Phenotype Modification in Cotton for Control of Verticillium Wilt Through Dense Plant Population Culture

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ABSTRACT

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The continuous threat to the cotton industry of California's San Joaquin Valley by Verticillium wilt is ultimately traceable to the long-practiced varietal monoculture of Acala cotton. A remedy is seen in genetic diversification of cultivars grown; this can be achieved by rotation with early-maturing, genetically distinct varieties that possess the highest possible wilt resistance and are adaptable to high-density planting. Two new cotton breeding lines developed for the San Joaquin Valley that meet these requirements are described. With their wilt resistance derived from *Gossypium barbadense* or a wild race of *G. hirsutum*, or both, their genetic backgrounds differ from that of the currently grown Acala SJ varieties. Their wilt resistance is optimized by their adaptability to high-density planting. Their early maturity and suitability for once-over harvesting by either stripper or spindle picker permit early shredding of stalks and early plow-down, factors favorable to containment of *Verticillium*. Yields and fiber qualities of the two breeding lines are competitive with those of current varieties.

Additional key words: Acala Cal-120, Acala Cal-150, earliness, Hopi cotton, immunity, One-Variety Cotton Law

Production of cotton (*Gossypium hirsutum* L.) in the San Joaquin Valley of California has long been limited by Verticillium wilt, caused by the micro-sclerotial form of *Verticillium albo-atrum* Reinke & Berth. (*V. dahliae* Kleb.). First noticed in 1927 near Bakersfield (8), the disease has become most severe in the northeastern portion of the valley. In this region, it is favored by large daily temperature fluctuations and by high inoculum levels that are most persistent in the heavy, most fertile soils (14). During the past 20 yr, cotton yields have declined substantially in the affected areas, which now make up about one-fifth of the valley's total cotton acreage. In Tulare County, for instance, the 10-yr average of per-acre yields for 1970–1980 (excluding 1978, an exceptionally wet year) was about 15% lower than that for 1956–1965 (3).

The major difficulty in controlling Verticillium wilt of cotton is without question the general absence of immunity to vascular infection of roots and stems. In our studies, the few cotton varieties and species that resisted foliar wilt symptoms under conditions of extremely heavy soil infestation all showed evidence of active vascular infection when cultured in the laboratory (15). Absence of immunity in cotton means that the resistance of a variety expressed under conditions of moderate soil infestation can break down in the presence of more severe infestations or in an environment more favorable to the pathogen than to the host. Absence of immunity also means that new, highly virulent *Verticillium* strains (assumed to be present in the environment) have an immediate selective advantage over less virulent strains and so pose a threat to the wilt resistance of any newly released variety. Hence, unless the resistance is supported by cultural measures that restrict the buildup of *Verticillium* inoculum, particularly to that of strains virulent to a new resistance, the absence of immunity eventually nullifies the so-called higher wilt tolerance achieved through breeding.

The cotton wilt problem in California has been seriously aggravated by the One-Variety Cotton Law, which mandated the exclusive cultivation (at any one time) of but one Acala variety that must have been derived by selection from the original Acala stock. Enacted in 1925 to ensure uniform quality and prevent mongrelization, this legislation has in effect forced a varietal monoculture on an average of about 1 million acres of cotton, forbad varietal development by hybridization, and thus promoted the increase and rapid spread of *Verticillium* strains pathogenic to the one variety (10). As a result, cotton cultivation in California became locked into a cycle of "boom and bust." Invariably, after a few years of initial success, each new variety showed wilt. Appearing first only in certain areas, the disease typically increased until the variety became unprofitable. For example, Acala 4-42, the first highly wilt-resistant cotton selected in California and initially planted valley-wide in 1949, declined severely from wilt within 12 yr. Acala SJ-1, developed by hybridization and released in 1967, had an even shorter useful life. Acala SJ-5, the variety designated for wilt-affected areas in 1977, is also extremely wilt-susceptible in some areas (7); Acala C-1, released in 1982 to replace Acala SJ-2, collapsed severely from wilt in our plots in 1983.

Objectives. Upon request from the California cotton industry, we began in 1965 to seek new ways to reduce the incidence of Verticillium wilt in the San Joaquin Valley. Our primary goal was to complement the Acala varieties with genetically distinct, wilt-resistant cottons of comparable quality that could be used effectively in a varietal rotation. The wilt resistance of such lines thus had to be derived from genetically useful sources outside the Acala background.

In addition, we aimed at adaptability to certain cultural measures known to check Verticillium wilt in cotton. Current Acala varieties and traditional growing practices are incompatible with these measures. Because of the nature of the Verticillium wilt fungus, particularly its inability to increase saprophytically in soil, we assumed that the inoculum potential per plant decreases proportionally to increasing plant density. Thus, within wilt-resistant materials, we selected for high yield under dense planting conditions. We also selected for early maturity. Because formation of *Verticillium* microsclerotia in the cotton stalk is favored by wet, cold weather, the common practice of leaving the stalks standing into late fall for a second picking is a major factor in the increase of wilt (4). Therefore, we assumed that if the stalks were shredded immediately after an early, once-over harvest and the shreddings dried on the soil surface within a few days, inoculum buildup would be greatly reduced. Thomas (13) showed this to be true.

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MATERIALS AND METHODS

Sources of resistance to Verticillium wilt. Among the New World tetraploid species of *Gossypium*, only a few forms possess substantial, heritable resistance to Verticillium wilt. In an exhaustive search for wilt resistance conducted between 1934 and 1953, G. J. Harrison, director of the U.S. Cotton Field Station at Shafter, CA, together with B. A. Rudolph, field-tested all available cotton varieties, whether or not they were commercial types. On the basis of lowest incidence of foliar wilt symptoms, they identified wilt resistance in three sources: *G. barbadense* L., represented by the Sea Island and Peruvian Tanguis forms; *G. hopi* Lewton, a land race of *G. hirsutum* L. represented by an American Indian cotton from Arizona; and the North Carolina Triple Hybrid 386, whose wilt resistance was attributed to *G. thurberi* Tod., a wild, diploid cotton of Arizona. None of the many varieties tested was immune to infection by *Verticillium* (G. J. Harrison and B. A. Rudolph, *unpublished*).

Forms of *G. barbadense* and of races of *G. hirsutum* are still the main sources of resistance to Verticillium wilt used in breeding. Under field conditions in the wilt-affected areas of the San Joaquin Valley, resistant *G. barbadense* plants typically recover permanently from early-season stem-vascular infection and prevent access of the pathogen to the leaves (15); some resistant wild races of *G. hirsutum* tend to resist defoliation in spite of leaf infection (16).

Evaluation of resistance. The new varieties described carry resistance from one or both of the sources mentioned. By methods already described (15), we tested more than 300 acquisitions of *Gossypium* species and varietal lines from worldwide sources, as well as progenies of more than 1,500 original crosses, for wilt resistance in the field. New seed acquisitions and F_1 plants were started in peat pots and transplanted to the field at a spacing of about 45 cm in the row. To assess the nature of the wilt resistance present, we scored each of these plants by repeated rating of foliar symptoms, by repeated culturing of mature leaf petioles in the laboratory, and by rating of vascular discoloration at the end of the season. Subsequent progenies were planted in 15-m rows at a density of 15–20 plants per meter. Selection for high wilt resistance was based on the performance of individual plants and on progenies as a whole. We also selected for prompt germination and rapid seedling growth, characters that often contribute to early maturity. Progeny selection for several years was followed by further evaluation of the lines under conditions of high-density planting in blocks of up to 0.1 ha with row spacing of 97 cm. Yield and fiber data were derived from subsequent field trials in cooperation with commercial growers, preferably in locations known to be wilt-affected.

Fig. 1. Portion of 80 acres (32.4 ha) of Acala Cal-120, Fresno County; two rows per bed, beds 38 in. (97 cm) center to center, planted 14 April 1980, with 22 lb of seed per acre (24.6 kg/ha), harvested by finger stripper 9 October. Note the absence of unopened bolls and ungathered lint in harvested rows.

Origins of new breeding lines (Acala Cal-120). The breeding line Acala Cal-120 resulted from a cross we made in 1966 between the early-maturing, fine-fibered Upland variety Acala-Hopi-Acala 6-1-5 (AHA 6-1-5) and the old, highly wilt-resistant variety Seabrook 12-B-2 (*G. barbadense*); seed of both was supplied by John Turner, director of the U.S. Cotton Field Station at Shafter, CA.

After growing the F_1 during the winter in the greenhouse, we transplanted 27 F_2 seedlings to the wilt nursery in 1967. Four critical scorings at approximately monthly intervals showed the plants free of foliar wilt symptoms, except for occasional lower-leaf dehiscence. Petiole cultures indicated vascular infection by *Verticillium* in 16 of the 27 plants on 13 June, in none on 18 July and 8 August, and in 4 on 5 September. The quick recovery of the young plants from mild, early-season infection and their freedom of symptoms thereafter were similar to the performance of the male parent, Seabrook 12-B-2; this reaction suggests that in the early growth phases, resistance to leaf infection is not fully developed.

At maturity, all plants showed vascular discoloration at the base of the stem, and without exception their lower stem xylem yielded *Verticillium* in laboratory culture. In all plants but one, vascular discoloration extended into the stem apex, and laboratory cultures from these plant portions likewise were positive. Before a killing frost on 5 December, a total of 19 plants had matured some bolls, with the number of seeds produced by each plant ranging from seven to 189; the remaining eight plants were barren.

Progeny row selection among F_3 to F_{10} of this hybrid conducted in the wilt nursery between 1968 and 1975 resulted in an advanced line that became Acala Cal-120. Phenotypically, the breeding line is an Upland type, but its wilt resistance, in the limited areas where it was grown in dense plantings, has been superior to that of any Upland cotton we have studied.

Acala Cal-120 was tested for 5 yr on wilt-infested land in blocks of up to 20 ha that were seeded at a rate of 22–24 kg/ha in either single or double rows per 97-cm bed and received only two or three irrigations per season. The breeding line matures uniformly and fully within 165–180 days of planting and is thus ideally suited to once-over harvesting. The finger-stripper harvester used in our tests readily snaps the bolls from the fine pedicels, leaving less than 1% of the cotton in the field (Fig. 1). Average lint yields have considerably exceeded the best yields of Acala SJ varieties that were grown nearby or even on land not infested with *Verticillium*.

Origin of the Upland component of Acala Cal-120. Part of the outstanding wilt resistance of Acala Cal-120 may have been derived from its female parent, Acala-Hopi-Acala 6-1-5. This variety, we believe, descended from a cross that G. J. Harrison made early in his research between an Acala × Hopi hybrid and an Acala line. Although the identity of these parents is uncertain, Harrison (*unpublished*) did refer to a cross fitting this general description, namely (F_7 Arizona Queen Creek Acala × Moenkopi Hopi) ×Acala 1517-5-12. He mentioned selection through 12 generations of progenies from this cross and reported that entire rows of the derivative line Hopi Acala 50 showed only traces of wilt. It is thus possible that Hopi Acala 50 was an ancestor of AHA 6-1-5. Hopi cotton, first described by Lewton (9) as *G. hopi* but now considered by Haley (5) to be *G. hirsutum* race *punctatum* Hutch., was long cultivated by the Hopi Indians of Arizona.

Acala Cal-150. The breeding line Acala Cal-150 is derived from our complex hybrid ([Yugoslav *G. hirsutum* × Acala 4-42] × Paymaster 909), × Russian Upland line 4727-S. In 1967, we made the Yugoslav × Acala cross to introduce earliness into the Acala 4-42 background. Of 18 F_1 individuals in the wilt nursery in 1968, 17 developed severe foliar symptoms of wilt and six died before maturity. One outstanding plant, however, showed only mild foliar symptoms and matured large Acala 4-42-type bolls. Selection and row testing for 3 yr within the progeny of that

Table 1. Fiber qualities[a] of densely planted new cotton lines harvested once-over with a finger-stripper harvester in Fresno County, CA

		Fibrograph length			
Year	Test cotton	2.5% Span (in.)	Uniformity (ratio-percent)	Strength (MPSI)	Micronaire reading (MIC)
1977	Acala Cal-120	1.14	43	92.1	3.8
		1.12	42	95.0	3.9
1978	Acala Cal-120	1.03	44	97.6	4.6
	Acala Cal-150	1.06	48	93.4	4.4
1979	Acala Cal-150	1.08	44	96.6	4.6
		1.12	38	99.9	4.6
1980	Acala Cal-120	1.07	43	98.3	4.7
		1.05	43	97.4	4.4
		1.08	43	97.4	4.4
	Acala Cal-150	1.15	43	98.3	4.2
1981	Acala Cal-120	1.08	42	99.0	4.0
	Acala Cal-150	1.07	44	98.0	4.6

[a] Fiber quality determinations by Cal-Cot, Bakersfield, CA.

Table 2. First-pick fiber quality values[a] from approved cotton varieties (A) and experimental lines (E) grown conventionally and harvested by spindle picker in 1982

	Fibrograph length						
Cotton designation	2.5% Span (in.)	50% Span (in.)	Uniformity (ratio-percent)	Strength (T1)	Elongation (E1)	Micronaire reading (MIC)	Yarn tenacity (YTEN)
Acala SJ-2 (A)	1.13	0.54	47.6	23.1	8.2	4.14	14.8
Acala SJ-5 (A)	1.13	0.54	47.4	24.6	7.8	4.15	15.5
Acala C-1 (A)	1.13	0.55	48.6	25.5	8.3	4.22	16.1
CPCSD C-11	1.13	0.55	48.9	24.8	8.3	4.06	15.5
CPCSD C-13	1.16	0.55	47.0	24.1	8.1	4.03	15.8
GC-510 (E)	1.13	0.55	48.8	25.1	8.1	4.24	16.1
GC-555 (E)	1.14	0.55	47.7	24.6	8.3	4.16	15.8
Acala Cal-150 (E)	1.14	0.53	46.6	22.0	8.3	3.89	14.4
LSD 0.05	0.02	0.01	0.9	0.7	0.3	0.12	0.3
C.V. (%)	1.40	2.60	2.0	2.9	4.9	4.00	2.6

[a] Values represent averages of eight cottons harvested from eight locations: Buttonwillow, Wasco, Earlimart, Woodville, University of California West Side Field Station, Cantua Creek, Kerman, and El Nido.

Table 3. First-pick lint yields and fiber properties[a,b] of approved cotton varieties (A) and experimental lines (E) grown conventionally in 38-in. rows in 1980 and in 30-in. rows in 1981 and harvested by spindle picker[c]

	Yield			Fibrograph length					
Cotton variety	Lint (lb/acre)	Lint (%)	Gin loss (%)	2.5% Span (in.)	50% Span (in.)	Uniformity	Strength (T1)	Elongation (E1)	Micronaire reading (MIC)
				1980					
Acala SJ-2 (A)	736	36.0	8.0	1.12	0.51	45	21.7	8.0	3.13
Acala SJ-5 (A)	715	37.0	7.0	1.13	0.50	44	20.1	8.2	3.24
Acala 4-42 (A)	588	36.0	9.0	1.13	0.53	47	23.8	8.2	3.49
Acala Cal-150 (E)	686	33.0	10.0	1.15	0.53	46	24.4	8.1	3.52
C.V. (%)	9.40	1.96	9.94	3.82	6.13	3.54	9.47	8.97	7.33
LSD 0.05	89.1	1.03	1.2	0.06	NS	NS	NS	NS	0.35
				1981					
Acala SJ-2 (A)	847	37.7	11.0	1.11	0.50	45	23.9	7.7	4.44
Acala SJ-5 (A)	776	38.4	9.8	1.13	0.53	48	25.4	7.8	4.34
Acala 4-42 (A)	880	37.5	10.2	1.08	0.48	44	22.3	7.8	4.27
Acala Cal-150 (E)	926	35.1	11.0	1.13	0.50	44	21.0	7.6	4.44
Acala Cal-120 (E)	884	36.4	11.4	1.13	0.50	45	21.8	8.0	4.33
C.V. (%)	14.41	2.65	16.8	2.48	3.81	3.11	5.91	6.22	3.39
LSD 0.05	167	1.40	2.9	0.04	0.03	2.00	1.95	NS	0.21

[a] Plots were 400 ft × four rows (four replicates).
[b] Statistical analyses were based on data from nine cottons in the 1980 tests and 14 in the 1981 tests.
[c] Data from William L. Weir, Merced Co.

Fig. 2. Portion of 50 acres (20.2 ha) of Acala Cal-150 growing in Fresno County; two rows per bed, beds 38 in. (97 cm) center to center, planted 19 April 1978 with 22 lb of seed per acre (24.6 kg/ha), ready for once-over finger-stripper harvest 1 November. The 1978 cotton harvest season was very wet from heavy rains; the normal harvest season for Acala Cal-150 is 25 September to 15 October.

plant resulted in an early-maturing, moderately wilt-resistant line.

In 1971, that line was crossed with a selection of commercial Paymaster 909 that had survived a *Verticillium*-inoculation-box test in the greenhouse (15) and had appeared to be more wilt-resistant than the other Paymaster 909 plants tested. Seed for this test had been supplied by D. C. Hess. Of the 41 F_1 individuals of the resulting hybrid, grown in the wilt nursery in 1972, 40 were free of foliar wilt symptoms on 28 June (the only scoring date of that year). Of 40 progenies grown in 1973, two were selected in their entirety for superior uniformity, earliness, and yield. A single-plant selection from these was then crossed with the Russian Upland line 4727-S, which in our tests had shown exceptional earliness though coupled with susceptibility to wilt. Of the 12 F_1 individuals of that hybrid planted in the wilt nursery in 1975, six developed slight and six developed moderate foliar wilt symptoms; all matured large, full bolls of long, strong fiber. A bulk selection comprising seed from the earliest-maturing plants with the highest wilt resistance of the group became the line that is now Acala Cal-150; it has been subjected to annual testing in blocks of up to 25 ha in various wilt-infested locations from 1976 to 1983.

Fig. 3. Portions of field test in dense plant stands. **(Left)** Verticillium wilt-susceptible standard Soviet line C 1211, and **(right)** wilt-resistant line J 5200, progenitor of Acala Cal-120 (16 July 1976). In contrast to severe defoliation and dieback of C 1211, J 5200 showed no wilt symptoms. Plants of J 5200 were tied upright to stakes to show canopy of healthy leaves and full load of green bolls.

RESULTS

The work described resulted in two wilt-resistant breeding lines whose phenotypical characters permit their resistance to be optimized by dense planting. Their short fruiting sympodia typically bear one to three bolls each on delicate pedicels. Development of monopodial side branches is suppressed, particularly in dense plant stands. Under the load of the green bolls, the central axis may arch toward the ground but returns to a nearly upright position as bolls mature. Leaves are shiny and bright green, in contrast to the matte, bluish green leaves of Acala SJ cottons. Key fiber properties of the breeding stocks are on a par with Acala standards (Tables 1–3), and yields were competitive with the Acala SJ varieties (Tables 3 and 4). The names Acala Cal-120 and Acala Cal-150 designate these breeding stocks.

In 1980, 1981, and 1982, Acala Cal-120 and Acala Cal-150 were included in the official screening and varietal tests conducted throughout the San Joaquin Valley by the Department of Agronomy and Range Science, University of California, Davis. Grown in the traditional Acala manner (ie, in wide rows and with wide plant spacing in the row), many cottons were compared in the tests. Tests were not harvested or ginned commercially. Lint yields, fiber properties, and spinning qualities for those years have been published by the department. Even though the traditional culture (ie, widely spaced rows and wide plant spacing in the rows) violates our approach to the control of Verticillium wilt, and even if initially successful it simply perpetuates the "boom and bust" phenomenon, we have reproduced a small portion of the extensive data collected. They apply to Acala Cal-150 in 1982, when it was compared in official variety trials with approved varieties and experimental lines at eight San Joaquin Valley locations (Table 4). In the 1982 publication of the department, Acala Cal-120 (which appears only in the screening tests) is coded as SJV550, and Acala Cal-150, as SJV100 (2). In addition, though it was not our intention to compare our cottons with the approved Acala varieties, we include data from tests of William Weir, Merced Co., conducted during 1980 and 1981 (Table 3).

Table 4. First-pick lint yields (lb/acre) of approved cotton varieties (A) and experimental lines (E)[a] grown conventionally and harvested by spindle picker[b] in 1982

Cotton designation	San Joaquin Valley locations[c] 1	2	3	4	5	6	7	8	Mean
Acala SJ-2 (A)	1,399	1,470	924	1,136	1,359	1,500	1,365	1,268	1,302
Acala SJ-5 (A)	1,395	1,375	713	1,277	1,496	1,425	1,129	1,231	1,255
Acala C-1 (A)	1,470	1,457	709	1,270	1,584	1,459	1,172	1,248	1,296
CPCSD C-11 (E)	1,361	1,445	633	1,239	1,569	1,513	1,191	1,287	1,280
CPCSD C-13 (E)	1,440	1,485	829	1,362	1,598	1,446	1,079	1,286	1,316
GC-510 (E)	1,461	1,541	851	1,386	1,646	1,483	1,253	1,249	1,359
GC-555 (E)	1,419	1,505	750	1,360	1,615	1,443	1,098	1,253	1,305
Acala Cal-150 (E)	1,328	1,535	767	1,289	1,358	1,468	1,182	1,218	1,268
LSD 0.05	46	NS	72	54	60	NS	75	NS	NS
C.V. (%)	2.2	4.7	6.3	2.8	2.7	2.7	4.3	4.9	3.8

[a]Experimental lines for the test were supplied by cotton seed producing companies; Acala Cal-150, by ourselves.

[b]Tests were conducted by the Department of Agronomy, University of California, Davis, under supervision of the Acala Cotton Board.

[c]Locations: 1 = Buttonwillow, 2 = Wasco, 3 = Earlimart, 4 = Woodville, 5 = University of California West Side Field Station, 6 = Cantua Creek, 7 = Kerman, 8 = El Nido. Locations 4 and 5 were Verticillium wilt-infested.

In dense stands, Acala Cal-150 has an outstanding capacity to yield well on wilt-infested land. During the past 7 yr, experimental stands of about 250,000 plants per hectare, planted on heavily wilt-infested land in either one or two rows per 97-cm bed, consistently produced lint yields between 1.0 and 1.6 t/ha. With this extremely high plant population, plant spacing in a single row amounts to about 4 cm. Like Acala Cal-120, Acala Cal-150 matures for once-over harvesting, which may be either by stripper or spindle harvester, within 165–180 days of planting (Fig. 2).

Wilt reactions of Acala Cal-120 and a wilt-susceptible Upland cotton in dense stands. In a replicated test in 1976, we compared the wilt reactions of Acala Cal-120 with those of the highly wilt-susceptible Russian Upland line C 1211 in dense plant stands. Phenotypically the two lines were similar. They were planted in adjacent single rows spaced 97 cm apart on heavily wilt-infested land. The seeding rate of 24 kg/ha gave stands of about 247,000 plants per hectare. Acala Cal-120 grew to maturity without showing symptoms of wilt and produced a heavy crop, although the stem xylem of nearly every plant was discolored and yielded *Verticillium* in laboratory culture. C 1211, on the other hand, suffered extensive defoliation and terminal dieback of the main shoots, and many plants died before maturity (Fig. 3). There was no significant yield. This showed that dense planting may optimize wilt resistance but will not reduce the disease in highly susceptible varieties.

DISCUSSION

Of the four commercially grown cotton species, *G. hirsutum* (comprising all Upland varieties) is the most susceptible to Verticillium wilt. The preeminent position of this species in world commerce is maintained only by a continuous breeding effort, with wilt resistance one of its major goals.

Although some forms of *G. barbadense* possess superior wilt resistance, they are not generally used in breeding with Upland cottons because of the well-known appearance and often predominance of agronomically worthless traits in generations beyond F_1 (12). Using instead certain wilt-resistant wild and land races of *G. hirsutum* (6) has great potential. Although these forms are perennial and rank-growing, their genetic behavior permits ready transfer of valuable characters, which they may or may not display, to the Upland phenotype and facilitates selection away from unwanted traits. This form of transgressive segregation, discussed by Barker (1), is peculiar to cotton and depends, we believe, on the accumulation of recessive factors.

It is thus that the use of *G. hirsutum* race *punctatum* in Harrison's early breeding work brought wilt resistance, earliness, and fiber strength as prominent characters into the Acala-Hopi-Acala lines, although Hopi cotton itself displayed neither the trait of earliness nor that of fiber strength. Harrison (*personal communication*) had collected this cotton from an elevation higher than 6,000 feet (1,800 m) at Moenkopi near Flagstaff, AZ. In our line Acala Cal-120, the constitution of the Acala-Hopi-Acala parent probably facilitated the transfer of resistance factors from Seabrook 12-B-2 (*G. barbadense*) to the hybrid. The C6 cottons, another series of the AHA lines Harrison developed, provided the wilt-resistant ancestor of Acala SJ-3, Acala SJ-4, and Acala SJ-5.

The general hybrid constitution, Upland × *G. hirsutum* race *punctatum* × Upland, is also the basis of the varieties Tashkent-1, Tashkent-2, and Tashkent-3, developed in the 1960s in the Soviet Union for resistance to Verticillium wilt, and very likely that of at least 15 more recent Russian wilt-resistant lines (17). Russian authors have referred to the source of resistance in these varieties as *G. mexicanum* Tod., or *G. hirsutum* L. subsp. *mexicanum* (Tod.) Mauer var. *nervosum* (Watt) Mauer. According to the English system, this cotton is identical with *G. hirsutum* race *punctatum* (5,15).

Acala Cal-150 is at best only moderately wilt-resistant, but its unusual adaptability to high-density cultivation permits it to succeed well under conditions of severe *Verticillium* infestation. Most of its resistance was probably derived from Acala 4-42, which Harrison presumed to have a distant *G. barbadense* ancestor (*unpublished*).

The principle that genetic diversity is essential to crop stability suggested to us that a planned rotation of cotton varieties of different genetic backgrounds would lessen the chances of buildup in the soil of any one specific *Verticillium* pathotype.

In high-density culture, where we have studied our new breeding lines, the growing period is shorter (often as much as 1 mo) than that required by Acala SJ-5, thus permitting once-over harvesting with a finger stripper by the third week of September. Although acceptable yield and fiber quality have been maintained, production cost was reduced an estimated 40% over the conventional Acala cotton cultivation system. Narrow-row cultivation, especially combined with the arching plant character in our lines, would seem to allow maximum utilization of solar energy for photosynthesis during boll maturation and thus promote the highest possible yields within the shortest possible time. Arching also causes girdling of the stem at the ground line, which we believe favors uniform maturity of the relatively few bolls produced per plant.

The uniform earliness of the new breeding lines, combined with once-over harvesting, allows early shredding of stalks and rapid drying of the residue before the land is worked for the next crop. This measure is a proven method for reducing the buildup of *Verticillium* according to Thomas (13). Double cropping with winter vegetables or grains, or with legumes for green manure, also is a possibility. In addition, as pointed out by El-Zik in Spencer (11), early crop termination is the key to control of midseason and late-season pests, especially the pink boll worm.

Ginning cost for stripper-harvested cotton, particularly if the stripper does not have a cleaner, is generally somewhat higher than for the spindle-picked crop; but stripper-harvested lint is never twisted, contaminated with rubber particles, or soiled with oil. A properly adjusted gin can easily handle the somewhat higher trash content of stripper-picked cotton.

The system of cultivation we recommend consists of dense or narrow-row planting, ie, two rows per conventional 38-in. (97-cm) bed, which optimizes the wilt resistance and provides the stress that ensures early maturity. Typically by 1 August, about 100 days after planting, the two lines have set essentially all the bolls they can mature, ie, 300,000–400,000 per acre (741,000–988,000 per hectare). This result has been achieved consistently over the past 8 yr by our successful cooperators, Floyd Bird and Sons, of Reedley, CA, who are the primary growers of the new cottons. During that period, while the experimental lines were rotated annually within the same land, the wilt disease has not increased perceptibly and resistance of the lines has been effective. The period of our testing is now nearly as long as the entire useful period of the resistant Acala 4-42, grown in monoculture and with wide row spacing. Acala Cal-120 and Acala Cal-150 have consistently yielded about 1,000 ± 100 lb of lint per acre (1,112 ± 111 kg/ha). This is two to three times the yield of the Acala SJ varieties grown by Floyd Bird and Sons before 1976, the year these studies were begun.

In summary, we suggest that when the option of choosing between improved Acala-quality cotton varieties becomes a reality in the San Joaquin Valley of California, cotton growers (especially in the wilt-infested areas) could benefit greatly from the described qualities of Acala Cal-120 and Acala Cal-150. Most importantly perhaps, the typical strengths of both of these cottons, supported by years of large-scale testing by growers, would contribute to the management of Verticillium wilt with cultural measures tailored to individual farm conditions.

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