THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

VOL. 8. - - - NO. 4.

DECEMBER, 1951.

JASSID RESISTANCE OF THE COTTON PLANT.

By A. W. S. MAY, M.Agr.Sc., Entomologist, Science Branch, Division of Plant Industry.

SUMMARY.

Terminal injury by jassids, expressed as grades of plant reaction, can be related to the nymphal population, irrespective of variety and state of growth of the crop. This association enables a determination of varietal susceptibility based on injury symptoms. For each variety, susceptibility to jassid attack can be expressed as a plant resistance index.

The method of sampling populations and the various grades of plant reaction recognised from normality to the extreme of jassid damage are described.

A correlation between plant resistance index, an expression of oviposition injury on the plant, and mean nymphal populations for each variety tested, suggests that differential varietal reaction to jassid populations is conditioned by the breeding potential within the terminal. Plant hairiness is associated with resistance to jassid oviposition.

Hair density and the type of hairs associated with the lower surface of the midrib are discussed.

A dense cover of simple unbranched and long stellate hairs for the entire length of the midrib is essential for resistance to jassid breeding. The presence of these two types automatically confers length on the general hair cover on the major veins.

Though the plant resistance index may suffice to differentiate plant material bred for jassid resistance during years when jassid populations are high, hairiness on the lower surface of the midrib can be employed in the absence of a jassid population. Only those plants possessing a uniformly long dense hair cover for the entire length of the underside of the major veins should be selected for jassid resistance.

INTRODUCTION.

In a previous paper (May, 1950) it was stated that observations made during the early 1940's suggested that the breeding of jassid-resistant varieties was the only measure likely to be of practical value in lessening damage caused by the cotton jassid (*Empoasca maculata* Evans) in Queensland.

Complementary to a plant breeding programme to evolve suitable cotton varieties, certain entomological aspects of the problem were investigated in the Central and Upper Burnett Districts from 1941 to 1945, and the findings are presented here.

The overall picture of susceptibility to jassid attack within a field of cotton represents an average value for the reactions exhibited by the individual plants. Marked contrasts in the intensity of these reactions are noticeable between fields as well as between varieties. To determine the cause of these variations an examination of the individual plant reactions within each field was undertaken.

The varying intensity of injury shown by individual plants within varieties subject to the same level of jassid population suggested a means of gauging varietal susceptibility once it had been established that intensity of injury was directly related to the jassid population on the plant. Further, variations in the plant's attraction to the jassids, as shown by gradations in leaf curl, stressed the importance of plant characters that prevented or hindered oviposition. The role of plant hairiness in this respect was also investigated.

These two lines of investigation were undertaken concurrently to determine the best method of gauging jassid resistance under Queensland conditions. The relevant literature is discussed under section headings.

RELATIONSHIP BETWEEN JASSID POPULATIONS AND PLANT INJURY.

Methods and Criteria.

Population Sampling.

Various methods have been employed in jassid population density studies. Moerdyk (1927) and Parnell and Gutsche (1928) counted the population on five leaves of plants selected at random within each variety as a means of comparing population densities. Verma and Afzal (1940) sampled the adult populations by sweeping with a hand net and counted the total population on plants selected at random so that both adults and nymphs could be considered. Gaddum (1942) counted the population on three leaves of plants selected at random, the result being expressed as the mean number of jassids per plant. Later the data were expressed as number of jassids per unit of leaf area, the leaves being assumed to be of the same size. None of these methods fulfilled requirements under Queensland conditions. Previously (May, 1950) it was shown that *Empoasca maculata* confines its activity to the region of terminal growth, and therefore population sampling must be concentrated on this region of the plant. The sampling of adult populations by sweeping was found unsuitable for plant-to-plant comparisons, while the counting of the total population on plants chosen at random was too slow and laborious for this work, particularly when plants were growing vigorously.

Since an association between population and damage to individual plants was sought, it was desirable that counts involve the wingless stages of the pest. These are mostly confined to the leaves on which eggs are deposited and hence their numbers can be expected to give a reasonably good representation of jassid activity.

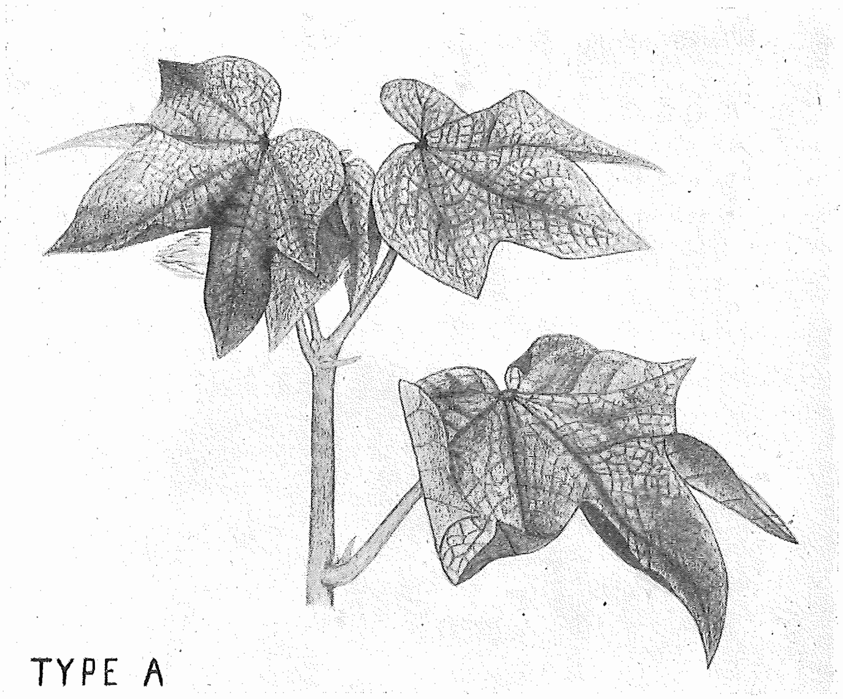

Fig. 1.
Plant Reaction Type A.

Complete counts were made of nymphal populations on the main stem terminals. Each leaf was turned back separately and carefully so that the nymphs were not unduly disturbed. In all instances, a terminal consisted of those leaves from the most recently formed down to and including the sixth. Any one series of counts was completed in the shortest time possible so that population fluctuations following variations in the growth rate of plants and the influence of adverse temperatures and storm rains were avoided.

Plant Reaction Types.

In the transition from normal growth to severe injury following jassid activity, five types of terminal injury were recognized. As this classification is somewhat arbitrary, the line of demarcation between types could not be gauged accurately, and the allocation of marginal samples was to a certain extent subjective. This was partly overcome by sampling as many plants as possible. Types are defined as follows:—

Type A (Fig. 1).—A slight folding of the lamina may be associated with bronzing in the region of the vein tips; otherwise there is little curling or crimping of the foliage. Older leaves may show a slight curling of the leaf margins. The only symptom of injury is a discoloration of the leaf margins or of areas at the tips of the veins. Leaf colour is normal or faintly yellow.

Type B (Fig. 2).—Distinct curling is noticeable and the second and third leaves are curled downwards at the tips. The third leaf shows slight crimping, with bronzing at the margins. The third and fourth leaves exhibit chlorotic areas at the leaf margins and the extremities of main veins. There is slight drooping of the vein tips and the leaf margins only in the fifth and sixth leaves.

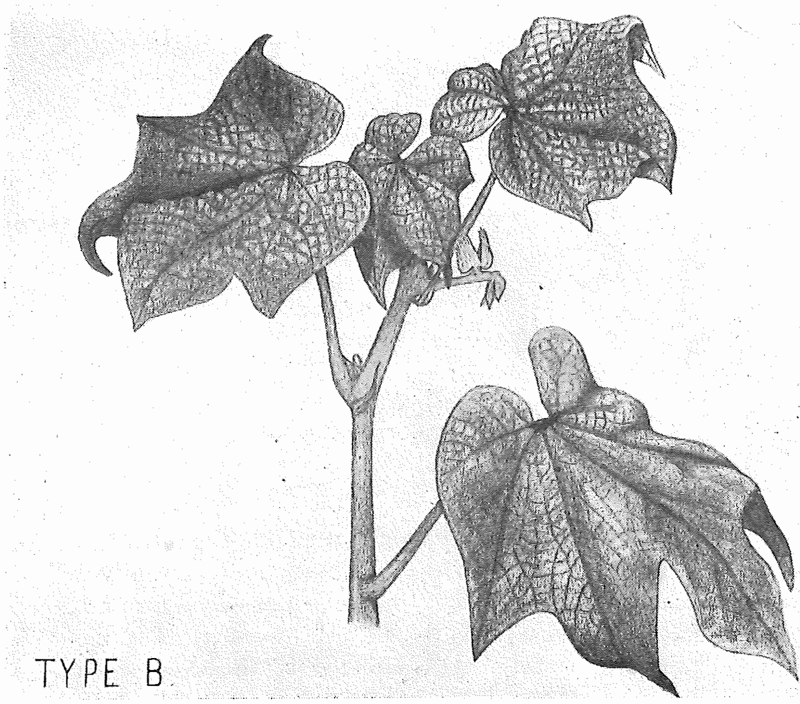

Fig. 2.

Plant Reaction Type B.

Type C (Fig. 3).—The second, third and fourth leaves show signs of curling and crimping, with the vein tips and the leaf margins curled to a moderate extent only. Slight crimping is apparent on the fifth leaf, and the sixth leaf is only slightly curled. The symptoms decrease in intensity from the second leaf downwards and the first leaf may be devoid of injury. Slight bronzing may be evident near the vein extremities of the third, fourth and fifth leaves. The foliage is more uniformly discoloured than in Type B. Plant growth is not arrested.

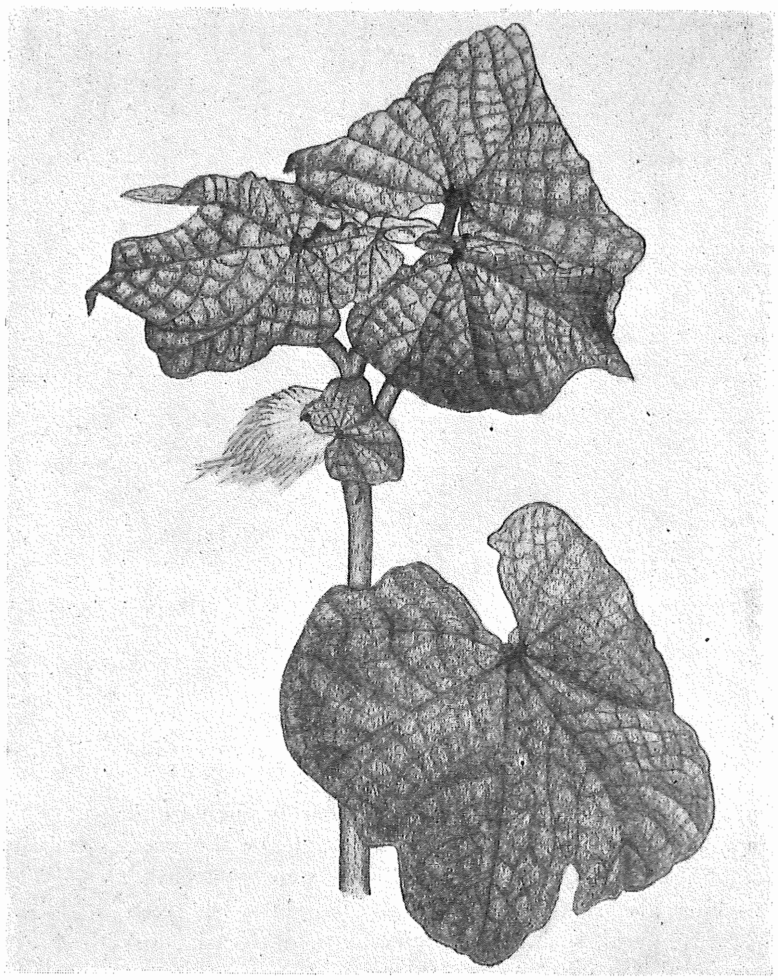

Fig. 3.
Plant Reaction Type C.

Type D (Fig. 4).—All leaves show signs of curling and crimping. The vein tips and the margins of the leaves are curled under and the tissue between the main veins is severely crimped and distorted; the foliage is stiff; and the leaf petioles are reddish. Growth has been arrested and the leaves present a reddish-bronze tinge against a pale-green to yellowish background. Undeveloped squares are clustered in the growing point.

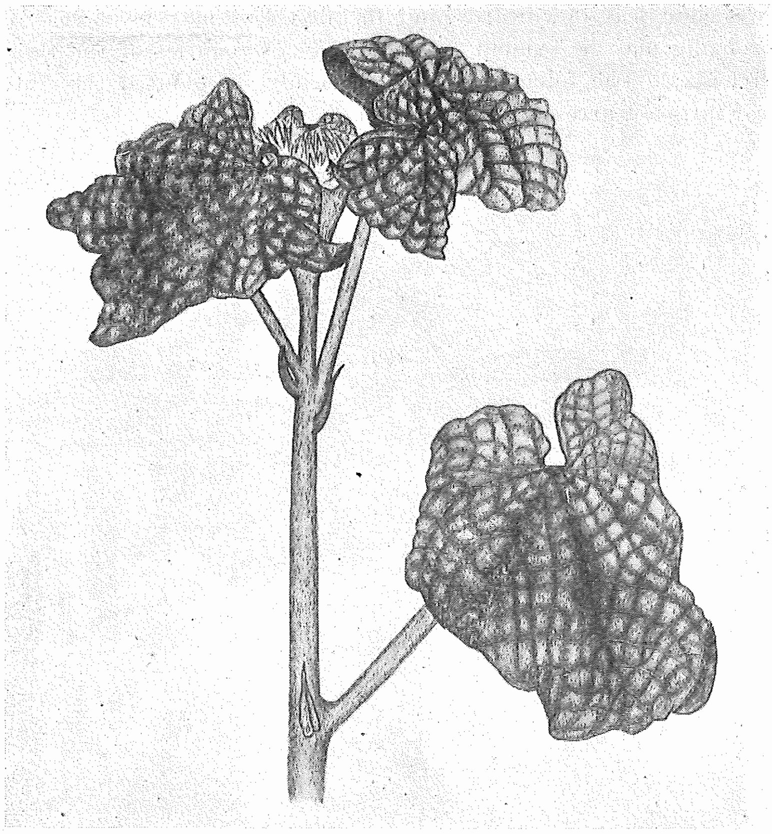

Fig. 4.
Plant Reaction Type D.

Type E (Fig. 5).—The leaves are severely curled and crimped, with the petioles short and standing at a greater angle to the main stem than usual. Undeveloped squares bunch at the growing point, or have already been shed. The leaf veins are reddish, the lamina is yellowish-green with some parts reddening, the petioles and the stems are dark-red, and the older leaves become brittle and stiff. The fourth leaf reddens at the margins and between the larger veins, and necrotic areas develop. The under-leaf surfaces are light-brown with epidermal cells conspicuous. This type is the extreme in terminal curling.

Data.

Early in the 1941-42 season, between March 12 and 21 when plant growth was reasonably good and early formed bolls had commenced to open, counts were made in three commercial varieties of cotton to determine the nymphal population associated with normal plants and the five types in the

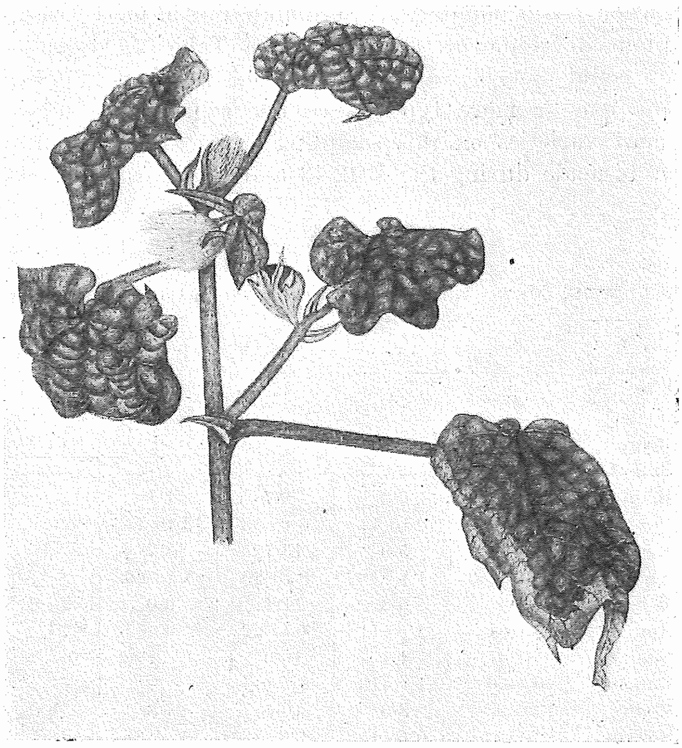

Fig. 5.
Plant Reaction Type E.

plant reaction scale. Fifty terminals were sampled for each type, but in some instances sufficient plants representative of types at either end of the scale were not available. These results are given in Table 1.

Table 1.

NYMPHAL POPULATION ASSOCIATED WITH PLANT REACTION TYPE.

Variety.	Population.	Plant Reaction Type.					
		Normal.	A	B	C	D	E
D. and P.L.	Mean ..	..	4·6	..	23·8	..	..
	Range ..	..	0 to 16	..	6 to 50	..	..
Miller ..	Mean ..	..	7·8	15·8	20·5	30·4	..
	Range ..	..	2 to 15	6 to 29	6 to 44	8 to 75	..
Half and Half	Mean ..	0·3	4·1	11·1	18·4	29·9	56·8
	Range ..	0 to 2	0 to 16	3 to 34	4 to 41	14 to 64	26 to 89

During the 1942-43 season, similar counts were made at intervals throughout late summer in a randomized varietal trial. The data collected on March 15, when jassid populations were high, but in most cases not sufficient to suppress plant development, are set out in Table 2. Some of the plant reaction types could not be sampled in equal numbers from the material available, while one or more types were not represented among the plant samples for most varieties on this sampling date. These results are typical of similar counts made during the 1942-43 and the two subsequent seasons.

Table 2.

NYMPHAL POPULATION, MEAN AND RANGE, ASSOCIATED WITH PLANT REACTION TYPE.

Variety.	Population.	Plant Reaction Type.					
		Normal.	A	B	C	D	E
III.–509 ..	Mean ..	1·0	..	..	..	..	..
	Range ..	0 to 5	..	..	..	..	..
B_1–29–2–0	Mean ..	2·5	6·3	8·7	21·4	..	..
	Range ..	0 to 5	2 to 11	6 to 13	13 to 41	..	..
III.–26–0	Mean ..	1·1	5·5	13·7	13·7	..	..
	Range ..	0 to 5	1 to 10	8 to 20	7 to 20	..	..
B_1–9–3–0	Mean ..	1·4	6·3	11·4	9·0	24·0	..
	Range ..	0 to 4	2 to 11	4 to 22	9	24	..
Ambassador	Mean ..	1·0	4·1	10·0	..	..	..
	Range ..	0 to 6	1 to 13	6 to 14	..	..	..
Farm Relief	Mean ..	..	8·0	10·5	27·8	18·0	..
	Range ..	..	0 to 15	4 to 19	19 to 38	18	..
Miller 41 ..	Mean ..	2·5	4·3	10·2	19·8	32·3	..
	Range ..	2 to 3	3 to 7	6 to 13	7 to 41	11 to 59	..
Stoneville 150	Mean ..	..	6·0	10·7	16·9	43·0	..
	Range ..	..	6	4 to 18	6 to 46	43	..
Watson ..	Mean ..	..	3·0	10·6	18·7	29·7	..
	Range ..	..	3	4 to 21	6 to 39	20 to 42	..
New Boykin 90	Mean ..	..	..	11·8	23·8	25·5	..
	Range ..	..	..	8 to 17	10 to 55	16 to 38	..
Russells Big Boll	Mean ..	..	2·0	9·0	25·7	28·5	..
	Range ..	..	2	5 to 12	6 to 54	13 to 39	..
Lone Star 30	Mean ..	..	..	10·0	16·0	32·7	..
	Range ..	..	..	5 to 15	6 to 45	10 to 68	..
Qualla ..	Mean ..	..	..	7·0	17·8	41·0	..
	Range ..	..	..	5 to 9	6 to 40	27 to 55	..
Triumph 124	Mean ..	..	2·0	9·7	17·6	20·3	24·0
	Range ..	..	2	7 to 12	7 to 36	5 to 39	24
New Mexico Acala 120	Mean ..	..	..	..	17·1	17·3	..
	Range ..	..	..	..	7 to 39	10 to 31	..

Discussion.

The data set out in Tables 1 and 2 demonstrate the relationship between the nymphal population on the terminal and each plant reaction type. This relationship occurs irrespective of the variety. There is a consistent increase in nymphal population for successive plant reaction types in all varieties.

Although an association between the mean nymphal population per terminal, the population range and each plant reaction type exists, the recorded values may vary at each sampling period. This is brought about by variations in the growth rate of the crop and its effect on jassid reproduction. Should the rate of plant growth remain uniform, values for the mean nymphal populations for each plant reaction type remain more or less constant. As the rate of plant growth is depressed by crop formation, adverse climatic conditions and severe jassid feeding, the chance of sampling the same terminal leaves on subsequent sampling dates increases. Although each of these leaves still exhibits much the same degree of curling, the insect population declines as some nymphs attain the more mature stages and disperse over the plants. This accounts for a gradual lowering of the mean population associated with each plant reaction type as the season progresses. With the suppression of growth, these values rapidly approach zero.

VARIETAL SUSCEPTIBILITY.

Similar injury symptoms are shown by plants subjected to equal numbers of jassid nymphs on the terminal, irrespective of variety. Thus, comparative measures of susceptibility could be arrived at simply by estimating the proportion of plant reaction types within the several varieties.

Method.

The same varieties were compared under different levels of jassid population and various climatic conditions during three subsequent seasons. The number of each plant reaction type occurring within each variety was employed as the basis of comparison. At each sampling period, determinations were completed on the one day, and for each plant sampled the injury exhibited by the main stem terminal was recorded. Where the main terminal was also injured by causes other than jassids, the plant was disregarded. Thus an equal number of plants could not be sampled for each variety.

The nymphal population associated with each terminal was also recorded.

To express more clearly the degree of curling by a variety, the data obtained on each sampling day were converted to a plant resistance index. This value was calculated by multiplying the number of terminals within each reaction type by a number from 1 to 6 representing that type, summing the products and dividing by the total number of terminals sampled. The index is given by the expression: $\frac{6n + 5a + 4b + 3c + 2d + 1e}{n + a + b + c + d + e}$, where n, a, b, c, d and e represent the number of terminals classed in plant reaction groups N (normal growth), A, B, C, D and E. The plant resistance index lies between 1 and 6, low values indicating little resistance and high values a considerable degree of resistance. Values for highly susceptible varieties will more closely approach unity during years of severe jassid activity.

Data.

Table 3 represents an example of the frequency with which the several plant reaction types occur within varieties on one sampling day. The values for each variety are an expression, at the time of sampling, of the cumulative effect of jassid activity. The mean nymphal populations associated with each plant reaction type are given in Table 2. Similar records, taken at a later date among the same plant material, showed a greater proportion of the terminals classified under the plant reaction types D and E, and with few or none towards the other end of the scale.

The varieties are listed in their order of resistance, the more susceptible being low in the scale.

Table 3.

FREQUENCY OF PLANT REACTION TYPES WITHIN VARIETIES.

Variety.	Plant Reaction Type.					
	Normal.	A	B	C	D	E
III.–509 ..	33	..	..	..	..	..
B_1–29–2–0	14	9	6	5	..	..
III.–26–0	14	11	4	6	..	..
B_1–9–3–0	14	8	9	1	1	..
Ambassador	8	10	4	..	..	..
Farm Relief	..	8	21	4	1	..
Miller 41	2	4	5	18	3	..
Stoneville 150	..	1	13	18	1	..
Watson ..	..	1	10	18	4	..
New Boykin 90	..	..	4	24	4	..
Russells Big Boll	..	1	4	20	6	..
Lone Star 30	..	..	2	25	3	..
Qualla ..	..	..	3	29	2	..
Triumph 124	..	1	3	19	8	1
New Mexico Acala 120..	..	..	..	22	11	..

After calculating the plant resistance index for each variety on each sampling date, Table 4 was completed.

A falling off in the growth rate, following the combined effect of crop formation and low rainfall in early April, together with decreasing temperatures, contributed towards the rapid decline in the jassid population after the end of March. During this period the more resistant varieties continued to grow and index values increased or remained almost stationary. With the more susceptible varieties, values continued to decline, although at a much reduced rate compared with that of early March, when populations were high. For some susceptible varieties, plant growth had been suppressed by the jassids by mid-March. These did not resume growth.

Table 4.

PLANT RESISTANCE INDICES.

Variety.	Plant Resistance Index.					Seasonal Mean Index.
	1.3.43.	15.3.43.	29.3.43.	19.4.43.	3.5.43.	
III.–509	6·0	6·0	6·0	5·97	6·0	5·99
B_1–29–2–0	5·81	4·94	5·06	5·35	4·97	5·23
III.–26–0	5·29	4·94	5·31	5·14	5·14	5·16
B_1–9–3–0	5·52	5·0	5·0	5·09	4·70	5·06
Ambassador	5·62	5·18	4·73	4·55	4·14	4·84
Farm Relief	4·59	4·06	3·88	4·24	3·82	4·12
Miller 41	4·67	3·50	3·33	3·45	2·85	3·56
Stoneville 150	4·53	3·42	3·36	3·21	2·21	3·35
Watson	4·45	3·24	3·15	3·06	2·36	3·25
New Boykin 90 ..	4·1	3·0	2·94	3·0	2·25	3·06
Russells Big Boll ..	4·27	3·0	3·1	2·65	2·03	3·01
Lone Star 30	4·1	2·97	2·87	2·76	2·0	2·94
Qualla	4·15	3·03	3·06	2·32	1·85	2·88
Triumph 124	3·94	2·84	2·85	2·71	1·82	2·83
New Mexico Acala 120..	3·39	2·67	2·48	2·27	1·42	2·45

Varietal susceptibility was investigated further during the 1943-44 and 1944-45 seasons, when jassid populations were lower than those recorded during the previous season. Even the more susceptible varieties showed only moderate damage. The values for the plant resistance index were high and differences between varieties were less easily established. Table 5 summarizes the findings for the three cotton seasons. All the varieties listed were not available for sampling each season.

Table 5.

RELATIONSHIP BETWEEN MEAN NYMPHAL POPULATION AND INDEX FOR VARIETIES.

Variety or Strain.	Season 1942–43.		Season 1943–44.		Season 1944–45.	
	Population.	P.R.I.	Population.	P.R.I.	Population.	P.R.I.
III.–509	·604	5·99	·009	6·0	..	..
III.–505	..	..	..	..	·27	5·96
III.–26–0–0–0	..	..	..	..	·37	5·98
B_1-29–2–0	4·11	5·23	·34	5·94	1·56	5·75
III.–26–0	4·78	5·17	·32	5·96	..	..
B_1–9–3–0	4·19	5·06	·14	6·0	·97	5·87
Ambassador	5·33	4·84	·89	5·84	3·81	5·17
Miller 41	10·45	3·56	1·89	5·61	2·85	5·35
Stoneville 150	12·27	3·35	·82	5·84	3·81	4·81
New Boykin 90 ..	13·02	3·06	3·87	5·33	7·4	4·6
Russells Big Boll ..	14·55	3·01	2·56	5·52	..	..
Lone Star 30	15·04	2·94	3·48	5·31	6·15	4·65
Triumph 124	13·22	2·83	3·42	5·42	7·17	4·7
New Mexico Acala 120..	14·72	2·45	6·44	4·81	7·85	4·46

C

Discussion.

Varietal differences occur in the proportions of each plant reaction type found among plants in the same field. Within each variety, plant-to-plant variation may be very marked and the summation of each plant's reaction to the existent jassid population, expressed in the plant resistance index, has enabled a comparison between varieties.

Varietal reaction to jassids is conditioned by the breeding potential within the terminal, and mean nymphal populations for varieties bear a distinct relationship to the plant resistance indices (Fig. 6).

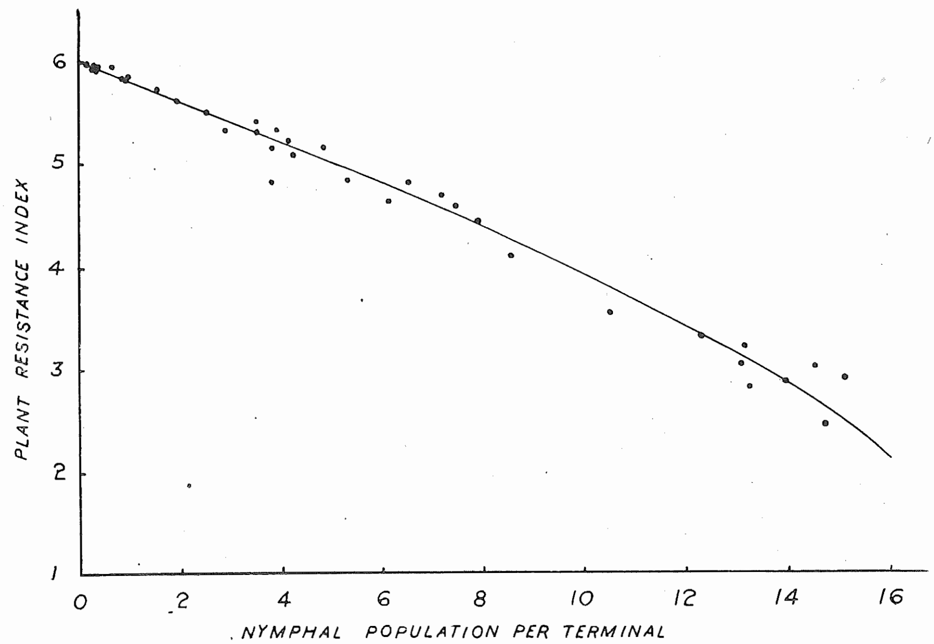

Fig. 6.

Graph Showing Relationship between Mean Jassid Population and Mean Plant Resistance Index.

The values for the plant resistance index for each variety may differ on separate counting days, although the trend remains consistent between varieties. Index values are dependent on the size of the jassid population and for any particular variety will vary considerably within a season as well as between seasons. The plant resistance indices for varieties are only comparable when recorded on the same day in crops subjected to the same jassid infestation and grown under similar cultural conditions.

Slight discrepancies in the comparative susceptibilities of the varieties studied can be understood when mean values for the nymphal populations are compared for individual seasons. The 1942-43 values of the plant resistance indices for both Triumph and New Mexico Acala are inconsistent. This is due to the suppression of plant growth by the pest, and with it the creation of conditions unfavourable for further jassid breeding. This behaviour has prevented an absolute correlation being obtained between low index values and mean nymphal populations in Fig. 6. However, the results are sufficiently consistent to show that the more resistant varieties or strains possess characters which inhibit the development of a jassid population.

PLANT HAIRINESS.

The nymphs of cotton jassids can flourish equally well on both susceptible and resistant varieties (Peat, 1928; Husain, 1938; Verma and Afzal, 1940), yet, when resistant varieties are subject to high jassid populations, the plants remain unattractive to the pest. Though the adult jassids may cause slight feeding injury, egglaying is largely inhibited. Between varieties ranging from highly susceptible to resistant, the diversity of leaf curl exhibited has its origin in a differential rate of egg deposition, since a correlation between the mean nymphal population and the plant resistance index was found to exist. Verma and Afzal (1940) showed that the chief difference between the comparatively resistant and susceptible varieties lay in the number of eggs inserted into the leaf veins, and that these eggs, once laid, hatched normally.

Although detailed work was not undertaken at the outset to ascertain causes influencing the rate of oviposition, it was obvious that plant hairiness was associated with jassid resistance. Numerous investigators elsewhere, including Worrall (1923), Parnell (1925 and 1927), Moerdyk (1927), Afzal (1936) and Lal (1938) have reported the importance of plant hairiness in this respect. Though Parnell stressed the mechanical hindrance to jassid activity conferred by the plant hairs, certain other investigators stated that hairiness is not the basis of resistance but is correlated with some other factor. Lal suggested peculiarities within the veins which would interfere with normal oviposition, while toughness of the cuticle was stressed by Afzal and Abbas (1944).

Monteith and Hollowell (1929) and Poos and Smith (1931), working with the potato leaf hopper (*Empoasca fabae* Harris), also associated plant hairiness with resistance to insect damage.

To understand the association between plant hairiness and jassid resistance, a knowledge of hair density and type and length of hair on the plant is a primary requirement.

Methods and Criteria.

Hair Types.

According to Youngman (1930), all cotton hair types have apparently evolved from the stellate hair group. This basic type consists of a number of hairs joined together at their base and arising from a common point on the epidermis. Hector (1936) explained how simpler forms have arisen from this basic hair type, represented on the cotton plant by a short tuft-like growth comprising six or eight rays. He stated that as the number of rays decrease, ray length increases. Simple unbranched hairs represent the extreme in this evolution.

The respective densities of the many hair types found on cotton vary considerably on different parts of the plant and also between plants. To facilitate these investigations the various hair types were grouped into three classes—(*a*) simple unbranched hairs; (*b*) long stellate forms with two or three rays; (*c*) short stellate forms with upwards of three rays per hair group.

Hair Density.

Although Parnell and MacDonald (1943) and MacDonald, Ruston and King (1944 and 1945) made use of sections or narrow strips of the petiole, midrib and leaf lamina to arrive at comparable hair density counts, others (Parnell, 1927; Peat, 1928; Afzal, 1936) counted the number of hairs within a fixed area of the surface of the leaf lamina. In all instances, the hair density was expressed as the total number of hairs, and no differentiation was made between the various hair types. Usually, a standard leaf, generally the first fully grown leaf below the growing point, was taken from each plant.

Kearney (1923) and Parnell and MacDonald (1942) were able to show that hairiness of the petiole can be correlated with that of the upper and lower leaf surfaces. Hairiness on any one of these areas presupposes that the remainder of the plant will carry a similar hair cover. Thus the hairiness of petiole, midrib or leaf lamina could be employed to present an accurate picture of plant hairiness. In these studies, the midrib was chosen as it represented the part of the plant where the greater portion of the jassid eggs are deposited. An estimate, within each variety, of the proportion of each of the three hair types on the midrib of plants provided a means of associating hair density and hair length with varietal susceptibility as expressed by the plant resistance index.

All counts were made under a binocular microscope, at x10 magnification. Only those hairs in focus along the centre of the underside of the midrib viewed from the side were considered. Values were obtained for the section between the base of the midrib and the nectary, a quarter-inch section on each side of the nectary, and a quarter-inch section approximately midway along the vein.

The choice of the leaf used for these counts was finalized after the association between hairiness and age of leaf was investigated. This involved counting the total number of hairs, irrespective of type, on each leaf in turn on the main stem of plants representing several varieties. Although some hairs were broken off the older leaves, the persistence of the hair scars enabled total counts to be obtained. The degree of leaf expansion was expressed as the measurement between the base of the midrib and the nectary.

The third leaf below the growing point was used to compare hair density between varieties. To ensure that the leaves taken at any one time were approximately of the same age, only leaves from growing terminals were sampled. Ten leaves were counted for each variety. Plant-to-plant variability was very marked within certain varieties, but the variations were rarely of sufficient magnitude to suggest that the mode of sampling would prove inadequate to express the relative varietal susceptibility.

Although no attempt was made to determine the length of the hair cover, classification into hair types provided an estimate of hair length.

Data.

Hairiness and Age of Leaf.

This association was investigated early in the 1943-44 season. Table 6 presents the total numbers of hairs counted between the base of the midrib and the nectary, together with the length of this section of the vein, for main stem leaves of plants of the same age, representing three varieties. The leaves are numbered from the growing point downwards.

Table 6.

HAIRINESS AND AGE OF LEAF.

Leaf No.	Total Hairs.					Length (sixteenths of inch).					Hairs per Unit Length (sixteenth of inch).				
	Plant No.*					Plant No.*					Plant No.*				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1 ..	25	7	35	31	29	5	5	4	3	7	5·0	1·4	8·8	10·3	4·1
2 ..	26	4	35	32	27	7	9	5	5	8	3·7	0·4	7·0	6·4	3·4
3 ..	29	4	37	30	31	10	10	6	6	10	2·9	0·4	6·1	5·0	3·1
4 ..	34	2	32	31	28	11	9	8	8	12	3·1	0·2	4·0	3·9	2·3
5 ..	28	8	35	31	24	11	11	8	10	13	2·6	0·7	4·4	3·1	1·9
6 ..	27	4	30	26	12	12	11	8	9	12	2·3	0·4	3·8	2·9	1·0
7 ..	20	5	27	26	20	13	12	8	10	11	2·0	0·4	3·4	2·6	1·8
8 ..	25	2	23	22	13	16	13	8	9	10	1·6	0·2	2·9	2·4	1·3
9 ..	20	1	23	18	9	16	11	9	8	9	1·3	0·1	2·6	2·3	1·0
10 ..	23	0	20	21	4	16	8	7	9	8	1·5	0	2·9	2·3	0·5
11 ..	23	0	†	19	11	14	9	†	7	7	1·6	0	†	2·7	1·6
12 ..	22	0	†	12	10	12	8	†	6	10	1·8	0	†	2·0	1·0
13 ..	9	..	†	17	..	10	..	†	6	..	0·9	..	†	2·8	..

* No. 1 = Labh Singh's Selection—4F Hirsutum; No. 2 = Triumph 124; Nos. 3, 4, and 5 = III–26–0–0–0.

† Leaves shed from plant.

The earliest formed leaves on these plants were produced when soil moisture and soil nutrients were adequate. Leaf area progressively increased until unfavourable growing conditions and the influence of crop formation retarded plant development. This slowing down in the growth rate is evident with leaf No. 8 in Table 6.

During the early stages of growth, hairiness increased as new leaves were formed, but this increase was not maintained on leaves formed after the crop had developed. The variation in hair cover on successive leaves is a function of plant growth and was recognized by Afzal (1936) and MacDonald, Ruston and King (1946).

Although the number of hairs may increase as new leaves are formed, hair density is a factor related to the growing conditions ruling at the time of leaf expansion. This effect was seen when hairiness was expressed as density per unit of midrib length in Table 6. Hair density remained more or less uniform, as continued leaf expansion offset the increase in hair numbers up to a point corresponding with leaf 8 on these plants. Above this, reduced leaf measurements caused a continuous increase in hair density.

The rate of increase in the number of hairs per leaf as new leaves are formed is not of sufficient magnitude to influence greatly the plant's ability to withstand jassid infestation, though low values for the early formed leaves may influence susceptibility should populations be high at the time these leaves are formed. Such conditions are sometimes satisfied in late planted crops.

Hairiness on Various Sections of Midrib.

In a series of hair counts made during the 1944-45 season, the association of hair types and hair density showed considerable variation on different sections of the midrib. This variation can be seen in the data set out in Table 7.

Table 7.

MEAN DENSITY OF HAIR TYPES ON DIFFERENT SECTIONS OF THE MIDRIB.

Variety.	Base to Nectary.			$\frac{1}{4}$" Section below Nectary.			$\frac{1}{4}$" Section beyond Nectary.			$\frac{1}{4}$" Section at Midpoint of Vein.		
	Hair Type.*			Hair Type.			Hair Type.			Hair Type.		
	1	2	3	1	2	3	1	2	3	1	2	3
III.–26–0–0–0 ..	17·5	8·8	6·7	10·7	1·7	·5	11·3	2	2·7	10·8	2·5	4·3
III.–505	13·2	5·3	·3	9·0	1·1	·1	9·0	3·0	·3	9·1	4·1	·2
B_1–29–2–0	12·5	7·3	1·1	7·4	1·3	·6	6·3	2·9	1·1	4·6	2·8	2·2
B_1–9–3–0	7·8	8·2	·4	4·5	1·7	·3	5·6	1·9	1·2	4·8	2·7	2·1
Ambassador	5·2	4·8	·5	2·7	1·5	·3	3·5	2·8	1·3	1·5	2·3	2·3
Miller 41	8·3	3·2	·3	3·6	·3	·2	2·8	1·3	1·1	2·8	2·9	·9
Stoneville 150 ..	8·3	2·6	·8	2·8	·2	·5	1·4	·7	2·3	2·2	·7	2·9
New Boykin 90 ..	4·8	3·1	·5	1·4	·1	·3	1·1	·6	1·7	1·1	1·2	3·2
Lone Star 30 ..	4·8	2·2	·7	1·0	·2	·2	1·3	·2	1·6	1·7	1·6	1·8
Triumph 124 ..	1·1	·1	·9	·2	..	·3	·4	..	1·2	·4	·3	1·4
New Mexico Acala 120	·9	·1	·4	..	..	·4	·7	..	·7	1·8	·1	·8

* Hair types: 1 = simple unbranched hairs; 2 = long stellate hairs; 3 = short stellate hairs.

The general picture outlined above was confirmed by further hair counts made during the same season. However, the individual values differed for the same varieties, as both plant growth and time of leaf sampling varied.

A clearer picture of the variation in hair density on the midrib for varieties can be gained from the diagrams in Figs. 7-10. These diagrams also serve to show how density may differ within varieties.

Fig. 7.

Distribution of Hair Types on the Lower Surface of the Midrib. Varieties III-26-0-0-0; III-509; and B_1-29-2-0.

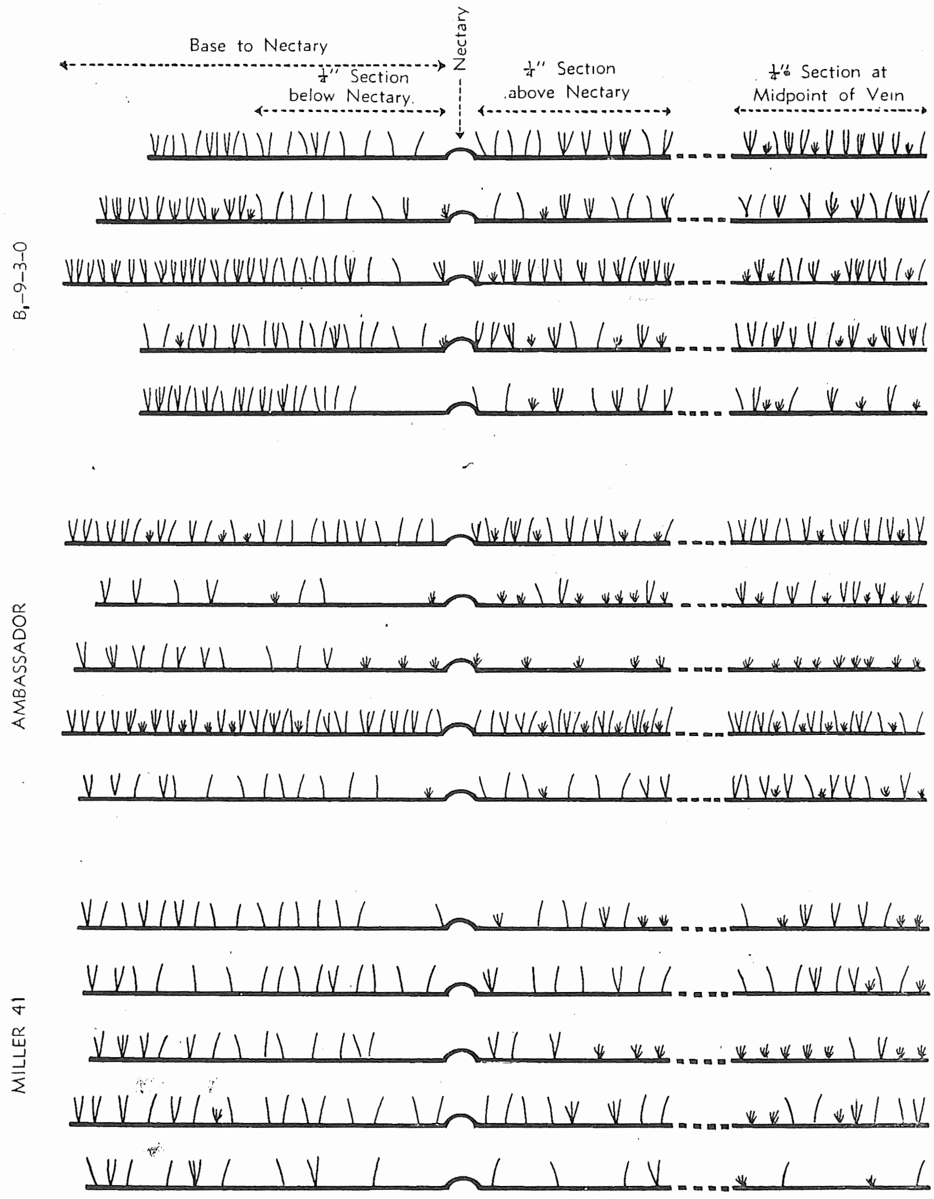

Fig. 8.

Distribution of Hair Types on the Lower Surface of the Midrib.
Varieties B_1-9-3-0; Ambassador; and Miller 41.

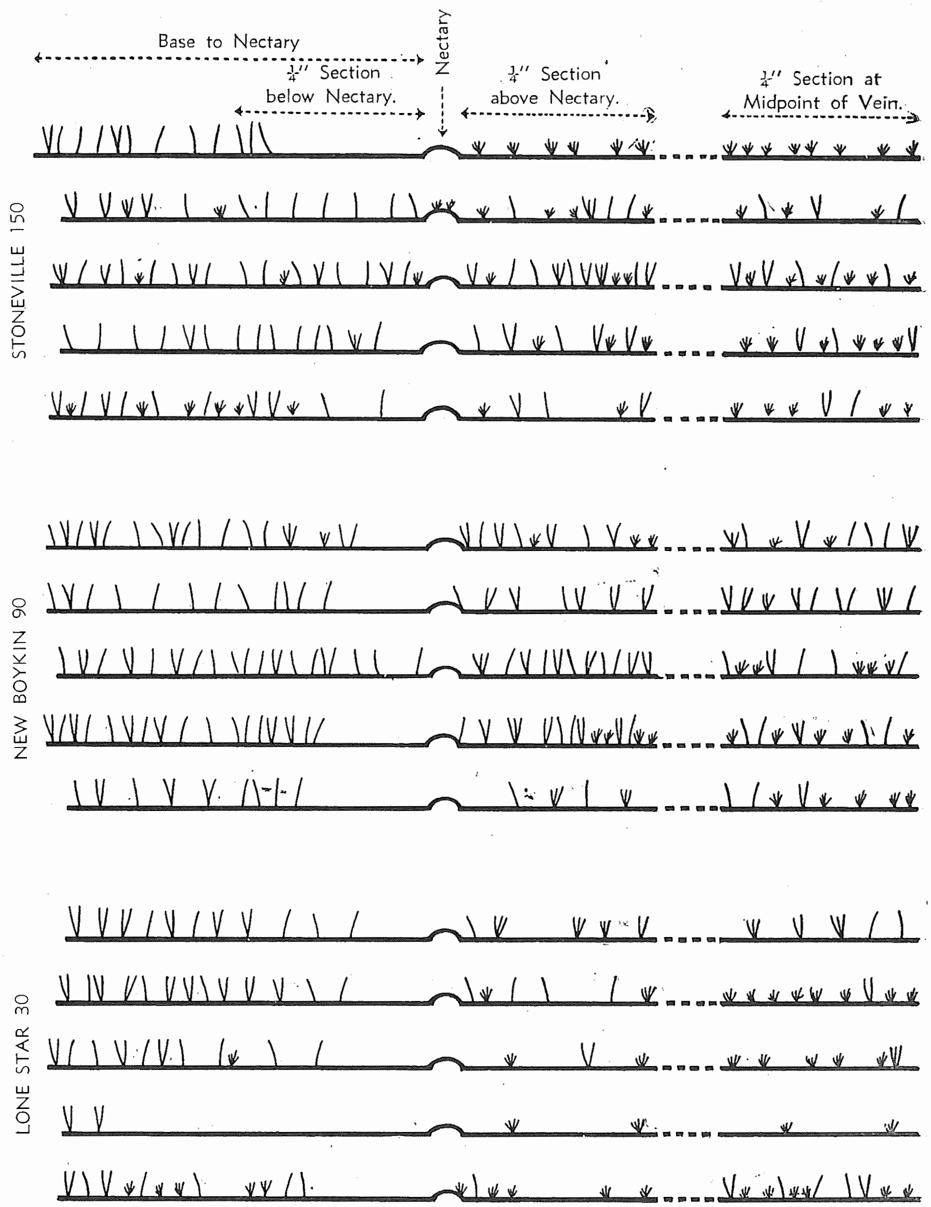

Fig. 9.

Distribution of Hair Types on the Lower Surface of the Midrib. Varieties Stoneville 150; New Boykin 90; and Lone Star 30.

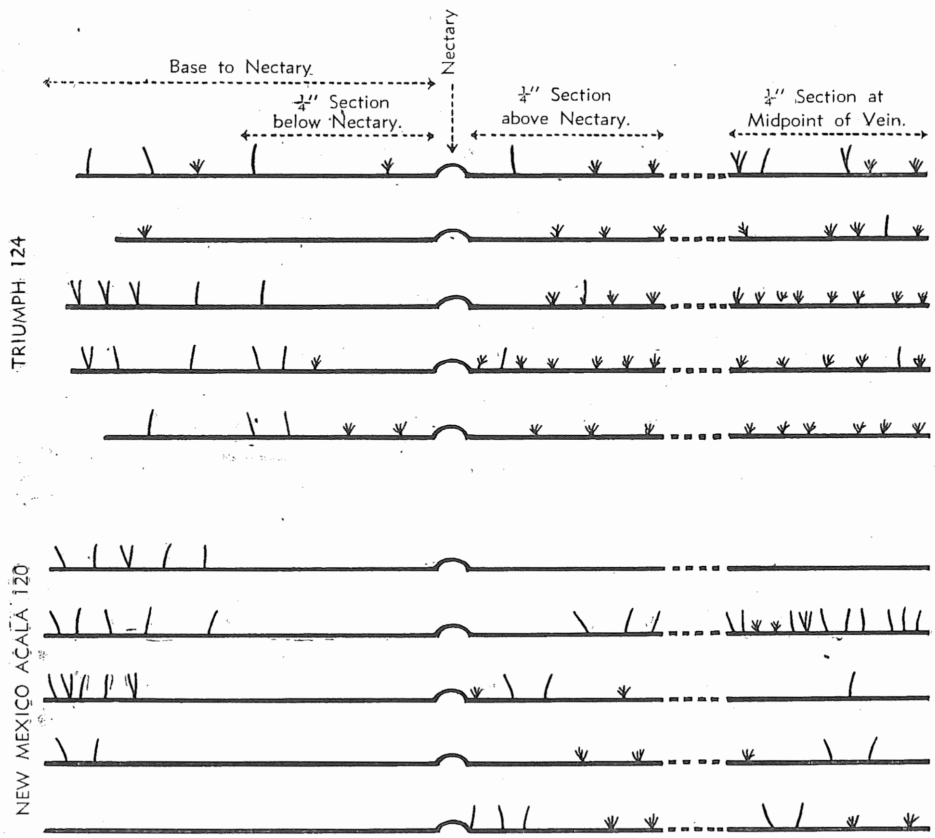

Fig. 10.

Distribution of Hair Types on the Lower Surface of the Midrib. Varieties Triumph 124 and New Mexico Acala 120.

Table 8.

HAIR DENSITY ON DIFFERENT SECTIONS OF THE MIDRIB (PER $\frac{1}{16}$ IN.).

Variety.	Base to Point ¼" from Nectary.	¼" Section below Nectary.	¼" Section above Nectary.	¼" Section at Midpoint of Vein.
III.–26–0–0–0	5·03	3·23	4·0	4·4
III.–505	4·1	2·55	3·08	3·35
B_1–29–2–0	2·37	2·33	2·58	2·4
B_1- 9–3–0	2·25	1·63	2·18	2·4
Ambassador	1·15	1·13	1·9	1·53
Miller 41	1·51	1·03	1·3	1·65
Stoneville 150	1·49	·88	1·1	1·45
New Boykin 90	1·08	·45	·85	1·38
Lone Star 30	1·26	·35	·78	1·28
Triumph 124	·34	·13	·4	·53
New Mexico Acala 120 ..	·02	·1	·35	·68

In all varieties examined, it was generally found that hairiness extended from the petiole on to the lower surface of the midrib to a degree dependent on the hairiness of the variety under examination. This extension from the petiole was evidenced by the association of hair types and their relative densities. Simple unbranched and long stellate hairs predominate on both this region of the midrib and the petiole.

Of the various sections of the midrib sampled, the quarter-inch section on the basal side of the nectary supported the least number of hairs. Table 8 also shows this, values being expressed as hairs per sixteenth of an inch.

Beyond the nectary, towards the tip of the vein, both hair density and the proportion of the three hair types considered were quite unrelated to that found on the basal portion of the midrib. The density of the simple unbranched hairs was more or less the same for each quarter-inch section sampled, though long stellate and short stellate hairs became more numerous with decreasing vein diameter.

Table 9.

CORRELATION BETWEEN HAIR TYPE AND JASSID RESISTANCE.

Variety.	Hairs on ¼″ Section below Nectary. Hair Type.* 1	2	3	Total Hair Types 1 and 2.	Total all Types.	Plant Resistance Index.	
III.–26–0–0–0	10·7	1·7	·5	12·4	12·9	..	Highly Resistant
III.–505	9·0	1·1	·1	10·1	10·2	..	ditto
B_1–29–2–0	7·4	1·3	·6	8·7	9·3	5·23	Moderately Resistant
B_1-9–3–0	4·5	1·7	·3	6·2	6·5	5·06	ditto
Ambassador	2·7	1·5	·3	4·2	4·5	4·84	Slight Resistance
Miller 41	3·6	·3	·2	3·9	4·1	3·56	ditto
Stoneville 150	2·8	·2	·5	3·0	3·5	3·35	ditto
New Boykin 90	1·4	·1	·3	1·5	1·8	3·06	Moderately Susceptible
Lone Star 30	1·0	·2	·2	1·2	1·4	2·94	ditto
Triumph 124	·2	..	·3	·2	·5	2·83	ditto
New Mexico Acala 120 ..	..	..	·4	..	·4	2·45	Very Susceptible

* Hair types: 1 = simple unbranched hairs; 2 = long stellate hairs; 3 = short stellate hairs.

Hairiness and Jassid Resistance.

In Table 7, the varieties are listed in the order of decreasing hair density, an arrangement that corresponds closely with decreasing jassid resistance, expressed as plant resistance indices. This correlation between the total number of hairs and the plant resistance index can also be obtained if hair density is expressed as the total of simple unbranched and long stellate hair types (Table 9).

The values for plant hairiness were compiled from data collected during the 1944-45 cotton season, when jassid populations were only moderately high. The values for plant resistance indices were calculated from the results obtained during the 1942-43 cotton season, when jassid populations were high and the number of plant reaction types within varieties enabled a more accurate estimate of jassid resistance to be made. The strains III-26-0-0-0 and III-505 were not available during the 1942-43 season, but the former proved almost completely immune to jassids during the moderate jassid attack of the 1944-45 season and was given a mean plant resistance index of 5·98. The strain III-505 is closely allied to strain III-509, which was assigned a mean plant resistance index of 5·99 during the 1942-43 season.

In the region of the nectary, hairiness increased with resistance. Resistant plants possessed a uniformly long dense cover for the entire length of the vein. Highly susceptible plants, on the other hand, were almost devoid of hairs for the greater length of the midrib but possessed a few long hairs towards the base and scattered hairs beyond the nectary towards the vein tip. These latter hairs were largely of the short stellate type. As plant hairiness and therefore jassid resistance increased, the extension of hairiness from the petiole became more pronounced. At the same time hairiness between the nectary and the vein tip intensified. In all cases this increased hairiness was due to a greater density of the longer hair types (Table 7).

Though plant hairiness tended towards a distinctive pattern for each variety, plant-to-plant variability within varieties was noticeable (Figs. 7-10). This variability depended largely on the purity of the plant material under examination. Pure strains of high jassid resistance, such as III-509 and III-26-0-0-0, showed little variation in hair density provided the plants compared were growing under similar conditions. Among commercial varieties, variation was more marked, particularly in those possessing a moderate resistance to jassid attack. Here resistant and highly susceptible plants were encountered in the same stand. The strain III-26-0-0-0 has been derived from a selection of resistant plants among a stand of the commercial variety Miller.

Discussion.

The association between hair density and susceptibility to jassid attack was repeatedly established throughout the course of these investigations. Though it has been suggested that genetically linked characters may be responsible for this apparent association (Afzal and Abbas, 1944), the findings presented in this paper discount this possibility and point to a direct relationship between hairiness and jassid resistance.

Even when resistant plants are grown in areas subject to high jassid populations, nymphs are rarely found on the plants, though considerable adult feeding injury may develop. Such injury is invariably near the distal portion of the veins where the hair cover is much shorter. Elsewhere on the veins, feeding and oviposition by the jassids are prevented. Lal and Husain (1945) stressed the association between lack of oviposition sites and resistance rather than the inability of the insect to feed on hairy leaves.

While some plants may appear hairy, the midrib is relatively bare in the region of the nectary. Oviposition may occur on such plants when pest populations are high in the vicinity. Classification of plants into grades of jassid resistance is possible by visual observation, using the criterion hair density on the quarter-inch section of the midrib immediately below the nectary. A rough classification of varieties into broad groups can be undertaken by this method, though differentiation within groups is not possible.

Although a dense hair covering for the entire length of the vein is necessary for jassid resistance, the length of this covering is equally important. Parnell, King and Ruston (1949), investigating jassid resistance and hairiness of the cotton plant in South Africa, came to the same conclusion. The prevalence of the simple unbranched, and to a less extent the long stellate, hairs governs the length of the hair cover on the leaf veins. The numbers of these types increase directly with resistance. The former type occurs more uniformly over the length of the midrib and would thus be directly associated with resistance to attack. The short stellate hairs play little part in conferring resistance, their numbers in the general hair cover remaining fairly uniform between varieties, and may predominate on the more susceptible varieties, New Mexico Acala, Lone Star and Triumph.

APPLICATION OF RESULTS.

The plant resistance index can be employed by the plant breeder to differentiate material only under appreciable levels of jassid population. Varieties or strains evolved for jassid resistance may be rogued under this visual method of estimating susceptibility but differentiation becomes difficult among material exhibiting a measure of resistance to the pest. Such material can be separated only in years of high jassid populations.

A more reliable method of differentiating material evolved for resistance to jassid attack can be based on an estimation of plant hairiness. This can be undertaken in the field and involves the selection of those plants exhibiting a uniformly long dense hair cover for the entire length of the major veins.

Although hairy plants may exhibit a dense hair covering on the leaves, petioles and stems, midrib hairiness is the safest guide to jassid resistance.

Where a dense, long hair cover is found on the midrib, hairiness on the remainder of the plant is invariably assured. A further check on the potential resistance of a plant is obtained if it is established that the circumference of the midrib below the nectary is clothed with a long dense hair cover. The setting of a high standard for both density and length of hairs on the midrib will ensure that all material selected will possess a high measure of resistance to attack at all levels of jassid population as well as over a wide range of growing conditions.

ACKNOWLEDGMENTS.

This work could not have been attempted without the co-operation of the many farmers throughout the Central and Upper Burnett districts on whose farms observations were carried out. All experiment plots were located on Mr. A. Tomlin's property at Gayndah. Mr. S. Marriott, at the time Plant Breeder at Biloela Regional Experiment Station, and several other Departmental officers contributed to these studies. All this assistance is gratefully acknowledged.

REFERENCES.

AFZAL, M. 1936. A note on the hairiness of cotton. Ind. J. Agric. Sci. 6: 823.

————, and ABBAS, M. 1944. Cotton jassid (*E. devastans* Dist.) in the Punjab. V. A note on the characters of the plant associated with jassid resistance. Ind. J. Entom. 5: 41-51.

GADDUM, E. W. 1942. Some observations on jassid at the Kenya Coast. Emp. J. Exp. Agric. 10: 133.

HECTOR, J. M. 1936. Introduction to the Botany of Crop Plants. Vol. II. Johannesburg: Central News Agency Ltd.

HUSAIN, M. AFZAL. 1938. The cotton jassid. Paper No. 3. First Conference of Scientific Research Workers on Cotton in India, March, 1937.

KEARNEY, T. H. 1923. Segregation and correlation of characters in an Upland-Egyptian cotton hybrid. U.S.D.A. Bull. 1164.

LAL, K. B. 1938. Anti-jassid resistance in the cotton plant. Emp. Cotton Gr. Rev. 15: 347.

————, and HUSAIN, M. A. 1945. Hairiness on cotton leaves and anti-jassid resistance. Curr. Sci. 14: 153-4.

MACDONALD, D., RUSTON, D. F., and KING, H. E. 1944. Cotton-breeding Station, Barberton, —progress reports for season 1942-43. Emp. Cotton Gr. Corp. Progress Reports 1942-43: 18-36.

————————. 1945. Cotton-breeding Station, Barberton —progress reports for season 1944-45. Emp. Cotton Gr. Corp. Progress Reports 1944-45: 14-28.

MAY, A. W. S. 1950. The cotton jassid problem in Queensland. Qld. J. Agric. Sci. 7: 24-41.

MOERDYK, J. L. 1927. The cotton jassid in South Africa. Trop. Agric. 4: 46-7, 73.

MONTEITH, J., JR., and HOLLOWELL, E. A. 1929. Pathological symptoms in legumes caused by the potato leaf hopper. J. Agric. Res. 38: 649-77.

PARNELL, F. R. 1925. The breeding of jassid resistant cottons. Report for the season 1924-25. Emp. Cotton Gr. Rev. 2: 330-6.

————. 1927. Cotton-breeding Station, Barberton—Report for season 1925-26. Emp. Cotton Gr. Corp. Rpts. Received from Expt. Stas. 1925-26: 24-25.

————, and GUTSCHE, D. E. A. 1928. Cotton-breeding Station, Barberton—Report for season 1926-27. Emp. Cotton Gr. Corp. Rpts. Received from Expt. Stas. 1926-27: 52-62.

————, KING, H. E., and RUSTON, D. F. 1949. Jassid resistance and hairiness of the cotton Plant. Bull. Entom. Res. 39: 539-575.

————, and MACDONALD, D. 1942. Cotton-breeding Station, Barberton. Report for season 1940-41. Emp. Cotton Gr. Corp. Rpts. Received from Expt. Stas. 1940-41.

————————. 1943. Cotton-breeding Station, Barberton. Report for season 1941-42. Emp. Cotton Gr. Corp. Rpts. Received from Expt. Stas. 1941-42.

PEAT, J. E. 1928. Cotton-breeding Station, Gatooma: Report 1926-27. Emp. Cotton Gr. Corp. Rpts. Received from Expt. Stas. 1926-27: 106.

POOS, F. W., and SMITH, FLOYD, F. 1931. A comparison of oviposition and nymphal development of *Empoasca fabae* (Harris) on different host plants. J. Econ. Entom. 24: 361-71.

VERMA, P. M., and AFZAL, M. 1940. Studies on the cotton jassid (*Empoasca devastans* Distant) in the Punjab. I. Varietal susceptibility and development of the pest on different varieties of cotton. Ind. J. Agric. Sci. 10: 911-26.

WORRALL, L. 1923. Jassid resistant cottons. U.S. Afr. Dept. Agric. J. 7: 225-228.

YOUNGMAN, W. 1930. The evolution of the cotton hair. Emp. Cotton Gr. Rev. 7: 7-12.

APPENDIX.

THE INFLUENCE OF PLANT HAIRINESS ON OTHER COTTON PESTS.

During these investigations the effect of plant hairiness on the activity of other cotton pests was observed. Generally speaking, the presence of a dense clothing of hairs on the leaf lamina is a definite hindrance to insect mobility. Mirids and other small active insects do not behave normally on such plants. There is no evidence to show that the incidence of the larger cotton bugs and lepidopterous larvae is unduly affected by plant hairiness.

It has been suggested that the cotton aphis (*Aphis gossypii* Glov.) breeds more freely on hairy plants. At no time were aphids a major problem in plots, although they were commonly located on the plants. Aphis populations were relatively high in a varietal trial during the 1942-43 season and the population density within each variety was estimated. Three fully developed leaves were selected at random from each of five plants in each of three plots, making a total of 45 leaves for each variety. The aphis infestation was classed into four grades:—(1) no aphids per leaf; (2) 0-20 aphids per leaf; (3) 20-50 aphids per leaf; and (4) over 50 aphids per leaf. The results obtained from this classification were:—

Variety.	Number of Leaves in each Grade.			
	Grade 1.	Grade 2.	Grade 3.	Grade 4.
New Mexico Acala 120	43	2	..	..
New Boykin	42	3	..	..
Miller	38	7	..	..
B_1–29–2–0	22	23	..	..
B_1–9–3–0	22	21	2	..
Stoneville	21	16	5	3
III.–26–0	15	28	2	..
III.–509	13	23	5	4

These figures suggest that conditions in jassid resistant varieties or strains favour aphis infestation. This phenomenon can scarcely be attributed to conditions within the plant and more likely is associated with the plant hairs.

Once aphids are established on the leaf, plant hairs would not greatly inconvenience their survival. However, these hairs would restrict the movement of aphis parasites and predators and may act as a deterrent to these latter insects.

Onion thrips (*Thrips tabaci* Lind.) were also found quite commonly on hirsute plants, their small size enabling them to move quite freely on the surface of the leaf. A dense hair covering would afford a certain measure of protection to this insect. However, high thrips populations were never recorded on hairy plants.