many cases and in a few cases they also out-yielded Acala SJ-2. Lint quality, characterized by 2.5% length (as measured by a digital Fibrograph) and T1 strength (as measured by 1/8 inch Pressley tester), was similar to that of Pima S-5 in many cases and it was always better than that of Acala SJ-2. Fiber fineness of the hybrids ranged from 3.0 to 4.2 micronaire units.

The wide range of values for lint yield and quality of the hybrids indicates that a breeding effort (for general and specific combining ability) should be made to find the right hybrid combination for a given environment. It also indicates that the hybrids are very sensitive to changes in environmental conditions (climate, irrigation, soil fertility, etc.). In Gal-On, however, there was no significant interaction between irrigation regimes and varieties. The pooled results of all irrigation treatments are given in Table A1.

Table A1. Results of field trials with cotton hybrids in Israel.

Year and Experi- ment	Hybrid or cultivar	Lint yield kg/ha	2.5% length inches	T1 strength g/tex	Fineness micro- naire
1981(1)	182	2520a	1.36	33.2	3.9
	Pima S-5	1620b	1.33	31.1	3.6
1981(2)	182	2400a	1.33	32.5	3.9
	Pima S-5	1820b	1.30	29.3	3.8
1981(3)	183	2220a	1.40a	33.5a	4.1
	Acala SJ2	2010ab	1.19b	26.5b	4.3
	Pima S-5	1910b	1.35a	33.0a	4.1
1982(1)	163	1910a	1.26	28.6	4.0
	164	1660c	1.32	30.0	3.4
	174	1830b	1.42	32.5	3.6
	182	1410d	1.38	32.1	3.2
	184	2110a	1.34	30.8	3.8
	194	1490d	1.38	32.0	3.5
	204	1480d	1.39	32.6	3.0
	382	1930b	1.35	31.9	3.6
	384	1120e	1.39	32.6	3.3
	404	1230e	1.33	30.6	3.1
	Acala SJ2	2090a	1.14	25.8	4.2
	Pima S-5	1880b	1.21	28.3	3.8
1982(2)	183	2710a	1.31	30.8	3.9
	173	1960c	1.35	31.5	3.7
	Acala SJ2	2230b	1.14	25.0	4.7
1982(3)	193	1870b	1.37	31.7	4.2
	Acala SJ2	2340a	1.19	25.4	4.3
1983	182	2070a	1.37a	32.2a	4.0b
	203	1690b	1.35b	31.8a	3.4c
	Acala SJ2	2170a	1.18c	25.5b	4.5a
	Pima S-5	1570b	1.34b	31.1a	3.8b

* Data designated by the same letters, within each year and experiment, were not significantly different by the Student - Newman - Keuls multiple range test.

B. EXPERIMENTS WITH INTERSPECIFIC HYBRID COTTON
AT MISSISSIPPI STATE

The objective of these experiments with the cotton interspecific hybrid (182) and its parents ('Acala SJ-2' - Gossypium hirsutum L. and 'R-142' - Gossypium barbadense L.) was to characterize the response of various physiological processes in the 3 varieties to temperature under optimal growth conditions (no stress, and a high level of atmospheric CO₂).

B1. MATERIALS AND METHODS.

The three varieties of cotton - 'Acala SJ-2', 'R-142', and their interspecific hybrid '182' - were grown in SPAR units. Four different types of experiments were carried out during the season of 1984:

1. In five SPAR units different temperature regimes were imposed. That experiment was conducted twice (1a): May-August; (1b): August-October.
2. In three SPAR units canopy photosynthesis and respiration were measured.
3. In two SPAR units the effects of mild water stress were evaluated. The plants for this experiment were grown in pots in a nearby nursery.
4. In a nearby field, germination of the three varieties was evaluated.

The plants of experiments 1 and 2 were seeded in the SPAR units and grown in a mixture of sand and vermiculite (3:1 v/v). The bins were filled to 20 cm below the plexiglass level in order to enlarge the available above ground volume for plants (the original height of 150 cm had been found insufficient for well fertilized cotton plants).

The plants for the water stress experiment were grown in pots in a nearby nursery. Seven liter pots were filled with pure sand and arranged in 1 m rows, with 10 pots/m and 1 m between rows. The nursery was planted on 22 May, 1984, and germination occurred on 29 May. Ten days later the plants were thinned to one per pot.

Field plots were planted on May 31, 1984 to test the emergence of the hybrid seeds in comparison to two cultivars of G. hirsutum. 'Acala SJ-2', 'Deltapine 90', and the 'Hybrid 182' were each planted in five replicates. Each replicate was a 4-row plot 4 m long, with 15 seeds planted per m of row. An irrigation of 40 mm was applied after planting, and germination was counted daily in each row.

All the SPAR and nursery plants were drip irrigated with a nutrient solution (Hoagland solution modified to 50 ppm N until flowering, then to 100 ppm N). The plants were irrigated to excess in 12 applications per day (one dripper per pot and 6 drippers in each SPAR unit). The daily amount of water applied was based on chamber transpiration and pan evaporation data (for nursery). Before sowing, lime and 0-24-24 fertilizer were mixed into the top 15 cm of the pots and SPAR soil bins at rates equivalent to 100 g m⁻².

Experiments 1a and 1b - Plant Development in Different Temperature Regimes:

Two consecutive experiments were conducted, each in five SPAR units, to compare the growth and development of plants in response to temperature, when all other factors were non-limiting (600 ppm v/v CO₂, and adequate water and fertilizer applications). Each chamber was under a different temperature regime and each chamber contained all three cultivars. Five SPAR units (No. 2, 3, 8, 9, and 10) were controlled at day/night temperatures of 20/11, 24/14, 28/17, 32/20, and 36/23 C, respectively. Each chamber contained 3 rows, one row for each cultivar.

This procedure was carried out twice. The first experiment was conducted in May-August 1984, and the second experiment in August-October 1984. Those two experiments differed in three factors, from each other, hence they could not be considered as two "replications". Those factors were:

- (a) Higher radiation values during the first experiment (summer vs. fall).
- (b) Number of plants per row: 4 in the first and 5 in the second experiment.
- (c) Temperature regimes for germination: in the first experiment the temperature gradient among the 5 SPAR units was imposed before planting, whereas in the second experiment all 5 units were germinated under optimal temperature (32/20 C). Only after plant emergence was completed in all the 5 chambers, were different temperature regimes were applied.

(1a) First experiment (May-August):

Planting day was 26 May 1984 and the germination period varied, according to the chamber temperature. First emergence day (50% of the seed emerged) was 29 May, (for the hybrid plants in chamber No. 10), and emergence continued until 2 June (for the Acala plants in chamber No. 2). During the month of June, the daily temperature of chamber No. 2 was above the set point (in the range of 26 to 28 C, instead of 20 C) because of problems with the cooling system.

Two weeks after germination, the rows were thinned to five plants each. As the plants developed in the cooler temperature regimes (chambers No. 2, 3, and 8), there was great variability in size among plants within each row (even though they were of the same variety). Hence on 2 July, the most outlying plant in each row was eliminated in order to achieve better uniformity. The final stand in each of the 5 chambers was 12 plants (3 rows x 4 plants in each). After thinning, a sheet of Naugahyde (vinyl impregnated cloth) was laid on the soil surface and sealed to the edges of the soil bin with silicon caulk to prevent CO₂ and water vapor fluxes between the soil and the air.

Weekly observations of plant height, numbers of mainstem nodes, numbers of leaves, and length of mainstem leaves were made from thinning until harvested and the dry weight of various plant parts (leaves, stems, fruit, and roots) was determined. The reasons for this early termination of the experiment were: (a) plant development was not uniform; (b) the hybrid plants were very vigorous, and they occupied almost half of the chamber volume and reached the ceiling (1.70 m above the ground).

(1b) Second experiment (August - October):

On 21 August, the five chambers were replanted and the plants germinated under a uniform temperature regime (32/20 C). After germination was completed in all the five chambers, (27 August), the various temperature regimes were applied. In order to observe the effect of temperature on germination, another set was planted in wooden boxes on 2 September. These were placed between the rows in the SPAR units. 20 seeds of each variety were planted in each temperature regime. Daily counts of germination were made, and the seedlings from the wooden boxes were harvested on 12 September, and the boxes were removed from the chambers. On 13 September, the plants in the SPAR chambers were thinned to the final stand (5 plants in a row, 15 plants per chamber).

The plants of the second experiment were more uniform (within a row) than in the first experiment (especially in the 3 chambers with suboptimal temperatures). The same weekly observations of growth parameters were made, from thinning to harvest, as in the first experiment. These plants were harvested on 23 October, at the age of 57 days.

Experiment 2 - Canopy Photosynthesis and Respiration Measurements.

The objective of this experiment was to compare canopy photosynthesis and respiration rates at optimal temperature conditions at 340 ppm CO₂ among cultivars. Three SPAR units (No. 5, 6, and 7) were planted with one variety in each ('Acala SJ2', 'R-142', and 'Hybrid 182', respectively) on 30 June, 1984. 36 seeds were planted in each chamber (3 rows x 12 seeds), and germination evaluation was carried out. Two weeks after germination, the rows were thinned to five plants each (15 plants in 1 m² ground area), and the soil surface was sealed with Naugahyde sheet. Growth conditions in these three chambers were 32/20 C and 340 ppm CO₂.

After thinning, weekly observations of growth were made until midbloom when the plants in chambers No. 5 and 7 (Acala and Hybrid plants, respectively) reached the ceiling. During that time, chamber photosynthesis and respiration were measured. After midbloom, 15 small bolls were tagged in each chamber and their diameter was measured weekly. The plants were harvested on 23 October at the age of 111 days.

Experiment 3 - Plant Responses to Mild Water Stress:

Potted, well irrigated, 'Hybrid 182' plants were transferred from the nursery into two SPAR units at the age of 46 days. There were ten plants in each chamber. One chamber (No. 4, no stress) received optimal water treatment. Twelve applications of water per day were applied. This amount of water was determined by the rate of transpiration, as measured in this chamber. The other chamber (No. 1, water stress) received only 2/3 of that amount of water (applications of water per day). Measurements of photosynthesis, transpiration and stem diameter were recorded automatically during 6 weeks, and the plants were harvested at the age of 90 days.

After that, a similar experiment was carried out with potted, well irrigated, Acala-SJ2 plants. The plants were transferred from the nursery

into SPAR units on 31 August, at the age of 93 days, and they were harvested on 15 September (plant age 108 days).

Measurements of Organ Growth:

There were two types of measurements:

a) Weekly measurements of plants included plant height, numbers of mainstem nodes, and numbers of leaves per plant. Mainstem leaves were tagged when unfolding. Their length (main vein right of the central vein) was recorded every week (8 fully-open mainstem leaves per plant). Some of these leaves were harvested for additional measurements including leaf blade area and dry weight in order to calculate their expansion rate and specific leaf area.

b) Destructive harvests were done twice in the chambers (at thinning time, and at the termination of each experiment). At these harvests, mainstem leaf length, area, and dry weight were recorded, in order to relate mainstem leaf length to whole plant leaf area. The shoots were divided into blades, petioles, stems, squares, and bolls. The numbers of leaves and the leaf area were recorded. Then all plant parts were oven dried at 80 C and weighed. The roots were carefully washed on 1/8 inch hardware cloth, and were floated in a water bath, for final separation from the sandy medium. In the SPAR soil bins, the roots were dug according to rows and layers.

After separation from the medium, the roots were grouped into two categories: (a) "large roots" - the main woody frame of the root system (taproot and root branches), and (b) "small roots" - fine and flexible unuberized roots, which can be separated easily from the main frame.

B2. RESULTS

(1) Germination.

In the first SPAR experiment the hybrid germinated faster than its parents in all temperature regimes. However, the population of plants in each chamber was too small (12 seeds from each variety only) to conduct a quantitative evaluation of germination.

The results of germination counts from the field plots are given, as percentage of final emergence (Figure B1). Results of germination of seeds in the wooden boxes placed in the chambers of experiment 1b are given in Figures B2 to B6. Results of germination from the three chambers (No. 5, 6, and 7) that had 36 seeds of each variety in a chamber, are shown in Figure B7.

All the data indicate that seeds of the interspecific hybrid germinate earlier than its parental varieties, especially when temperatures are lower than the optimum. 'R-142' germinated earlier than 'Acala SJ-2' in all temperature regimes. Usually, Pima varieties germinate earlier than 'Acala SJ-2' and that advantage was greater under suboptimal temperatures (see Figures B2-B3).

Fig. B1. Germination of cotton seeds in field plot experiment, percentage of final germination count.

Fig. B2. Germination of cotton seeds in boxes placed in chamber #2, day/night temperature 20/11 C.

Fig. B3. Germination of cotton seeds in boxes placed in chamber #3, day/night temperature 24/14 C.

Fig. B4. Germination of cotton seeds in boxes placed in chamber #8, day/night temperature 28/17 C.

Fig. B5. Germination of cotton seeds in boxes placed in chamber #9, day/night temperature 32/20 C.

Fig. B6. Germination of cotton seeds in boxes placed in chamber #10, day/night temperature 36/23 C.

Fig. B7. Germination of cotton seeds in chambers #5, 6 and 7, day/night temperature 32/20 C.

Fig. B8. Weekly measurements of plant height, cm, in experiment #1, chamber #2, day/night temperature 20/11 C.

(2) Seeding vigor.

The advantage of the hybrid plants over the parental cultivars was apparent from the early stages of their development. On thinning day, 11 to 12 day-old plants were harvested in experiments 1, 2, and 3. Samples of these seedlings from each variety were measured, dissected, oven-dried, and weighed. The results are shown in Tables B1, B2, and B3. The seedlings of the hybrid variety exceeded those of the other cultivars in plant height, root biomass, leaf area and total dry weight per seedling. Those differences were consistent and significant in all three experiments. The stem dry weights were inconsistent. In experiment 1a (Table B1) the hybrid had significantly smaller stems than its parents, whereas, in experiments 1b and 2 the opposite results occurred.

By comparing tables B2 and B3 (same temperature but different CO₂ concentrations) it may be observed that CO₂ levels had a significant effect on seedling development, especially in the hybrid where total dry weight per seedling was increased 93%. This effect was especially evident on hypocotyl length, leaf area, dry weight of cotyledons, and root. It is of interest to compare the specific leaf area values of the hybrid seedlings grown in different CO₂ atmospheres. Under 600 ppm CO₂, hybrid leaves averaged a specific leaf area of 334.6 compared to 294.3 cm²/g at 340 ppm. This is a thickening of 12%.

(3) Growth and development.

Figures B8-B12 show the results of weekly measurements of plant height. In all cases, the hybrid was taller than either of the two parents. Plant height is a very important parameter in modeling the crop because it affects canopy light capture and dry matter production. The height advantage is most evident at the lower temperatures. At the lower temperatures the Pima parent "outgrew" the Acala parent. At mid-range temperatures they were nearly equal, and at the very high temperature the Acala "outgrew" the Pima cotton.

Figures B13-B17 show the effect of temperature on plastochron intervals. In most treatments the hybrid developed faster (shorter plastochron intervals). The Pima cultivar tended to develop mainstem nodes more rapidly than the Acala in most temperature treatments. It appears that the height difference in the hybrid were due both to more vigorous growth and to more rapid development. Further analysis in the format of the simulation model will be needed to weigh the relative contributions of these two factors in overall plant size.

Figures B18-B22 depict the influence of temperature on rates of leaf initiation. This determines fruiting rates and provides the basis for leaf area growth. Again the hybrid developed more rapidly and this was more apparent at the lowest temperature. The Acala was inferior to the Pima at the lowest temperature and superior at the highest.

The weekly observations of plant height were analysed by fitting polynomial regression curves to the data. Third degree or second degree polynomials were found to give a good fit (R^2 values greater than 0.95).

Table B1. Plant characteristics of 11 day old seedlings of experiment No. 1a (plants were thinned out on 13 June). Data from chambers # 2, 3, 8, 9 & 10; 600 ppm CO₂. Means of 3 replications of 4 to 6 plants. Means of varieties within each temperature regime, in the same column, not followed by the same letter, differ at the 0.05 probability level as determined by the SNK range test.

Variety	Leaf	Leaf	Dry Wt of plant parts (g)					Total
	Area (cm ²)	number Coty- ledon	Leaves	Stem	Root	Hypo- cotyl		
20/11 C								
Acala SJ2	0.0	0.0	.081ab	.000	.000	.057a	.035	.173a
R-142	0.0	0.0	.072b	.000	.000	.032b	.034	.138b
Hybrid 182	0.0	0.0	.096a	.000	.000	.063a	.032	.191a
24/14 C								
Acala SJ2	0.0	0.0	.083	.000	.000	.038b	.037	.157b
R-142	0.0	0.0	.079	.000	.000	.045b	.034	.159b
Hybrid 182	0.0	0.0	.099	.000	.000	.088a	.033	.221a
28/17 C								
Acala SJ2	0.0	0.0	.139a	.000b	.021a	.064b	.049a	.273b
R-142	0.0	0.0	.102b	.000b	.021a	.065b	.035b	.223c
Hybrid 182	0.4	0.3	.156a	.014a	.015b	.111a	.048a	.344a
32/20 C								
Acala SJ2	0.5b	0.4b	.141a	.028a	.023a	.077b	.058a	.326a
R-142	0.0b	0.0c	.091b	.000c	.025a	.063c	.039c	.219b
Hybrid 182	2.8a	0.8a	.146a	.022b	.015b	.097a	.050b	.329a
36/23 C								
Acala SJ2	7.5b	1.8a	.163a	.047a	.031a	.072b	.076a	.388b
R-142	7.9b	1.5b	.103b	.039b	.022b	.074b	.050b	.288c
Hybrid 182	9.5a	1.2c	.163a	.046a	.016c	.114a	.077a	.416a
LSD (0.05)	1.0	0.2	.018	.003	.003	.009	.006	.024

Table B2. Plant characteristics of 12 day old seedlings of experiment #1b (plant were thinned out on 13 September). Means of 12 replications. Means in the same column not followed by the same letter differ at the 0.05 probability level as determined by the SNK range test. Data from chambers # 2,3,8,9,10 of experiment #2 ; 32/20 C (day/night), 600 ppm CO₂.

Variety	Plant Height (cm)	Leaf Area (cm ²)	Hypocot. Length (cm)	Dry Wt of plant parts (g)					Specif. Leaf Ar. (cm ² /g)
				Coty.	Leaves	Stem	Root	Total	
Acala SJ2	1.3b	11.5b	13.0b	.198a	.038b	.012b	.056b	.304b	302.6
R-142	1.8b	14.0b	9.7c	.130b	.045b	.012b	.042b	.229c	311.1
Hybrid 182	3.2a	35.9a	14.4a	.224a	.122a	.019a	.097a	.462a	294.3
LSD(.05)	0.6	6.8	1.4	.038	.031	.005	.015	.058	

Table B3. Plant characteristics of 11 day old seedlings of experiment #2. Means of 10 replications. Means in the same column not followed by the same letter differ at the 0.05 probability level as determined by the SNK range test. Data of 16 June from chambers # 5, 6, 7; 32/20 C (day/night), 340 ppm CO₂.

Variety	Plant Height (cm)	Leaf Area (cm ²)	Hypocot. Length (cm)	Dry Wt of plant parts (g)					Specif. Leaf Ar. (cm ² /g)
				Coty.	Leaves	Stem	Root	Total	
Acala SJ2	1.7b	11.1b	9.8a	.079b	.038a	.010c	.061a	.188b	292.1
R-142	1.9b	15.2a	6.8b	.061b	.047a	.015b	.044b	.167b	323.4
hybrid 182	2.5a	17.4a	9.6a	.107a	.052a	.019a	.061a	.239a	334.6
LSD(.05)	0.4	4.0	1.0	.023	.015	.003	.013	.035

Fig. B9. Weekly measurements of plant height, cm, in experiment #1, chamber #3, day/night temperature 24/14 C.

Fig. B10. Weekly measurements of plant height, cm, in experiment #1, chamber #8, day/night temperature 28/17 C.

Fig. B11. Weekly measurements of plant height, cm, in experiment #1, chamber #9, day/night temperature 32/20 C.

Fig. B12. Weekly measurements of plant height, cm, in experiment #1, chamber #10, day/night temperature 36/23 C.

Fig. B13. Weekly measurements of number of mainstem nodes in experiment #1, chamber #2, day/night temperature 20/11 C.

Fig. B14. Weekly measurements of number of mainstem nodes in experiment #1, chamber #3, day/night temperature 24/14 C.

Fig. B15. Weekly measurements of number of mainstem nodes in experiment #1, chamber #8, day/night temperature 28/17 C.

Fig. B16. Weekly measurements of number of mainstem nodes in experiment #1, chamber #9, day/night temperature 32/20 C.

Fig. B17. Weekly measurements of number of mainstem nodes in experiment #1, chamber #10, day/night temperature 36/23 C.

Fig. B18. Weekly measurements of number of leaves per plant in experiment #1, chamber #2, day/night temperature 20/11 C.

Fig. B19. Weekly measurements of number of leaves per plant in experiment #1, chamber #3, day/night temperature 24/14 C.

Fig. B20. Weekly measurements of number of leaves per plant in experiment #1, chamber #8, day/night temperature 28/17 C.

Fig. B21. Weekly measurements of number of leaves per plant in experiment #1, chamber #9, day/night temperature 32/20 C.

Fig. B22. Weekly measurement of number of leaves per plant in experiment #1, chamber #10, day/night temperature 36/23 C.

The daily growth rates were estimated from the derivatives of these curves. These data, presented in Figures B23-B25, indicate that the hybrids had greater initial growth rates at lower temperatures, and that growth was inhibited more by low temperatures in the Acala than the other cultivars. The numbers of mainstem nodes (Figures B13-B17) increased at a constant rate, indicating that the average ages of the top several internodes were constant throughout the experiments in all treatments. However, the rate of stem extension data presented in Figures B23-B25 increased over this time interval and it apparently cannot be attributed to decreasing ages of the expanding internodes. We must therefore attribute this accelerating stem extension phenomenon to more rapid internode elongation caused by an improving supply of carbohydrates and (possibly) other metabolites.

Final plant height and the components of leaf area are shown in Table B4. The hybrid plants were taller than the other cultivars, especially at the lower temperatures. At the lower temperatures, they also had more mainstem nodes. The results also indicate that the number of leaves per plant, as well as total leaf area per plant and the average area per leaf were higher in the hybrids than in the other cultivars. This too was more prominent at the lower temperatures. Mainstem leaves of the hybrid plants were especially large and reached their maximum size at 28/17 C. In the hybrid plants of the nursery, mainstem leaves did not grow as large. It should be borne in mind that these phenomenal "giant mainstem leaves" (some leaves were larger than 550 cm² in a high CO₂)

At the end of experiments No. 1a and 1b, there was an indication that hybrid 182 had more squares and bolls per plant than Acala SJ2, especially at low temperatures, but the differences were not significant in most cases, because of very large variations among plants. R-142 also produced many squares and bolls. The advantage of the hybrid over the Acala parent in cumulative numbers of flowers in the nursery plantings is shown in Figure 26. Total dry weight per plant, and dry weights of dissected shoot parts (Table B5) were significantly higher in the hybrid than in the other varieties at all temperatures. Associated with this, the hybrid plants had significantly large roots than did either of the parents. However, the dry weights of fine roots of all three varieties were about the same at the three lower temperatures. Apparently the growth rate of root tips is more sensitive to temperature than the thickening process of the taproots and the woody branches. The temperature regime (20/11 C) was suboptimal and there was greater variation among plants in a row. We believe that the failure to find significant differences among varieties at the low temperatures is because the plants were not old enough in those chambers at harvest time for the differences to be manifested. Lack of significance was also due to the increase of variation among plants of the same variety. More than that, it seems as though there was a specific 'chilling' effect due to continuous suboptimal temperature at the seedling stage. Differences between plant growth at optimal daily temperatures (28-32 C) and at suboptimal regimes were too large to be explained as simple temperature effects. Complete interpretation must await further analysis with the model (see also Figures B23-B25).

Perhaps the most outstanding examples of hybrid vigor were in the process of leaf growth. Figures B28 and B29 contain leaf area and leaf dry weight data from the two experiments. Mean separation test results (SNK)

Fig. B23 Height growth rates of Acala SJ2 at five temperature regimes. □ unit #2, 20/11C; + unit #3, 24/14C; ○ unit #8, 28/17C; Δ unit #9, 32/20C; X unit #10, 36/23C. A. Experiment #1. B. Experiment #2.

Fig. B24. Height growth rates of R-142 at five temperature regimes. Legend as in Fig. B23.

Fig. B25. Height growth rates of Hybrid 182 at five temperature regimes. Legend as in Fig. B23.

Accumulation of flowers in chamber

Fig. B26. Cumulative number of flowers, per plant, in the nursery. □ Acala SJ2; + R142; ◇ Hybrid 182.

RATIO PETIOLE/LEAF

Fig. B27. Petiole/leaf ratio of Hybrid 182, under stressed (□ , unit #1) and non-stressed (+ , unit #4) conditions.

Table B4. Plant height, mainstem node number, leaf data, and number of fruiting parts per plant in hybrid plants and their parental cultivars. The first experiment was harvested at the age of 76 days, and the second one at the age of 57 days. The plants were grown in five temperature regimes (chambers No. 2, 3, 8, 9, and 10). Means are given of 4 and 5 replications in exp.1 and 2, respectively. Means in the same column, within each temperature regime, not followed by the same letter differ at the 0.05 probability level as determined by the SNK range test.

Variety	Height cm	Node number	Leaf number	Total leaf area (cm ²)	Average area per leaf	Square number	Small boll number	Large boll number

experiment 1a								

20/11 C								
Acala SJ2	56.0c	11.3b	31.0a	1994b	65.1b	14.0a	0.0	0.0
R-142	85.5b	13.5a	46.0a	2960b	62.9b	26.8a	0.0	0.0
Hybrid 182	109.5a	14.0a	56.2a	5816a	103.9a	33.5a	0.0	0.0
24/14 C								
Acala SJ2	88.0c	12.8b	42.2b	3596b	83.9b	19.0b	0.0a	0.0
R-142	100.3b	15.0a	50.7b	3508b	70.0b	37.8ab	0.0a	0.0
Hybrid 182	140.5a	17.0a	89.7a	11183a	124.2a	56.5a	0.3a	0.0
28/17 C								
Acala SJ2	104.0b	16.3b	52.5a	5563b	105.8b	25.5a	0.3a	0.0
R-142	98.7b	17.3ab	59.2a	4512b	75.3c	46.0a	0.0a	0.0
Hybrid 182	144.2a	19.0a	67.5a	10165a	150.6a	46.0a	1.3a	0.0
32/20 C								
Acala SJ2	134.7b	19.8b	60.5a	7374ab	121.2b	34.8a	5.8a	1.7b
R-142	137.7b	22.3a	67.5a	5830b	88.3c	42.8a	6.5a	2.5b
Hybrid 182	154.0a	21.5ab	65.0a	9435a	146.7a	33.8a	5.8a	4.0a
36/23 C								
Acala SJ2	139.7b	21.8b	63.7a	7309b	115.2b	36.2a	2.0a	0.0
R-142	112.0c	21.8b	52.2a	5374b	103.1b	30.0a	1.0a	0.0
Hybrid 182	150.5a	24.5a	79.0a	11186a	143.0a	44.5a	2.5a	0.0
LSD(0.05)	11.1	2.2	24.2	2665	17.9	25.1	2.3	1.3

Table B4. (continued)

Variety	Height (cm)	Node number	Leaf number	Total leaf area (cm ²)	Average area per leaf	Square number	Small boll number	Large boll number

experiment 1b								

20/11 C								
Acala SJ2	18.0c	6.2b	13.0b	371a	30.1b	0.0a	0.0	0.0
R-142	30.4b	7.6ab	16.2b	497a	32.1b	1.0a	0.0	0.0
Hybrid 182	57.4a	9.0a	30.6a	1564a	51.7a	6.0a	0.0	0.0
24/14 C								
Acala SJ2	29.2b	9.0b	20.6a	787a	38.2b	5.0a	0.0	0.0
R-142	51.4a	10.0ab	26.0a	931a	35.4b	11.2a	0.0	0.0
Hybrid 182	60.0a	11.0a	32.6a	1983a	58.9a	12.0a	0.0	0.0
28/17 C								
Acala SJ2	106.4c	14.8b	40.0b	3669b	91.0b	21.4c	1.4a	0.0
R-142	125.2b	17.2a	50.2ab	3362b	66.9c	48.2a	1.0a	0.0
Hybrid 182	141.6a	17.2a	61.2a	6883a	111.1a	38.2b	3.2a	0.0
32/20 C								
Acala SJ2	100.2b	15.4b	41.0b	3352b	82.3b	21.8b	4.8b	1.0b
R-142	91.0b	12.8c	32.6b	1737c	53.5c	11.8c	6.6b	0.8b
Hybrid 182	142.8a	18.0a	58.4a	7049a	121.6a	32.0a	10.0a	2.6a
36/23 C								
Acala SJ2	139.8a	18.0a	58.6a	4635b	79.9b	29.6a	2.8b	0.0
R-142	120.0b	19.2a	60.0a	3490b	58.4c	23.8a	12.4a	0.0
Hybrid 182	148.8a	19.0a	65.6a	7332a	110.0a	32.0a	4.8b	0.0
LSD (0.05)	9.9	1.5	15.0	1599	12.6	9.2	2.4	0.5

Table B5. The ratio of petiole to whole leaf dry weight and dry weight of plant parts and the whole plant, in hybrid plants and their parental cultivars. The first experiment was harvested at the age of 76 days, and the second one at the age of 57 days. The plants were grown in five temperature regimes (chambers No. 2, 3, 8, 9, and 10). Means are given of 4 and 5 replications in exp.1 and 2, respectively. Means in the same column, within each temperature regime, not followed by the same letter differ at the 0.05 probability level as determined by the SNK range test.

	Petiole ratio %	Dry weight, g per plant						
		Leaf	Stem	Large roots	Small roots	Total roots	Fruit	Total plant
----- experiment 1a -----								
20/11 C								
Acala SJ2	15.6a	15.3b	6.5a	2.8b	2.2a	5.0a	0.4a	27.2b
R-142	9.8c	23.1b	16.0a	3.5b	1.3a	4.8a	1.1a	45.0ab
Hybrid 182	12.7b	42.9a	23.7a	7.9a	2.3a	10.2a	1.7a	78.5a
24/14 C								
Acala SJ2	17.5a	21.1b	15.3b	4.8b	2.3a	7.1b	0.6a	44.1b
R-142	11.5c	23.4b	15.8b	3.9b	1.3a	5.1b	1.8a	46.1b
Hybrid 182	14.1b	67.3a	63.8a	13.4a	2.3a	15.7a	4.0a	150.7a
28/17 C								
Acala SJ2	20.3a	32.4b	20.7b	5.9b	4.0a	9.9a	1.8a	64.8b
R-142	11.8c	27.5b	16.5b	4.3b	1.7a	6.0a	2.2a	52.2b
Hybrid 182	17.4b	56.6a	43.6a	10.3a	1.9a	12.2a	4.5a	116.9a
32/20 C								
Acala SJ2	20.7a	42.4a	31.4a	8.9b	6.9c	15.8c	5.6a	95.3b
R-142	13.8c	33.1a	35.5a	8.3b	16.4b	24.7b	6.9a	100.3b
Hybrid 182	18.8b	55.1a	48.8a	12.8a	21.2a	34.0a	8.7a	146.5a
36/23 C								
Acala SJ2	21.1a	45.4b	47.7a	9.1b	8.1a	17.2b	3.7a	114.0b
R-142	14.8c	34.2b	24.7b	8.1b	5.5a	13.6b	2.8a	75.2b
Hybrid 182	18.6b	65.9a	61.9a	17.3a	7.9a	25.1a	4.3a	157.2a
LSD(0.05)	1.8	19.5	19.3	3.7	3.4	5.7	3.2	43.6

Table B5. (continued)

	Petiole ratio	Dry weight, g per plant						
	%	Leaf	Stem	Large roots	Small roots	Total roots	Fruit	Total plant
experiment 1b								
20/11 C								
Acala SJ2	13.8a	2.2a	0.7a	0.9a	1.0a	1.8a	0.0a	4.7a
R-142	10.7b	2.7a	0.9a	0.8a	1.1a	1.9a	0.0a	5.5a
Hybrid 182	9.7b	7.0a	3.5a	2.6a	0.7a	3.3a	0.1a	13.9a
24/14 C								
Acala SJ2	12.9a	3.9a	1.5a	1.7a	1.0a	2.7a	0.1a	8.2a
R-142	5.9b	4.5a	2.1a	1.3a	0.8a	2.1a	0.2a	8.9a
Hybrid 182	14.3a	9.1a	4.1a	2.6a	1.0a	3.6a	0.3a	17.0a
28/17 C								
Acala SJ2	22.1a	15.9b	11.2b	5.9b	2.3ab	8.2b	1.3b	36.6b
R-142	11.9c	15.7b	13.9b	4.3b	1.6b	5.9b	2.2ab	37.8b
Hybrid 182	16.7b	28.2a	25.7a	9.2a	3.2a	12.5a	2.9a	69.3a
32/20 C								
Acala SJ2	21.6a	14.6b	9.4b	5.6b	4.0b	9.6b	2.0b	35.6b
R-142	13.9c	7.5c	5.8b	3.5c	4.0b	7.5b	1.7b	22.5b
Hybrid 182	19.0b	29.3a	29.7a	9.3a	11.1a	20.4a	6.4a	85.8a
36/23 C								
Acala SJ2	22.8a	20.2b	20.0b	7.2b	6.6ab	13.8b	1.5b	55.6b
R-142	14.9c	14.1c	15.7b	4.6c	5.6b	10.2c	2.1ab	42.0b
Hybrid 182	19.7b	26.0a	30.5a	9.8a	7.6a	17.4a	3.0a	76.9a
LSD(0.05)	2.5	6.0	6.9	1.8	1.2	2.9	1.2	16.5

Fig. B28. Leaf area, cm² per leaf, of three cultivars at five temperature regimes. A - 1st experiment, harvested 13 August 1984. B - 2nd experiment, harvested 23 October 1984.

Fig. B29. Leaf dry weight, g per leaf, of three cultivars at five temperature regimes. A - 1st experiment, harvested 13 August 1984. B - 2nd experiment, harvested 23 October 1984.

are represented in the letters above the bars. The petiole ratio (Table B5), i.e., the proportion of petiole dry weight to the dry weight of the whole leaf, is a typical character of the species. Leaves of Acala varieties were upright on long petioles, whereas leaves of Pima varieties were dependent on short petioles. The result of these morphological differences was that Acala leaves had much higher petiole ratios than Pima leaves. The petiole ratio of hybrid plants appeared to be closer to their Acala parent than the Pima. The three varieties were significantly different in their petiole ratio in all temperature regimes. However, the petiole ratios were smaller at the lower temperatures in all the varieties. When cotton plants were grown in higher temperatures (up to 32 C) their petiole growth rates were increased more than their leaf blade growth rates. The additional petiole growth was most impressive in Acala and hybrid plants. When daily temperature changed from 20 to 28 C, there was additional petiole growth of about 50%, compared to the leaf blade growth at that temperature gradient).

4) Flowering and early fruiting.

The flowering curves of plants in units #5, #6, and #7 (Figure B26), and number of fruit in the harvested plants from the SPAR units (Table B4), show the early initiation of fruiting in the hybrid plants. During the first 30 days of bloom the accumulative number of flowers in the SPAR units was 126, 322, and 200 per m² for Acala SJ2, R-142, and Hybrid 182, respectively.

In general, Pima plants hold their square stronger than Acala plants. Square retention in the hybrid appear to be intermediate between its parents, and the flowering rate of the hybrid was also intermediate between that of its parents.

5) Responses to water stress.

Potted Acala plants were grown under a mild water stress for a period of seven weeks (plant ages 46 to 90 days). The major effect of this stress was a reduced vegetative growth rate (Table B6). The stressed plants were smaller in height and had reduced numbers of nodes and smaller leaves. Many leaves were senesced and shed as a result of that mild stress. However, new leaves grew smaller and, surprisingly, with much smaller petioles (see Figure B27). When the plants were transferred to SPAR units they had 15 nodes. The petiole ratio of fully expanded leaves (20 - 24 days from unfolding stage, fourth node from the apex) of well irrigated hybrid plants remain constant (about 17% from whole leaf dry weight). However, the water-stressed plants continuously reduced their petiole ratio from 17% to 9%. Dry matter accretion in the petiole was much more affected than in the leaf blade. The reduction of petiole size as a results of water stress is another indication to the role of petiole as "carbohydrate storage organs".

Apparently change in assimilate partitioning occurred in water- stressed plants. Roots continued to grow (both large and fine roots, see Table B6) under water stress. And formation of new leaves to replace the shedded ones was crucial to plant survival, so the plant adjustment to stress was to produce thinner leaf blades on smaller petioles. When the water-stressed plants were harvested they had about half the leaf area of the control plants.

Table B6. Plant characteristics of stressed and unstressed plants of Hybrid 182, grown in pots and transferred to SPAR chambers at age 46 day. Means of 10 plants, harvested at age 90 days.

Character Stress	Hybrid 182		Percentage of Stress Plants from No Stress Plants
	<u>Stressed (#1)</u>	<u>No Stress (#4)</u>	
	Mean (S.E)	Mean (S.E.)	
Plant height, cm	98.3 (1.7)	146.9 (1.2)	66.9
Number of nodes	17.5 (0.3)	21.5 (0.2)	81.4
Number of leaves	44.7 (1.1)	77.4 (2.2)	57.8
Leaf area index	4.0 (0.1)	7.9 (0.1)	50.6
Number of squares	7.7 (0.7)	37.4 (3.0)	20.6
Number of small bolls	0.9 (0.5)	5.4 (0.7)	16.7
Number of large bolls	12.8 (0.5)	13.4 (0.7)	95.5
Stem dry weight, g	33.5 (1.1)	50.7 (1.6)	66.1
Large roots dw, g	15.9 (0.4)	13.5 (0.5)	117.8
Small root dw, g	10.2 (0.7)	9.4 (0.6)	108.5
Large bolls dw, g	34.6 (2.0)	27.6 (1.5)	125.4
Total shoot dw, g	100.3 (1.4)	136.6 (1.8)	73.4
Total root dw, g	26.1 (1.0)	23.0 (0.9)	113.5
Shoot / root ratio	3.9 (0.2)	6.0 (0.2)	65.0

Table B6a. Plant characteristics of stressed and unstressed plants of Acala SJ-2, grown in pots and transferred to SPAR chambers at age 93 day. Means of 10 plants, harvested at age 108 days.

Character	Acala SJ-2		Percentage of Stress Plants From No Stress Plants
	<u>Stressed (#1)</u>	<u>No Stress (#4)</u>	
	Mean (S.E)	Mean (S.E.)	
Plant height, cm	165.9 (5.5)	161.1 (4.3)	103.0
Number of nodes	22.6 (0.4)	22.8 (0.4)	99.1
Number of leaves	62.1 (1.5)	67.9 (3.8)	91.5
Leaf area index	6.7 (0.3)	8.2 (0.3)	81.7
Number of squares	9.6 (1.4)	13.4 (1.5)	71.6
Number of small bolls	1.7 (0.7)	1.7 (0.6)	100.0
Number of large bolls	8.5 (0.8)	8.4 (0.6)	101.2
Stem dry weight, g	60.3 (3.7)	64.4 (3.1)	93.6
Large roots dw, g	11.3 (0.6)	11.7 (0.5)	96.6
Small root dw, g	6.6 (0.6)	8.4 (0.7)	78.6
Large bolls dw, g	46.3 (5.0)	40.9 (4.1)	113.2
Total shoot dw, g	100.0 (3.8)	111.7 (3.5)	89.5
Total root dw, g	17.9 (0.9)	20.1 (0.8)	89.1
Shoot / root ratio	5.6 (0.2)	5.6 (0.2)	100.0

Although the unstressed plants continued to produce squares for a longer period of time, the final number of large bolls was about the same in the two treatments. Dry weight of the shoot was significantly reduced by water stress, but dry weights of roots and of large bolls were slightly greater in the stressed plants. The shoot dry weight reduction was greater in the hybrid than in the Acala parent.

In a similar experiment with Acala SJ-2, these responses (Table B6a) were much less noticeable. The main difference between the two consecutive experiments was plant age. Acala plants were transferred to the SPAR units at age of 93 days and they were in midbloom. The growth of non-stressed plants was reduced because of their boll load so there was not much difference in vegetative parameters (plant height, mainstem nodes, leaf area) between the treatments (see Table B6a).

6) Canopy Photosynthesis.

Canopy apparent photosynthesis was measured every fifteen minutes in the three SPAR units containing the Acala and Pima parents and the hybrid. Dark respiration was measured four times via a closed system technique immediately after sunset each day. Daytime temperature was maintained during those measurements. The apparent photosynthesis data for each day were fitted to quadratic equations on light intensity. These equations were then solved for daily apparent photosynthesis values at 700 w m⁻² average dark respiration value for the day was added to obtain an approximation of gross photosynthesis (P700). Those values are presented in Figure B30. The mean P700 values were analyzed via the SAS general linear model procedure. The results are presented in Tables B7 and B8. Table B7 contains the equations of the lines describing P700 vs. days from emergence for the three cultivars (TRT). At the outset of the measurement period the hybrid was more efficient than the Acala parent. P700 values for the Acala improved over the course of the experiment, but remained constant in the Pima and in the hybrid. Table B8 indicates that the Pima parent was, on the average, about 30 percent less efficient than the Acala parent or the hybrid. On the average, over the course of the experiment, there was not a significant difference in photosynthetic efficiency between the hybrid and the Acala parent. The fact that the hybrid did not exhibit greater photosynthetic efficiency than the Acala parent shows that the higher dry matter yield in the hybrid is due to more vigorous seedling growth (greater internode expansion and leaf area expansion) and greater light capture. On the other hand, the marked inferiority of the Pima parent suggests that (at least between species) it may be possible to select for photosynthetic efficiency. Such differences in cotton are rarely reported in the literature.

Figure 30. Time course of photosynthetic rates at .700 w/m² for the interspecific cotton hybrid and its parameters

Table B7. Linear regression analysis of P700 vs. days from emergence.

Parameter		Estimate	t for HO: Parameter=0	PR > T	Standard Error of Estimate
TRT Acala	1	0.982	16.20	0.0001	0.0606
PIMA	2	0.852	14.71	0.0001	0.0589
Hybrid	3	1.202	20.72	0.0001	0.0580
DAY*TRT	1	0.010	3.45	0.0010	0.0031
	2	0.003	1.10	0.2731	0.0029
	3	0.002	0.67	0.5066	0.0029

Table B8. General linear models procedure.

TRT	P700 LSM*	Std. Error LSM	Prob > T HO:LSM=0	Prob > T I/J	HO: LSM(I)=LSM(J) 1 2 3
Acala 1	1.1606	0.0327	0.0	AC1	0.0001 0.1028
Pima 2	0.9058	0.0308	0.0	PI2	0.0001 0.0001
Hybrid 3	1.2358	0.0307	0.0	HY3	0.1028 0.0001

*LSM = Least Significant Means.

C. Experiments in New Mexico

Introduction

In 1926, a breeding program began with Acala cotton types at New Mexico State University in cooperation with the U. S. Department of Agriculture. Since 1930 more than twenty Acala- type varieties have been released, among them Acala 1517-75, which established a yield plateau that has not yet been significantly improved upon by conventional pure line varieties. The latest improvement in cotton has been an interspecific (Gossypium hirsutum x G. barbadense) hybrid released in 1979 under the name NX-1. This hybrid has yielded more than Acala 1517-75 on the average over six years at the Mesilla Valley .

Acala 1517-75 is a full-season variety with early fruiting and a slightly broader plant shape. It is susceptible to bacterial blight (Xanthomonas malvacearum) but it is highly tolerant to verticillium wilt (Verticillium dahliae), and it has an excellent fiber quality. NX-1 is an interspecific hybrid obtained by crossing the male sterile line 5-1E of Gossypium hirsutum L., and the fertile restorer strain E-1097-sel-OG. of G. barbadense L.

Materials and Methods

Hybrid NX-1 and Acala 1517-75 were planted in a split-split plot under a completely randomized block design on May 4, 1983, at the Plant Science Research Center of NMSU in Las Cruces, N.M. Two levels of irrigation (4 and 3 irrigations after planting) were randomized as whole plants, the two genotypes as sub-plots and three plant densities (40,000; 80,000; and 120,000 plants per hectare) as sub-sub plots. Two and three replications were used to study growth and yield respectively.

All plots were given a preplant irrigation on April 15. Four more irrigations were given to the plants with normal level of irrigation on June 16, July 13, July 29 and August 22. A reduced irrigation level had only three irrigations at the same schedule except that the irrigation of June 16 was eliminated. This meant that the first irrigation after planting was applied at 42 and 72 days for normal and reduced irrigations, respectively.

NX-1 and A-1517-75 were planted as sub-plots and in order to obtain the three plant densities of 40,000, 80,000 and 120,000 plants per hectare within each genotype, nine randomly scattered areas of $1m^2$ (1m length and 1m between rows) were thinned to get 4, 8, and 12 plants uniformly distributed along 1m row. Seven of the nine areas were successively harvested at selected intervals and the remaining two areas were used to study yields on a per plant and per unit of area basis. These seven dates were: June 29, July 11, July 25, August 8, August 22, September 13, and October 4 which corresponded to 55, 67, 81, 95, 109, 131, and 152 days after planting. The final harvest ($2m^2$) dedicated to study yield was made on 11 November, 190 days after planting.

On the seven growth sampling dates all plants within a $1m^2$ area were individually cut just below the cotyledonary node, and taken to the laboratory

where they were partitioned into the following fractions: the stem with branches, leaves, squares, flowers, immature bolls, and open bolls. These plant structures were first counted, then dried in order to determine dry weights. Leaf area was determined for each plant by using a LI-COR model LI-3000 portable leaf area meter with a transport belt conveyer accessory Model LI-3050A made by LI-COR, Inc., Lincoln, Nebraska.

To study yield, all the plants in two areas of 1m^2 were individually harvested boll by boll recording the yield of each boll and its position upon the plant. Seed cotton yield, lint yield and seed yield in grams per plant and in kilograms per hectare were determined.

From the data on plant partitioning, 38 variables were generated for growth analysis. For the analysis of yield, 9 variables were obtained after the final harvest.

Preliminary results of 6 of these 47 variables are presented here in terms of data per square meter. More extended treatment of the results will be published later.

Results and Conclusions

Detailed results of this experiment may be found in the Ph.D. thesis of C.G.S. Valdes-Lozano "Growth and yield response of a cotton hybrid (NX-1) and an upland cotton cultivar (Acala 1517-75) to plant densities and irrigations" (New Mexico State University, Las Cruces, New Mexico, July 1985). Numerical data, figures, and results of statistical analyses are given in this thesis.

Acala 1517-75 is a most appropriate check for this experiment. Nine years after its release it is still unchallenged as the leading commercial variety in the state. Of other leading cultivars tested only McNair 220 has consistently yielded more (2%) than Acala 1517-75 and McNair is decidedly inferior to Acala in fiber quality and market value. NX-1 has been compared to Acala 1517-75 in 55 tests covering a span of 7 years, and has out yielded it by 11.4% on the average (mean yields are 1188 kg/ha for NX-1 and 1065 kg/ha for Acala 1517-75).

In the present experiment both varieties exhibited typical developmental responses to the near ideal growing conditions (soil fertility, water and heat units) in 1983. The average lint yield of 2050 kg/ha made it the highest single test of the entire series and, therefore, an ideal environment for modeling. The Acala check cultivar actually out yielded the hybrid in this particular set of experiments by 4.8%. To place this performance in perspective, of 55 total comparisons, hybrid NX-1 has led in 41 tests; while Acala 1517-75 has led in 14, usually when there are near optimum conditions. Figure C1 shows that NX-1 matured more bolls/ m^2 but, since the Acala bolls are larger, the latter had a 2099 to 2002 kg/ha lint yield advantage. In point of fact, even Acala cultivars now long obsolete had the ability to deliver up to 2400 kg/ha lint under optimum conditions. Optimum conditions for Acala include an exceptionally long and hot growing season. Note that Acala 1517-75 lagged in total dry matter throughout the season until the very end (Figure C2). At this location, the large plant mass at the end of the season normally

Figure C1. Number of open bolls per m^2 for A-1517-75 and NX-1 in eight growth periods, planted at 12 plants/ m^2 . 1983.

Figure C2. Total dry weight in grams per m^2 for A-1517-75 and NX-1 in seven growth periods, planted at 12 plants/ m^2 . 1983

has negative value because of delayed immaturity. Hybrid NX-1 has been consistently superior when stress is a factor. The reasons why these two cultivars perform in this particular fashion is believed to be largely a function of early development which will be clearly illustrated by the studies here presented.

There were no significant differences in plant height between the two cultivars at any date of sampling during the course of the experiment. However, the hybrid was clearly superior in leaf area index (LAI) during early development (Figure C3). Plant density was a factor in LAI throughout with the 120,000 pl/ha densities having a higher LAI at all times with the single exception of the 109 day sampling. At 81 days after planting there was a significant interaction of genotypes x densities with the high density hybrid plots significantly greater than all check treatments.

The early advantage in light interception may lead to the NX-1 advantage in production of squares at 81 days (Figure C4) although the hybrid also carries qualitative genes for early bloom.

Early leaf and square production in the hybrid lead logically to an advantage in flower production, which is expressed at 95 days (Figure C5). It follows naturally that the hybrid would have an advantage in the immature boll fraction during the early fruiting period and this is indeed the case (Figure C6).

Table C1 shows that plant density is also a factor in early fruit development. The significant interaction of genotypes x density might be misleading if we looked no further than the analysis. Table C2 shows that the differences due to density were expressed completely within cultivars, as NX-1 is far superior to Acala in the elaboration of early bolls. It is this clear superiority in early fruit that probably gives the hybrid its edge in yield under stress conditions.

The effective fruiting period of the hybrid is extended considerably and, therefore, the ability to sustain damage is probably higher in the hybrid, hence its better response to stress. More importantly, the early fruiting response of the hybrid in high densities could lead to a new management system for cotton in New Mexico. Table C2 shows that, at 95 days, the high density planting of NX-1 had already elaborated over 10^6 bolls/ha. With an average size of 1.25g lint, this represents a potential yield of 1250 kg/ha already on the plant. High yield potential early in the season could open the way to short season management. Traditionally high yields have been associated with long seasons, but these data show that there may be an alternative high yield prospect through short-season, high density hybrid populations. Short season systems could stabilize higher yields since they would be less subject to adverse fall growing conditions.

The conclusions from these New Mexico studies are as follows:

NX-1 and Acala 1517-75 reduced plant height by elaborating fewer internodes as a result of plant density increases from 40,000 to 120,000 plants per ha.

Figure C3. Leaf area index for A-1517-75 and NX-1 in seven growth periods, planted at 12 plants/m². 1983.

Figure C4. Number of squares per m^2 for A-1517-75 and NX-1 in seven growth periods; planted at 12 plants/ m^2 . 1983.

Figure C5. Number of flowers per m^2 for A-a517-75 and NX-1 in seven growth periods, planted at 12 plants/ m^2 . 1983.

Table C1. mean squares for number of immature bolls per m² per sampling.

Sources	d.f.	Sampling (days after planting)				
		81	95	109	131	152
Replications	1	360.4	2420.04	280.17	130.67	30.37
Irrigations	1	51.0	1218.37	726.00	1734.00	12195.04
Error (a)	1	45.4	513.37	726.00	253.50	425.04
Genotypes	1	1552.0*	12105.04*	13066.67	12240.16	3775.04*
Irr. x Gen.	1	2.0	287.04	433.50	5162.67	2.04
Error (b)	2	20.5	162.20	1206.08	9802.08	90.20
Densities	2	155.8*	2119.54*	247.54	1393.16	833.62
Irr. x Dens.	2	52.8	60.87	326.62	261.50	1725.79
Gen. x Dens.	2	85.5*	543.04*	836.79	1508.15	406.79
Irr. x Gen. x Dens.	2	20.0	14.54	1168.87	155.15	506.79
Error (c)	8	13.46	90.08	419.95	1282.08	622.83
*Significant with an value = .05						
CV(a) = E(a)/bc/Y....		22.1	15.7	9.4	4.3	8.5
CV(b) = E(b)/c/Y.....		21.0	12.4	17.1	37.8	5.5
CV(c) = E(c)/Y.....		29.4	16.1	17.5	23.7	25.2
Y.....		12.46	59.04	116.92	151.08	99.12

Table C2. Protected LSD tests for immature bolls/m² in those samplings in which there were significant differences.

Treatment	Sampling 81 days	Treatment	Sampling 95 days
Genotype/Density		Genotype/Density	
NX-1/120,000	28.00 a	NX-1/120,000	103.00 a
NX-1/80,000	20.75 b	NX-1/80,000	85.50 b
NX-1/40,000	12.75 c	NX-1/40,000	56.00 c
A-1517-75/80,000	5.50 d	A-1517-75/80,000	44.50 cd
A-1517-75/120,000	5.00 d	A-1517-75/120,000	40.00 d
A-1517-75/40,000	2.75 d	A-1517-75/40,000	25.25 d
LSD (0.05)	6.0		15.5
Genotype		Sampling 152 days	
NX-1		111.67 a	
A-1517-75		86.58 b	
LSD (0.05)		16.7

Figure C6. Number of immature bolls per m^2 for A-1517-75 and NX-1 in seven growth periods. Planted at 12 plants/ m^2 . 1983.

NX-1 produces more leaf area than Acala 1517-75 early in the season because of a larger leaf size. These genotypes did not differ, however, in number of leaves per plant. Leaf area per plant was reduced by increasing plant density due to a reduction in the number of leaves per plant rather than a reduction in the size of the leaf.

Similar numbers of squares, flowers, immature bolls and open bolls per plant occurred earlier in NX-1 than in Acala 1517-75. Numbers of squares, flowers, immature bolls and open bolls per plant were reduced when plant density increased.

NX-1 has a higher potential than Acala 1517-75 to produce more open bolls per plant, but it is subject to proportionally greater reduction in boll load than Acala 1517-75 when plant density increases.

Reduction in one irrigation did not adversely affect the numbers of reproductive structures per plant.

Increasing plant densities reduced total plant dry weight by reducing the dry weight of vegetative and reproductive plant components.

NX-1 developed more total dry weight per plant than Acala 1517-75 during the first 95 days after planting, primarily because of a higher dry weight of leaves and squares rather than more dry weight of stem and branches per plant.

Early squaring, flowering and boll filling occurred in NX-1 at the expense of the dry weight accumulation in the stem and branches. This permitted an early boll opening.

As plant density increased, the number of leaves per m^2 increased and consequently leaf area index increased as well, in spite of a reduction in leaves per plant. NX-1 produced the highest LAI at 120,000 plants per ha at 81 days after planting.

NX-1 produced most squares, flowers, immature bolls and open bolls per m^2 . At 120,000 plants per ha, 81 and 95 days after planting, NX-1 attained the most immature bolls per m^2 , making it potentially earlier than Acala 1517-75.

Acala 1517-75 responded to the reduced irrigation treatment by producing more dry weight of stems and branches per plant and per m^2 than NX-1.

Leaf dry weight per m^2 was greatest in NX-1 early in the season and this difference was enhanced under reduced irrigations. This effect increased with plant density increases.

The production of dry weight of squares, flowers, and immature bolls per m^2 was greater and earlier in NX-1 at 120,000 plants per ha and three irrigations than in other treatments.

NX-1 maintained, at least up to 95 days after planting, a higher total dry weight per m^2 than Acala 1517-75 and this was enhanced, or at least ensured, by high plant densities and reduced irrigations.

The coincidence, in NX-1, of an early and well-developed photosynthetic apparatus, with an early and vigorous reproductive phase, partly explains why this genotype produced high numbers of immature bolls early in the season, and a high number of open bolls at harvest (per individual plant and per m²).

Yield per plant of NX-1 and Acala 1517-75 was not affected by the reduction of one irrigation under any of the plant densities studied.

Increased plant density reduced seed cotton yield per plant in both genotypes and this reduction was determined early in the season, by an initial reduction in squares during the first twelve weeks of growth.

NX-1 developed longer and stronger fiber than Acala 1517-75. These traits, as well as fiber percent, were not affected by plant densities and irrigations.

NX-1 averaged 4.3 more open bolls /plant than Acala 1517-75. However, seed cotton yield and its components per unit of area were not affected by genotypes, irrigations or plant densities.

Summary

The wide range of lint yields and quality values in the the experiments in Israel and the superior performance in the hybrid under temperature and water stress in Mississippi and New Mexico indicates that breeding efforts for general and specific combining ability to match the right hybrid to given environmental conditions should be profitable. It is hoped that the physiological data presented here, when incorporated in the model, will assist in that process.

The hybrids always emerged more quickly and their seedling growth was more rapid. This was more evident at lower temperatures. The hybrids exhibited greater ability to shift dry matter partitioning in response to water stress. Fruiting was earlier in the hybrids than in the Acala parents. More rapid stem internode elongation and leaf area expansion gave the hybrid the ability to capture more light during the vegetative growth period. This, and not a superior leaf photosynthetic efficiency explains the relative vigor and greater dry matter production of the cotton hybrid.

The experiments reported here have provided data for the developmental and organ growth rate functions needed to modify a physiological model to simulate hybrid cotton. No changes will be needed in the calculation of photosynthesis or respiration for the hybrid. However, photosynthesis will have to be reduced approximately 30 percent to simulate the Pima parents. The model will have to be modified to reflect differences in dry matter partitioning and fruit retention in response to stress.

Description of Cooperation

All the research activities have been jointly planned, and their implementation in both countries has been coordinated.

The results have been jointly evaluated and discussed, and the report has been written by all the cooperating investigators. Several visits have been made, by Dr. A. Marani to the U.S.A., and by Dr. D.N. Baker to Israel, to achieve this cooperation.

Evaluation of Research Achievements

(a) Scientific.

- The quantitative traits pertaining to yield and quality of interspecific hybrid cotton have been evaluated, and the interaction of these traits with environmental conditions have been defined.

- The necessary modifications of existing process - oriented cotton simulation models, in order to enable them to simulate interspecific hybrids have been defined.

- The breeding objectives of interspecific cotton hybrids, both for New Mexican and Israeli growing conditions, have been reevaluated.

(b) Agricultural and economical.

- The advantages of producing interspecific cotton hybrids have been evaluated. It has been concluded that these hybrids would be especially advantageous under conditions of cool temperatures during the beginning of the growing season, under adverse conditions of moisture stress, and in environments with a short growing season. The data base obtained in these studies will enable development of a physiological model of value in managing hybrid cotton crops.