Theoretical and Applied Genetics 46, 249-256

Estimates of Genetic Parameters for Lint Quality in Upland Cotton *(Gossypium hirsutum)*

N.L. Innes, R.H. Wimble and H.E. Gridley, Cotton Research Corporation, Namulonge Research Station, Kampala (Uganda), and Rothamsted Experimental Station, Harpenden, Herts (England)

Summary. In a half diallel set of crosses involving twelve AH(67) parents and in a full diallel set with nine Albar 51 lines the genetic control of three characters of fibre quality, namely effective length, fibre bundle strength and micronaire value could largely be accounted for by an additive (parent + parent) model. Nevertheless, there were non-additive effects that could be attributed to particular parents. However, for practical plant breeding purposes, it seems that where improvements in lint quality only are being sought, the best breeding method is pedigree line breeding, supported by recurrent selection using crosses of the best lines to produce superior recombinants. Significant interactions between parents and sites for the three lint quality traits indicate that quality tests over a wide range of conditions are advisable at a fairly early stage in any selection programme in Uganda.

1. Introduction

Although cotton is primarily a self-pollinating crop, cross-pollination occurs to an extent that is governed largely by the effective population of insect pollen vectors, mainly bees. In cotton breeding there has been considerable emphasis on pedigree breeding, when self-pollination is usually ensured by sealing cotton flowers to prevent the entry of pollen vectors.

Genetic improvement of cotton in East Africa has been achieved mainly by pedigree selection methods (Arnold 1971), although the first seed issue of Satu bred by Low (1968) was a mass selected population from an open pollinated modal bulk. However, improved SATU 71 is a mixture of two pedigree lines selected from the original Satu bulk (Jones 1973).

The success of pedigree selection, aimed at producing homozygous lines, suggests that yield and lint quality in cotton are governed largely by loci at which the genes are additive in action and lends support to Matzinger's (1963) conclusion that, for a wide range of characters in self-fertilized crops, there is a predominance of additive genetic variance. Matzinger was however, careful to emphasize that in planning a breeding programme for such crops, genetic information should be sought for each specific situation and he outlined a simultaneous selfing and diallel test crossing design for tobacco in which estimates of genetic variance were obtained together with an early evaluation of selfed progeny.

Although several genes causing male sterility in cotton have been found (Weaver and Ashley 1971), no satisfactory system of inducing sterility and restoring fertility has been discovered and crossing has to be achieved by tedious and time-consuming methods of emasculation and hand-pollination. Nevertheless, in two groups of material in the cotton breeding programme at Namulonge, recurrent selection was introduced in an attempt to rearrange genes so that as many favourable combinations as possible could be concentrated into one plant type. In one of the groups, which involved Albar selections, information was also being sought on the combining ability of selected lines as part of a study of multiline seed mixtures. The inheritance of yield components and lint quality characters was studied in the first cycle of crossing in both groups of material. Data for lint quality are presented here; results for yield components are being prepared for publication.

2. Materials and Methods

Twelve F_4 pedigree strains (denoted AH(67)-) from a cross between Albar A(61)21, a locally adapted pedigree line closely related to the commercial variety BPA, and Barhop, a variety bred for high lint strength in the Sudan (Low 1962), were crossed in all combinations without reciprocals (Innes 1973b). The pedigree of these strains is shown in Fig. 1.

Parents and hybrids from this 12 × 12 half diallel set were included in a 9 × 9 balanced lattice square with 5 replicates at Namulonge in 1969-70, along with BPA, A(61)21 and Barhop. Plot size was $4.32\,m^2$ with two plants per stand in two rows at a spacing of 0.9 m between and 0.3 m within rows.

The second group of material used in recurrent selection work involved the pedigree selections BPA 68, A(66)22, 29, 36, 102, 131, 134 and A(67)8, 12, from Albar 51; all nine selections stemmed from A(57)5 (Innes and Jones 1972) and were used in the BPA improvement programme (Arnold and Innes 1975). The derivation of these nine lines is shown in Fig. 2. A(57)5 is a sixth generation inbred from A474, with single plant selection in each generation. The parents in the 9 × 9

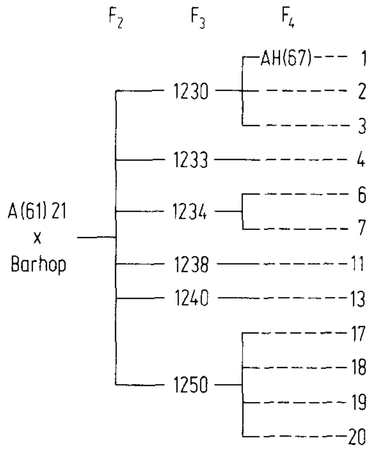

Fig.1. Pedigree of AH(67) parents used in 12 × 12 half diallel set

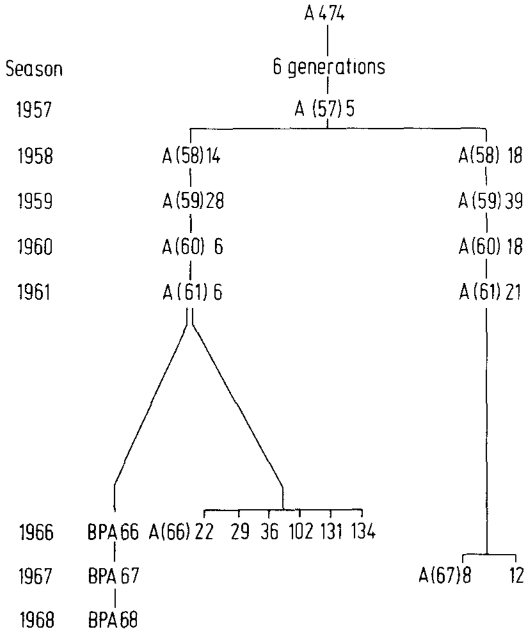

Fig.2. Pedigree of Albar 51 selections used in 9 × 9 full diallel set

full diallel set were therefore highly inbred, in contrast to those used in the 12 × 12 half diallel set which were F_4 selections from an inter-varietal cross. A 9 × 9 full diallel set of crosses provided 72 hybrids which were included with the nine parents in a 9 × 9 balanced lattice square with 5 replicates at Namulonge (Southern Uganda) and at Mubuku (Western Uganda) in 1970-71. Plot size was 4.32 m^2 in the rainfed trial at Namulonge and 3.24 m^2 in the irrigated one at Mubuku.

Lint for testing in the Namulonge fibre testing laboratory (see Innes 1973a) was a composite sample from all picks. Measurements were made for effective length, fibre bundle breaking strength at ⅛'' gauge and micronaire value; details of these lint quality characters are given by Lord and Underwood (1958) and Lord (1961).

Hayman's (1954) analysis of variance was used for both sets of crosses, the rows and columns of the lattice square design being ignored. Jinks' (1954) Wr, Vr regression method was not used for the half diallel set as the parents were not highly inbred. Canonical variate analysis (Seal 1964; Whitehouse 1970) was used to represent graphically the parents and the hybrids in each data set. This technique often makes possible the construction of an approximate graphical representation of parents and hybrids in two or three dimensions, using as axes two or three linear combinations of a much larger number of measurements originally made on them. In the application considered here the reduction in dimensionality was only from three variates to two, but nevertheless it represented a worth-while simplification. The analysis was carried out on plot estimates of the lint quality measurements after removing replicate effects. The linear combinations, usually termed canonical variates, were scaled to have unit standard deviation and parents and hybrids were plotted using the first two canonical variates as axes.

All statistical analyses were carried out at Rothamsted Experimental Station on an I.C.L. System 470 computer using Genstat.

3. Results and Discussion

12 × 12 Half Diallel Set

Included in Table 1 are mean values for the characters effective length, bundle strength and micronaire value for the AH(67) parents. Analyses of variance (Hayman 1954) are shown in Table 2. In these analyses, item 'a' refers to additive parental effects, and 'b' to non-additive effects. The latter is partitioned into terms of b_1, which provides a test of mean potence; b_2, which represents variation of mean potence from array to array and b_3, which measures non-additive genetic variance ascribable to residual specific interactions after accounting for parental array effects. Variance ratios (VR) were calculated using the associated block interaction terms. General and specific combining abilities (Griffing 1956) were also calculated for the three traits. General combining abilities (g.c.a.'s) are given in Table 3, as are also values for mean potence.

The analyses in Table 2 indicate that while additive effects are the largest in the three traits, there are some non-additive ones also. For micronaire value, the statistical significance of the b item is associated with b_3, and from an examination of the specific combining abilities (s.c.a's) for this trait, it appears to be due to large non-additive effects in three particular crosses involving parents AH(67) 1,2,4 and 7. Additive effects, however, are overwhelmingly large for this trait, with the parent AH(67)13 giving an unusually large g.c.a. value. For effective length and bundle strength, the mean squares for b_2 and b_3 are similar to their associated block-interaction errors. However, the non-significance of b_1 for effective length needs to be treated with caution because the degrees of freedom of its

Table 1. Effective length, bundle strength and micronaire value of twelve AH(67) parents

AH(67)	1	2	3	4	5	7	11	13	17	18	19	20	Mean	S.E. of a single parent mean
Effective length	38.8	39.7	40.7	40.1	38.9	37.8	40.9	38.9	41.0	40.7	40.6	41.7	40.0	0.36
Bundle strength	20.0	22.0	21.3	21.6	22.5	22.7	21.5	22.3	23.4	23.0	22.3	22.6	22.1	0.46
Micronaire value	4.3	4.2	4.0	4.4	4.3	4.1	4.5	5.1	4.3	4.5	4.3	4.1	4.34	0.06

Table 2. Hayman analysis of variance for effective length, bundle strength and micronaire value in 12 × 12 half diallel set of AH(67) crosses

	DF	Effective length		Bundle strength		Micronaire value	
		MS	VR	MS	VR	MS	VR
a	11	15.23	26.6***	10.69	7.5***	1.230	42.4***
b	66	0.80	1.4*	1.03	1.0 ns	0.030	1.6**
b_1	1	10.62	5.7 ns	4.63	29.7**	0.073	1.3 ns
b_2	11	0.85	1.5 ns	0.97	1.0 ns	0.026	1.4 ns
b_3	54	0.60	1.1 ns	0.98	<1 ns	0.031	1.6**
a × blocks	44	0.57		1.42		0.029	
b × blocks	264	0.58		1.03		0.019	
b_1 × blocks	4	1.86		0.16		0.056	
b_2 × blocks	44	0.57		0.96		0.019	
b_3 × blcoks	216	0.56		1.06		0.019	

*** $P < 0.001$
** $P < 0.01$
* $P < 0.05$

ns non-significant

Table 3. General combining ability estimates for twelve AH(67) parents and values for mean potence in 12 × 12 half diallel set

Parent		Effective length	Bundle strength	Micronaire value
AH(67)	1	-0.62	-0.98	-0.02
	2	-0.15	0.03	-0.04
	3	0.16	-0.05	-0.14
	4	0.15	-0.17	0.10
	6	-0.19	0.16	-0.01
	7	-0.93	0.35	-0.15
	11	0.33	-0.36	0.05
	13	-0.34	0.35	0.33
	17	0.31	0.37	-0.01
	18	0.24	0.38	0.09
	19	0.25	-0.09	-0.06
	20	0.77	0.01	-0.13
Parental mean		39.98	22.09	4.35
Hybrid mean		40.44	21.79	4.31
Mean potence		+0.46	-0.30	-0.04

error, 4, make the test of low power and hence insensitive to a difference which may be present in reality.

For effective length hybrids tend to have high values; this is borne out by the mean potence figure of 0.46 in Table 3. The g.c.a's given in Table 3 show a range of -0.93 to +0.77 for length, and indicate that for this character parent AH(67)20 is superior to the other parents. By contrast the average bundle strength of hybrids is below the parental mean, with a mean potence of -0.30 (Table 3).

The first two canonical variates accounted for 56 per cent and 32 per cent of the canonical variation, and were closely identified with micronaire value and staple length respectively. Parent AH(67)13 was well separated from the remainder by virtue of its large micronaire value and its crosses with other parents were generally a little closer to the latter, contributing to the small negative mean potence for this trait (Table 3). The three crosses involving parents AH(67)1,2,4 and 7 referred to previously all lay further from their respective mid-parent values than either of their parents.

Correlations for the three pairs of traits were calculated using the parental means taken from the diagonal of the diallel table. They proved small, all being less than 0.22.

Examination of the data in Table 3 shows that parents AH(67)17 and 18 both have positive g.c.a. values for length and strength, while those for micronaire value are about zero. Both these lines appear to be suitable parental components of a population for recurrent selection work aimed at improving lint quality. Other possible parents for a recurrent selection programme are AH(67)19 and 20, as both have positive g.c.a. values for lint length.

9 × 9 Full Diallel Set

Included in Table 4 are mean values at Namulonge and Mubuku for the three lint quality characters of the parents in the 9 × 9 full diallel set. These data reveal that for each trait, differences among parents are small by comparison with the AH data of Table 1. However, relatively small differences in fibre characters can lead to an improvement in the strength of cotton yarn, as is shown by results from two duplicate small scale spinning tests (Table 5) on lint of BPA 68 and A(66)134 from replicated trials at Namulonge and Masindi in the 1969-70 season. Lint of A(66)134, which was only marginally longer, finer and stronger than BPA 68 produced yarn that was 8% stronger than that of BPA.

Hayman' analyses are summarised in Table 6. In general there is rather limited evidence of non-additivity. The main instance is bundle strength at Mubuku, where the b and b_3 effects are statistically significant. Since the parents were inbred there is a possibility that an additive-dominance model of the type described by Mather and Jinks (1971) might be appropriate and the statistical tests described by them using Wr and Vr were performed. The slope of the associated Wr, Vr regression was 0.94 with a standard error of 0.23, indicating a rather wide scattering of the points about the regression line. There was no evidence of heterogeneity of the block regressions, but an analysis of (Wr + Vr) gave no significant differences between the parents. One might tentatively conclude from this that an additive dominance model might be appropriate though with reservations because of the scatter of points about the regression. The non-significant ($W_R + V_R$) differences suggest a low level of dominance in general; nevertheless, inspection of the data and a histogram of the specific combining abilities indicate that at least two individual crosses depart widely from additive expectation consistently in all blocks.

The first two canonical variates accounted for 85 per cent and 90 per cent of the canonical variation at Namulonge and Mubuku respectively; plots of the 45 parents and hybrids in the Namulonge trial using the first two canonical axes indicated that parents A(66)22, A(66)102, A(66)134, A(67)8 and A(67)12 performed very similarly and that A(66)36 showed some dominance over the other parents. The two crosses referred to above as showing non-additive effects for bundle strength at Mubuku both lay considerably further from their respective mid-parent values than either of their parents. At neither site could the canonical variates be identified with particular measurements.

In Table 6, there is also a suggestion of a b_1 effect for length at Namulonge, but since the variance ratio for b_1 is less than unity at Mubuku and is not statistically significant at Namulonge, it seems best to ignore it.

For bundle strength at Namulonge, there is an effect of 'c'; this relates to differences between arrays of reciprocal crosses. Inspection of the fibre strength data failed to reveal a consistent pattern of reciprocal differences, although there were indications that hybrids with BPA 68 were contributing. Of eight hybrids involving this parent, six with BPA as the female parent had shorter lint than their reciprocals but differ-

Table 4. Effective length, bundle strength and micronaire value of parents in 9 × 9 full diallel

	Effective length		Bundle strength		Micronaire value	
Parent	Namulonge	Mubuku	Namulonge	Mubuku	Namulonge	Mubuku
BPA68	41.8	41.8	22.2	22.4	3.4	3.2
A(66)22	41.6	41.7	22.7	22.7	3.4	3.1
29	40.9	41.0	22.5	22.1	3.5	3.4
36	42.5	42.3	22.8	22.2	3.2	3.1
102	41.8	42.0	22.8	23.2	3.4	2.9
131	42.4	42.0	22.4	22.2	3.5	3.2
134	41.7	42.2	22.9	23.6	3.3	3.1
A(67)8	41.7	42.1	23.0	23.0	3.4	3.3
12	41.7	41.8	23.0	23.1	3.3	3.1
Mean of 9 parents	41.8	41.9	22.7	22.7	3.38	3.16
S.E. of a single parent mean	0.21	0.23	0.23	0.32	0.05	0.10

Table 5. Fibre and yarn characteristics from two duplicate small scale spinning tests on BPA68 and A(66)134 from trials at Namulonge and Masindi, 1969-70

	Effective length	Maturity ratio	Standard fibre weight	Fibre bundle strength	Micronaire value	Yarn strength at 40's
BPA68	42.0	0.87	187	21.4	3.9	2303
A(66)134	42.5	0.88	178	22.3	3.9	2487

Table 6. Hayman analysis of variance for effective length, bundle strength and micronaire value in 9 × 9 full diallel set of Albar crosses

		Effective length				Bundle strength				Micronaire value			
		Namulonge		Mubuku		Namulonge		Mubuku		Namulonge		Mubuku	
	DF	MS	VR	MS	VR	MS	VR	MS	VR	MS	VR	MS	VR
a	8	4.35	18.3***	1.79	6.9***	2.08	5.1***	6.45	13.2***	0.188	26.9***	0.217	3.8**
b	36	0.25	1.3 ns	0.25	1.2 ns	0.29	1.2 ns	0.73	1.5*	0.014	1.1 ns	0.036	< 1 ns
b_1	1	1.66	6.2 ns	0.12	< 1 ns	0.01	< 1 ns	0.13	< 1 ns	0.066	4.1 ns	0.017	< 1 ns
b_2	8	0.20	< 1 ns	0.13	< 1 ns	0.28	1.8 ns	0.38	< 1 ns	0.016	1.6 ns	0.031	< 1 ns
b_3	27	0.21	1.1 ns	0.29	1.6 ns	0.30	1.1 ns	0.85	1.7*	0.012	< 1 ns	0.038	< 1 ns
c	8	0.40	1.3 ns	0.35	1.1 ns	0.55	2.7*	0.67	< 1 ns	0.011	1.1 ns	0.093	1.8 ns
d	28	0.34	1.4 ns	0.22	< 1 ns	0.33	1.1 ns	0.72	1.3 ns	0.011	1.1 ns	0.060	2.0*
a × blocks	32	0.24		0.26		0.41		0.49		0.007		0.057	
b × blocks	144	0.20		0.21		0.24		0.47		0.013		0.041	
b_1 × blocks	4	0.27		0.15		0.38		0.68		0.016		0.053	
b_2 × blocks	32	0.21		0.32		0.16		0.40		0.010		0.041	
b_3 × blocks	108	0.19		0.19		0.26		0.49		0.014		0.041	
c × blocks	32	0.28		0.31		0.20		0.71		0.010		0.051	
d × blocks	112	0.25		0.30		0.30		0.56		0.010		0.030	

ences between reciprocals were very small. For practical purposes such small differences can probably be ignored. For micronaire at Mubuku, the significant 'd', which relates to differences between reciprocal crosses other than those measured by 'c', appears to be due to the behaviour of three particular crosses, two involving BPA 68.

Graphs and regressions of Wr on Vr were examined, but as might be expected from the Hayman analyses, nothing of importance emerged from them. For this diallel set therefore, there is in 5 out of 6 trials a simple picture of an additive (parent + parent) model, emphasising the great importance of additive effects. General combining abilities were calculated for the parents and are given in Table 7.

A joint Hayman analysis was carried out, putting the data from the two sites together. When parent × site interactions were compared with those of parent × block at the individual sites, it became clear that the apparent interactions with site were real; Table 8 shows the relevant mean squares and variance ratios. As there was heterogeneity of variance in micronaire between the two sites, the variance ratio for this variate was calculated using the larger mean square only. Since parts or even all of these interactions might be due to scale differences at the two sites, the rank order of the parents was also compared for each of the variates, using the general combining ability estimates in Table 7. The BPA 68 parent proved remarkably consistent in the two environments both in terms of rank and of g.c.a. in all three variates. Most of the A(66) and A(67) parents, however proved inconsistent over the environments in at least one variate, especially A(66)29 for bundle strength and A(66)102 for micronaire; a change of scale could not remove interaction of this type.

Between parent correlations for the 3 pairs of traits were calculated as for the AH(67) data at each site, and they again proved small, except for bundle strength

Table 7. General combining ability estimates for the parents in the 9 × 9 full diallels at Namulonge (N) and Mubuku (M) and mean potence values

Parent		Effective length		Bundle Strength		Micronaire value	
		N	M	N	M	N	M
BPA	68	-0.09	-0.07	-0.33	-0.28	0.01	0.01
A(66)	22	-0.01	-0.01	0.03	0.16	-0.01	-0.05
	29	-0.34	-0.33	0.12	-0.27	0.04	0.07
	36	0.43	0.17	-0.10	-0.38	-0.11	-0.03
	102	-0.01	0.09	-0.01	0.22	0.01	-0.08
	131	0.22	0.04	-0.06	-0.13	0.03	0.02
	134	-0.09	0.06	0.07	0.31	0.03	-0.02
A(67)	8	0.02	0.05	0.11	0.07	0.01	0.05
	12	-0.13	0.00	0.17	0.30	-0.01	0.02
Parental mean		41.78	41.88	22.72	22.71	3.39	3.18
Hybrid mean		41.58	41.93	22.73	22.77	3.35	3.16
Mean potence		-0.20	0.05	0.01	0.06	-0.04	-0.02

Table 8. Analysis of parent × site interactions for effective length, bundle strength and micronaire value in 9 × 9 full diallel set of Albar crosses

	DF	Effective length		Bundle strength		Micronaire value	
		MS	VR	MS	VR	MS	VR
Parent × Site	8	0.85	3.4**	2.16	4.8***	0.144	2.6*
Parent × Block							
Namulonge	32	0.24		0.41		0.007	
Mubuku	32	0.26		0.49		0.056	
Pooled	64	0.25		0.45		0.032	

Note: The variance ratios (VR) for length and strength are based on pooled interactions with blocks. That for micronaire value is based conservatively on the Mubuku MS.

and effective length at Mubuku, which gave a value of 0.66. Graphical plots of the two variates at the two sites showed that the correlation was associated with A(66)134 improving its performance at Mubuku in both traits, an aspect of the interaction noted in the previous paragraph.

4. General Discussion

Although Innes (1974) detected epistasis for lint length and strength in a set of tester crosses involving ten Upland parents of diverse origin, several of which were derived from interspecific crosses at the tetraploid and tetraploid/diploid levels, he failed to find any evidence of it in a 5 × 5 half diallel set of Upland varieties for which an additive-dominance model satisfactorily accounted for the genetic control of these two traits. In investigations in the USA into the inheritance of length and strength (Miller and Lee 1964; Lee, Miller and Rawlings 1967; Verhalen and Murray 1967, 1969; Al-Rawi and Kohel 1970) genetic variance was mainly of the additive-dominance type.

As micronaire value reflects both coarseness and maturity (Arnold 1969) it is particularly sensitive to environmental variations and it is not surprising that variable results have been obtained for the inheritance of this trait (Verhalen and Murray 1967, 1969; Murray and Verhalen 1969; Al-Rawi and Kohel 1970). Although overdominance for micronaire value has been found in some studies, the degree of dominance was affected by environment.

Although there are examples of heterosis for lint quality from intervarietal crosses, the present results and those obtained by others indicate that where improvements in quality only are being sought the breeding method adopted by most cotton breeders, namely the synthesis of homozygous lines by inbreeding, interspersed with controlled crossing among improved lines adapted to local conditions to produce more favourable recombinants, offers the best practical approach. There are, of course, advantages to be gained from F_1 hybrids in terms of yield but this subject is outside the scope of this paper.

The effect of environment on lint quality is well documented (see Arnold 1969), a fact well appreciated by the processor of Uganda cotton who is prepared for example, to pay more for lint produced under rainfed conditions in Mengo/Entebbe zone than for lint of the same variety also grown as a rainfed crop in Bunyoro. There is, however, little published evidence on interactions between varieties and environments for lint quality characters, although in the USA Lee et al. (1967) obtained relatively small but significant interactions between additive genetic effects, locations and/or years for length, strength and micronaire value. The present data indicate that, even among material with a relatively narrow range of character expression, there are real interactions between parents and sites. Arnold and Innes (1975) have shown that because of striking interactions between genotypes and environments for lint yield, there is a need to evaluate breeding material under a wide range of ecological conditions over several seasons. The present results serve to emphasize that, at the early selection stages of a breeding programme, lint quality tests over a wide range of conditions are also advisable. Because of limited resources it has previously been necessary to wait until the advanced breeding stage for quality tests over a wide range of environments, and usually early selections have been made using tests of one site only. Moreover, unpublished data from spinning tests on samples from district variety trials indicate that the magnitude of the genotype × environment interaction for lint quality is much lower than that obtained for lint yield. The extensive new lint testing laboratory built by the Uganda Lint Marketing Board at Namulonge in 1972, has increased enormously the capacity for fibre and spinning tests and should enable cotton breeders to test larger numbers of relatively undeveloped selections over a wide range of conditions.

Literature

Al-Rawi, K.M.; Kohel, R.J.: Gene action in the inheritance of fibre properties in intervarietal diallel crosses of Upland cotton, *Gossypium hirsutum* L. Crop Sci. 10, 82-85 (1970)

Arnold, M.H.: Developments and prospects in cotton quality. 1st Symposium International de la Recherche Textile Cotonniere, Paris, April 1969. Institut Textile de France (1969)

Arnold, M.H.: Cotton improvement in East Africa. In: Crop Improvement in East Africa ed. Leakey, C.L.A. Commonwealth Agricultural Bureaux Techn. Comm. 19, 178-208 (1971)

Arnold, M.H.; Innes, N.L.: Plant breeding. In: Agricultural Research for Development. The Namulonge Contribution. Cotton Research Corporation. London and Cambridge: University Press 1975, in press

Griffing, B.: Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9, 462-493 (1956)

Hayman, B.I.: The analysis of variance of diallel tables. Biometrics 10, 235-244 (1954)

Innes, N.L.: Selection for fibre characters in Upland cotton. Cotton Grow. Rev. 50, 101-105 (1973a)

Innes, N.L.: Promising selections from inter-varietal crosses at Namulonge. Cotton Grow. Rev. 50, 296-306 (1973b)

Innes, N.L.: Genetic variability for lint quality in Upland cotton. Cotton Grow. Rev. 51, 85-98 (1974)

Innes, N.L.; Jones, G.B.: Allen - a source of successful African cotton varieties. Cotton Grow. Rev. 49, 201-215 (1972)

Jinks, J.L.: The analysis of quantitative inheritance in a diallel cross of *Nicotiana rustica* varieties. Genetics 39, 767-788 (1954)

Jones, G.B.: Improving the Satu variety in Uganda. Cotton Grow. Rev. 50, 218-224 (1973)

Lee, J.A.; Miller, P.A.; Rawlings, J.O.: Interaction of combining ability effects with environments in diallel crosses of Upland cotton. (*Gossypium hirsutum* L.). Crop Sci. 7, 477-481 (1967)

Lord, E.: Manual of cotton spinning. The characteristics of raw cotton. The Textile Institute and Butterworths (1961)

Lord, E.; Underwood, C.: The interpretation of spinning test reports. Emp. Cotton Grow. Rev. 35, 26-46 (1958)

Low, A.: New cotton varieties for the Sudan. Emp. Cotton Grow. Rev. 39, 95-105 (1962)

Low, A.: Developments toward tufted seed in varieties of *Gossypium hirsutum*. Cotton Grow. Rev. 45, 101-114 (1968)

Mather, K.; Jinks, J.L.: Biometrical Genetics 2nd Ed. London: Chapman and Hall 1971

Matzinger, D.F.: Experimental estimates of genetic parameters and their applications in self-fertilizing plants. In: Statistics and Plant Breeding. Publication 982, Nat. Acad. Sci. - Nat. Res. Counc., Washington D.C. pp. 253-279 (1963)

Miller, P.A.; Lee, J.A.: Heterosis and combining ability in varietal top crosses of Upland cotton, *Gossypium hirsutum* L. Crop Sci. 4, 646-649 (1964)

Murray, J.C.; Verhalen, L.M.: Genetic studies of earliness, yield, and fiber properties in cotton (*Gossypium hirsutum* L.). Crop Sci. 9, 752-755 (1969)

Seal, H.: Multivariate Statistical Analysis for Biologists. London: Methuen 1964

Verhalen, L.M.; Murray, J.C.: A diallel analysis of several fiber property traits in Upland cotton (*Gossypium hirsutum* L.). Crop Sci. 7, 501-504 (1967)

Verhalen, L.M.; Murray, J.C.: A diallel analysis of several fiber property traits in Upland cotton (*Gossypium hirsutum* L.). II. Crop Sci. 9, 311-315 (1969)

Weaver, J.B.; Ashley, T.: Analysis of a dominant gene for male sterility in Upland cotton, *Gossypium hirsutum* L. Crop Sci. 11, 596-598 (1971)

Whitehouse, R.N.H.: An application of canonical analysis to plant breeding. Proc. 5th Cong. Eucarpia, Milano, pp. 61-96 (1970)

Received March 21, 1975
Communicated by R. Riley

N. L. Innes
National Vegetable Research Station
Wellesbourne, Warwicks (England)

R.H. Wimble
Rothamsted Experimental Station
Harpenden, Herts (England)

H.D. Gridley
Institute of Agricultural Research
Samaru, PMB 1044
Zaria (Nigeria)