THE COTTON JASSID PROBLEM IN QUEENSLAND.

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

SUMMARY.

The cotton jassid (Empoasca maculata) *affecting American Upland varieties of cotton grown in Queensland is shown to differ from the more important species affecting cotton elsewhere in that it restricts its activity to the terminal growth of the plant.*

Oviposition and feeding injuries are intensified with increase in jassid population on the plant; severe damage suppresses plant growth and depresses yields of lint.

Early spring rains influence jassid development during the early summer, but the most severe injury is associated with the late summer rainy period, when the plants are growing rapidly.

Soil condition, cultural treatment, time of planting, and variety of cotton are shown to influence plant susceptibility to jassid injury.

The breeding of jassid-resistant varieties is stated to be the only control measure which is likely to be practicable.

INTRODUCTION.

Jassids have attained importance as pests of cotton in several countries where this crop is grown commercially. Though the species concerned and their respective habits vary considerably in the several regions where these pests are recorded, the damage produced and the ultimate effect on plant growth and crop formation are somewhat similar.

In contrast with the position overseas, it is only in recent years that the jassid problem has become a widespread major factor in cotton production in Queensland. Though damage may fluctuate from year to year, the increasing importance of this pest some years ago threatened to limit production in areas suitable for the development and expansion of cotton growing. Accordingly, a study of the problem was initiated in 1941. The specific identification of the jassids concerned preceded investigations into their relative importance as pests, and once the identity of the cotton jassid was established an observational study of the bionomics and types of damage produced was undertaken. This work was followed by a more detailed study of plant reaction to attack and the part played by plant hairiness, which will be reported in a later paper.

SPECIES OF COTTON JASSIDS.

The earliest known records of jassids attacking cotton come from India, where according to Verma and Afzal (1940) introduced American and Egyptian varieties were damaged in Bihar province in 1906. These workers traced the incidence of jassid pests in the Punjab in 1913-14, Cawnpore in 1916, North Bihar in 1919, Madras in 1935, and Sind in 1936. Prior to the introduction of American Upland cotton into the Punjab on a commercial scale, jassids were of little importance, as the Asiatic cotton (*Gossypium arboreum* var. *neglectum* H. et G.), grown previously, is practically immune to the pest (Afzal, 1941). Further records from the Indian region show that this pest is now widespread, while Gwynn (1938) recorded jassids as a pest of cotton in Ceylon.

In India, numerous species have been recorded from cotton, though the taxonomic validity of some of the species is uncertain (Husain, 1938). According to Husain, by far the most important species (*Empoasca devastans* Dist.) injures crops in the Punjab, Sind and Madras, while two other species—*E. gossypii* De Long and *E. notata* Mel—have also been recorded from those areas. Cherian and Kylasam (1938) stated that two species—*E. devastans* Dist. and *E. formosana* Paoli—are found on Cambodia, Uppana and Karunganni cottons in Madras Province, but the former is by far the more abundant. Recently three new species—*E. minor* Pruthi, *E. kerri* var. *motti* Pruthi, and *E. punjabensis* Pruthi—were recorded from cotton in the Punjab, but they are of little economic importance (Afzal and Abbas, 1945).

Verma and Afzal (1940), quoting from earlier records, cited *Empoasca flavescens* F. as a pest of cotton in the Philippines. The species implicated in Fiji was described by Anson (1928) as a small yellow jassid but has not been identified.

In Africa the dominant species on cotton (*Empoasca facialis* Jac.) has been recorded from the French Sudan, Nigeria, Southern Rhodesia, Uganda, Kenya, Anglo-Egyptian Sudan, Swaziland, Transvaal, and other cotton-growing regions. Husain (1938), in a survey of species attacking cotton, cited *E. facialis* as the dominant species in Africa. He stated also that *Erythroneura lubiae* China is found on cotton in the Anglo-Egyptian Sudan and Italian Somaliland, and that other species (including *E. distinguenda* Paoli and *E. benedottoi* Paoli) have also been recorded from cotton, though their economic status is uncertain.

In Queensland, Ballard (1925) recorded the presence of jassids in large numbers in crops at Mount Larcom and in the vicinity of Emerald, and stated that a few individuals may be encountered in crops elsewhere. During the 1935-36 season the pest caused serious damage throughout the Callide and Burnett Valleys. Sloan (1938) found the pest widespread throughout the cotton districts of Central Queensland. At present, this pest occurs in all the cotton-producing areas of the State.

The earliest records of jassids as pests of cotton in Queensland do not designate the species concerned, but merely indicate that the pests belonged to the genus *Empoasca*. For a considerable time their identity remained obscure and a great deal of the damage now known to be caused by the cotton jassid was wrongly attributed to the tomato jassid (*E. terra-reginae* Paoli). This latter species is frequently associated with cotton, particularly during the early life of a crop and was identified as a pest of cotton at Biloela (Sloan, 1938). Though Sloan stated that damage to cotton in the Upper Burnett, Callide and Dawson Valleys may have been due to jassids of the genus *Empoasca,* he discounted the possibility that *E. terra-reginae* was the only jassid concerned and concluded that ''other unidentified species may also be implicated.''

Following a study of jassid material collected from several cotton-growing districts in 1941, it was obvious that another and more important species was associated with the typical damage attributable to jassid attack. This species has been described (Evans, 1941) as *Empoasca maculata.* Later, cotton jassid material in the collection of the Queensland Department of Agriculture and Stock, that had been collected from cotton severely affected by jassids at Yamala, near Emerald, in 1924, was identified as *E. maculata.*

Apart from *E. maculata* and *E. terra-reginae,* two other species—*E. alfalfae* Evans and *Thamnotettix argentata* Evans—may also be found on cotton, but they are of no economic importance.

A comparison of the habits and damage of the Indian and African species, *E. devastans* and *E. facialis,* with *E. maculata* suggests that the jassids attacking cotton overseas have somewhat different habits from the principal pest species here. Unlike *E. maculata, E. devastans* is not confined to the region of terminal growth, while *E. facialis* may be found on all parts of the plant. In both Africa and India the general picture of plant injury is much the same as found in Queensland; workers in both these countries (Parnell, 1925; Moerdyk, 1927; Husain, 1938) recording leaf curling accompanied by discolouration and final necrosis of the damaged tissues. The information given by Parnell (1925) shows that the mode of jassid injury and the factors governing such injury are far different in Africa from those experienced in Queensland, though the ultimate effect on cropping may be the same. The African species may oviposit on any part of the plant, causing injury symptoms to develop rapidly, and the majority of leaves on each plant may support a nymphal population. Leaf curling and discolouration are also features of the attack, while total defoliation of plants is not uncommon. Another characteristic which differentiates *E. facialis* from *E. maculata* is the ability of the African species to produce severe damage during years which do not favour normal plant development.

BIONOMICS OF EMPOASCA MACULATA.

Description of the Adult.

The adult of *E. maculata* (see Fig. 1) is a bright-yellow leaf hopper. The distinguishing external characteristics of the species are given by Evans (1941) as follows:—

> "*Length* 3 mm. General colouration bright yellow. *Head,* ventral surface white, but for the fronto-clypeus antero-laterally, which is green; eyes black. Crown yellow, with or without white markings; ocelli marginal, large. *Pronotum* yellow with irregular white markings, usually four in number, lying against the

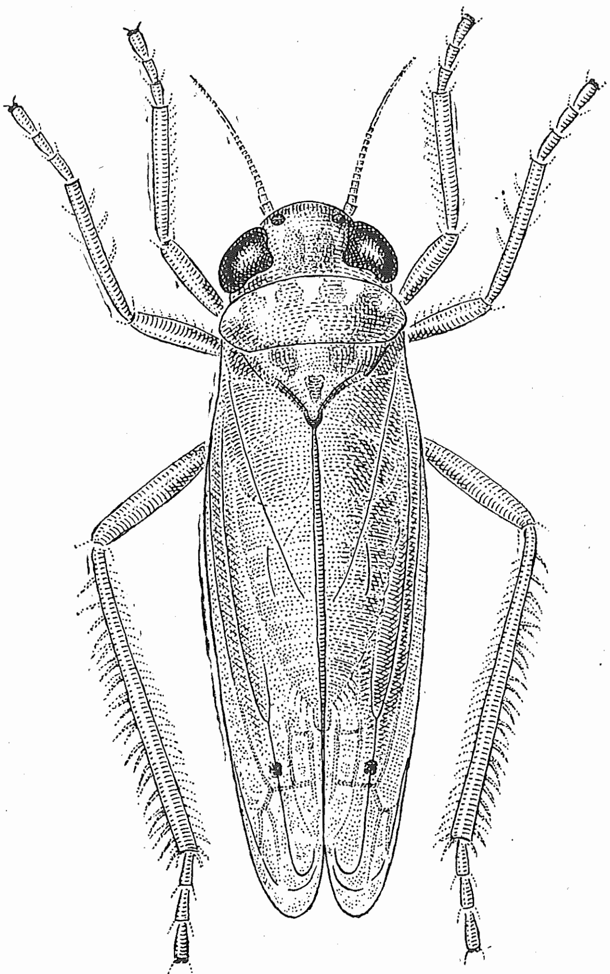

Figure 1.
Adult of *Empoasca maculata* (x30).

[*Drawing by William Manley*

anterior border. *Scutellum* yellow with white markings. *Tegmen* yellow, hyaline with a distinct brown spot in the distal portion of the cell that lies between the claval suture and Cu 1. . . . ."

"*Note.—E. maculata* resembles *E. terra-reginae* Paoli in the shape and colour pattern of the head and pronotum. It differs in colour, being yellow and not green, and may be readily identified by the presence of the brown spot in the tegmen."

Development and Behaviour.

The field survey of the cotton jassid problem did not afford an opportunity for a detailed study of the life history of *E. maculata*. It seems, however, that given ideal conditions for breeding and survival, the population increase is extremely rapid and the number of eggs laid by each female relatively high. For the related species, *E. terra-reginae,* the life cycle is completed in from 25 to 30 days in June at Bowen (Atherton, 1933).

Oviposition.

Egg-laying is only associated with leaves of a growing terminal and leaves that have not fully expanded. Thus, other factors being equal, population increase will be correlated with the rate at which new leaves are formed by the plant. Whenever conditions favour rapid and sustained vegetative growth, jassid development can proceed apace on susceptible varieties. Conversely, should plant growth be retarded, increase in jassid population is slowed also.

The eggs are placed principally within the tissues on the undersurface of the larger leaf veins, but may be found also in the petioles and the terminal portions of the stems. The eggs, sickle shaped and faint greenish in colour, are inserted singly with their long axis parallel to the direction of the vein. The number of eggs laid in any part of the vein varies with its diameter, the greater number being laid in the basal half.

Oviposition punctures may be evident on the young leaves soon after they open, and the number of eggs per leaf on a growing terminal increases on successive leaves to attain a maximum on the third or fourth leaf below the growing point.

Nymphs.

Hatching invariably occurs in the early morning and nymphs arising from those eggs deposited in the petioles and stems migrate to the nearest leaves soon after hatching. The newly-emerged nymphs are almost colourless and relatively inactive, sheltering in leaf folds or alongside the larger veins. With feeding and subsequent growth, activity increases and the individuals assume a faint yellowish-green colour. The more mature nymphs and the pre-adult stage are coloured a uniform rich yellow.

The nymphs are particularly active when disturbed, moving with a characteristic sideways and then forward motion in search of shelter. They are sensitive to direct sunlight, and soon seek shelter on the undersurface when leaves are turned for examination. The early instar nymphs are particularly difficult to dislodge from the foliage by shaking, while the almost mature nymphs, as well as the pre-adult stage, hop and move about the plant quite freely when disturbed. This greater degree of mobility also enables them to spread from the leaves where the eggs were deposited.

Adult.

The adults are very active and readily move from plant to plant. When disturbed, they fly rapidly, seeking shelter on the undersurfaces of leaves of plants in the vicinity. When confined to glass tubes in midsummer, adults failed to survive longer than 24 hours without food, but when supplied regularly with fresh cotton leaves this period was increased to 12 days. However, the duration of adult life in the field may be even longer.

Feeding Habits.

Feeding is confined to veins on the undersurface of the leaf, and though the adult and more mature nymphs may ingest cell sap from the larger veins, most feeding is associated with the lesser veins. Chloroplasts taken up in the sap may give rise to a small green spot in the abdomen of the semi-transparent early stage nymphs. The insect remains stationary for a considerable period while feeding, piercing and re-piercing the veins with its proboscis.

Distribution on the Cotton Plant.

Newly-emerged nymphs usually complete their development on the leaves in which the eggs were deposited, and nymphal populations are rarely associated with the more newly formed leaves of a terminal unless plant growth has been arrested. Nymphal development is completed before many more new leaves are formed, and therefore the densest populations are between the 3rd and 6th leaves from the growing point. Below this region the nymphal population decreases sharply and consists of more mature individuals. In a severe infestation, as many as 30 nymphs may be found feeding under a single leaf, while a six-leaved terminal may carry a population of over 100. The marginal curling associated with such an infestation provides ideal shelter throughout the development of the nymphs.

The adults may be encountered on any part of the foliage but are more usually found in the vicinity of the growing point, where egg-laying activity is centred.

Though the leaves at the apex of the main stem invariably carry the greater proportion of the population associated with an infested plant, all growing points provide a medium for egg-laying and nymphal development. The growing points of the main stem and vegetative branches provide better conditions for jassid breeding than those of the fruiting and extra-axillary branches. The diagrammatic sketch in Figure 2 is an example of the distribution of the population on an infested plant selected at random.

Alternate Hosts.

Early in each cotton season, *E. maculata* presumably spreads from its overwintering hosts and infests the new season's crop. Possible sources of infestation would be expected in those areas more subject to regular attack, and accordingly a host survey was undertaken to shed light on this aspect of the problem.

An examination of ratoon cotton has failed to reveal the presence of jassids during winter months. As the old stalks are invariably cut down or destroyed by stock prior to this period, there is no growth which could provide facilities for overwintering. However, as new foliage develops in the early spring, ratoon cotton may become infested and maintain the pest until the new season's crop is sown.

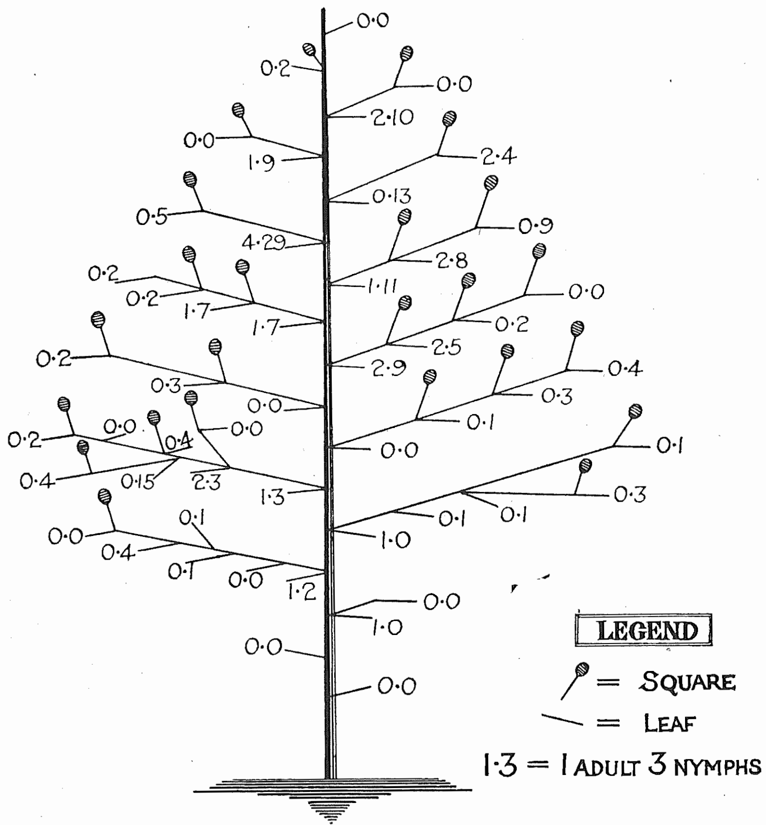

Figure 2.
Diagram Showing Distribution of Adults and Nymphs of *Empoasca maculata* on a Cotton Plant.

[*Drawing by William Manley.*

For a number of years the practice of ratooning cotton has been discouraged, and ratoon crops are now so rarely encountered that they could hardly give rise to widespread jassid infestation. Newly planted crops have become infested early in the season where no ratoon or standover cotton could be associated with this infestation.

Since ratoon and standover cotton plants do not normally serve as overwintering hosts, a thorough search was made of all plants which might support the insect. The comparative absence of jassids in certain years and their appearance in crops growing on newly cleared land, far removed from areas where cotton has been cultivated previously, suggests that other hosts are widespread. Though a large number of weeds and shrubs was examined, the number found to support the cotton jassid was surprisingly small. The significance of each host is discussed below.

Clerodendron tomentosum R. Br. (Verbenaceae) is found among regrowth monsoon forest throughout the Central and Upper Burnett. It is a very widely distributed tall shrub or small tree, the foliage and inflorescence of which may or may not exhibit a velvety pubescence.

In one locality near Gayndah, a number of these shrubs carried a heavy infestation of adult jassids towards the end of June, but the population decreased fairly rapidly as the winter progressed. No nymphal instars were recorded during this period. However, the adult infestation was noticed only in one year, and had originated from a heavily infested cotton crop nearby. In subsequent years, cotton was not grown in this locality and jassids failed to appear on these shrubs, while examination of specimens in other districts also failed to reveal any evidence of jassid infestation during the colder months. This is the only record of a plant supporting jassids during the winter months, but it is doubtful whether it can be classed as an overwintering host for the jassid.

Abutilon sp. (Malvaceae) is a tall growing herbaceous perennial, tomentose, large leaved, and commonly found in monsoon forests and on these forest lands after they have been cleared for cultivation. This plant is often encountered in suitable habitats throughout the Burnett Valley, and was occasionally found to support both adults and nymphs of *E. maculata* when growing in or very near fields of jassid-infested cotton. However, these migrants from the adjacent cotton invariably failed to overwinter on this plant and any infestation of *Abutilon* was of a secondary character.

Sida corrugata Linn. (Malvaceae) is a perennial procumbent weed found growing on forest soils of the Burnett. This weed also supports all stages of the cotton jassid as migrants from neighbouring infested cotton fields. Its occurrence in relatively low-lying areas subject to frost suggests its unsuitability as an overwintering host.

Amaranthus viridis Linn. (Amarantaceae) is a common weed which, when growing among infested cotton, can provide a source of food for adult jassids, but being a summer-growing annual it cannot be an overwintering host. Nymphal instars were never located on this plant.

Chenopodium carinatum R. Br. (Chenopodiaceae), like the previous weeds, was found to support the adult insect only when growing near infested cotton. Its annual habit would detract from its importance as a host, and though feeding does take place, rarely does the adult population attain any magnitude.

During this survey other jassids were encountered, and it was evident that the adults of these species have a much greater host distribution than the nymphs. Also, once their normal host has died or been destroyed, the adults migrate to and feed on other plants not necessarily related to the previous host. Thus it is probable that, after the completion of the cotton season, adult cotton jassids are able to survive on quite a number of plants other than those observed. Furthermore, in the spring months adult populations are seldom large and the pest rarely occurs in appreciable numbers before early January. This would suggest a low winter survival or conditions unsuited to the pest's development during the early summer months. A list of the jassids encountered and their host ranges is set out in the appendix.

Seasonal Population Trends.

The development of jassid populations in the spring is largely dependent on the availability of host plants and suitable seasonal conditions. Once infestation is apparent, the subsequent build-up depends almost entirely on the growth of the crop and the susceptibilities of the cotton varieties concerned.

Early spring rains may promote a relatively high jassid population during the early growth stages of a September-planted crop, but the subsequent population will be dependent on the seasonal conditions during the early summer months. The hot, dry periods of relatively short duration during the early summer and midsummer months periodically check plant growth and retard the rate of population increase. In these circumstances the pest rarely attains significance prior to early square formation. These periodical checks to plant growth in early summer may arrest breeding, but the adults will remain on the plant and resume oviposition in the new growth as the bush responds to more favourable conditions. Should summer conditions fail to produce rapid and continuous growth following good growing conditions in the spring, the rate of population increase will be slowed down and even a heavy infestation early in the life of the crop may eventually fade to unimportance.

In years when regular summer storms occur, adult survival between periods of growth ensures a steady and protracted population build-up until, with the advent of the late summer rains, rapid plant growth, particularly in late planted or late maturing varieties, presents ideal conditions for jassid development and peak populations ensue. The resultant injury to the plants and the relatively dry and cool conditions in the autumn are unfavourable to further jassid development, and populations wane at rates dependent on the severity of these separate influencing factors. Individuals may still persist on the plants until plant growth is finally arrested by the first frosts.

INJURY CAUSED BY E. MACULATA.

Leaf Symptoms and Damage.

Feeding is entirely on the undersurface of leaves, the nymphs, except a small proportion of older nymphs, confining their attention to the smaller veins nearer the leaf margins. The activity of only a very few nymphs per leaf may not greatly affect plant growth, but with larger populations the characteristic symptoms develop.

Loss of cell sap from the veins is followed by reduced turgidity in those regions adjacent to the affected areas, and partial wilting of leaves may result. However, this wilting is usually temporary, though necrosis of the affected tissues occurs on hot, dry days. A more permanent symptom is the downward curling of the leaf margins. At first this may be localised to areas of early feeding, but as the nymphs grow and spread to other parts of the leaves the curling is intensified until entire leaf margins are affected. Continued feeding may so intensify curling that the margins eventually contact the undersurface of the leaves. When viewed from above, those portions of the leaf lamina near feeding punctures gradually become yellowish green. Coupled with this intensified rolling is a general discolouration of the entire leaf, bronzed, yellowish-green and green areas combining to give the leaf a mottled appearance.

Nymphal damage is chiefly around the terminal growth. As these damaged leaves age, a general bronzing of the marginal areas takes place, particularly on surfaces directly exposed to the sun. Later, these bronzed areas extend to the midribs, while the margins redden and the undersurface becomes yellowish-brown. Regions of intense red are usually the sites of heavy nymphal feeding. With further ageing, small black spots develop within each reddened section, and these may expand into appreciable areas of brownish-black dead tissue which eventually coalesce and extend between the larger veins. The necrosis, which may occur long before shedding of leaves, is associated with severe nymphal injury and is rarely encountered even on very susceptible varieties. More usually, leaves merely redden and are shed before necrotic areas have developed to any extent. Invariably, necrosis commences at a point equidistant from the adjacent larger veins, or at the margin of the leaves.

In addition to nymphal feeding, adult activity also influences the extent of leaf damage. The larger veins are punctured during feeding and oviposition; splitting and necrosis follow. The upper portions of the vein elongate more rapidly than the undersurfaces and the vein tips curl downwards. This vein curling proceeds at the same time as the marginal curling due to nymphal injury; crimping and buckling of the leaf results. When conditions are conducive to severe buckling and curling, the lamina of the leaves becomes harsh and brittle to the touch and the undersurfaces are discoloured by jassid excreta.

In varieties possessing jassid resistance, leaf injury is only encountered when the plants are grown in close proximity to heavily infested susceptible varieties; any symptoms that develop are due solely to adult feeding. In such instances, injury is confined to vein extremities.

In effect, jassid injury causes the premature ageing of the leaves and therefore leaf shedding is hastened. There is some evidence to suggest that only fully expanded leaves are shed; those which curl extensively and are restricted in their normal expansion as a result of jassid attack persist long after less damaged leaves have dropped from the plants. Thus the general picture of jassid injury is accentuated.

Injury cannot be attributed wholly to mechanical damage to the tissues, though splitting and distortion in the larger veins do occur. The more characteristic injury—namely, marginal curling and associated leaf discolouration—suggests the injection of some material by the insects whilst feeding, for relatively small numbers of nymphs can produce these symptoms. In contrast, large colonies of aphids, though ingesting cell sap in appreciable amounts, cannot be associated with a comparable amount of leaf distortion and discoloration; aphid damage is, in fact, far less than what would be expected from a population of only a few nymphal jassids.

When the jassid population is destroyed following applications of DDT, new growth will be produced that is entirely free from any evidence of curling or chlorosis, though the damage in the older leaves will persist. Normal leaf production may continue as long as jassids do not reinfest these leaves. This phenomenon suggests that toxic substances are injected by the feeding jassids but are localized in their effect. Overseas workers have previously recognized this fact. Parnell (1927) and Peat (1928) found that, by confining jassids in small containers attached to the cotton leaves, characteristic discolouration of the foliage occurred within that area of the lamina enclosed by the container, but was not ultimately transmitted outwards to the leaf margins. Workers in other crops, particularly Monteith and Hollowell (1929) in their studies of the potato leaf hopper in legumes, have advanced the theory that the insects inject some chemical or enzymic toxin into the tissues of their host plants.

Effect on the Plant and Crop.

Though the existence of an appreciable adult population at a time when the plants are still in the seedling stage may cause severe leaf damage and plant stunting, this form of injury is rarely experienced in an early planted crop and damage is seldom noticeable before the first formed bolls are set. Following the initial signs of jassid activity in early summer, and depending on conditions that favour jassid development, populations may increase rapidly at this time. Later the resultant drain on cell sap due to the high infestation, together with the reduced rate of plant development following increased boll formation, may be sufficient to arrest growth.

Marked differences in the effect on growth are noticeable between plants possessing varying degrees of susceptibility to jassid damage. The growth of highly susceptible plants may be completely suppressed, while those possessing some measure of resistance will continue growing. When plants are restricted in growth, the rate of square formation is materially reduced and flowering occurs nearer to the extremities of the fruiting branches. Some squares are shed. This phenomenon may occur despite adequate soil moisture and can be likened to the effect on crop formation in early summer when soil moisture is inadequate.

Following the cessation of growth, flowering ceases and the undeveloped squares remain bunched within the stunted terminal, to be shed eventually as the plants age. The plants then present a severely curled and bunched appearance, while the petioles of the more severely damaged leaves stand at a greater angle than usual to the main stem. The premature shedding of the older leaves gives the plants an open appearance and reveals the vivid red colour of the stems and petioles.

Suppression of growth, following severe jassid damage, will materially affect the likelihood of profitable crop returns, particularly in the case of late planted crops. Early planted cotton may form a bottom and middle crop of bolls before jassid populations develop sufficiently to prevent further boll formation. Should this early-formed crop be destroyed by *Heliothis armigera* Hb., the possibility of a further crop developing during the remaining period of plant growth may be completely nullified by the larger jassid population that quickly develops on the resultant vegetative growth. Once plant development is retarded or totally suppressed by jassids, recovery is unlikely.

In addition to preventing further square formation, severe jassid populations by reducing plant vigour interfere with the normal development of squares and bolls already formed on the plants. Those squares forming bolls at a time of intense pest activity are rarely retained by the plant, while bolls already formed may either develop slowly or shrivel. Bolls that do develop may not open fully on reaching maturity, while the lint does not "foam" from the opened bracts as in the case of bolls maturing earlier.

The yield of seed cotton is materially affected following jassid attack and differences in yield between varieties are accentuated if planting is delayed and cropping coincides with the high jassid populations of midsummer.

Factors Governing the Extent of Injury.

As stated earlier, the density and dispersal of jassid populations and consequent injury to cotton are dependent on the availability of host plants, seasonal conditions, varieties grown, and crop growth. These major factors, either singly or collectively, are in turn dependent on circumstances which are to some extent often localized.

Early records in Queensland show that jassid damage was confined mainly to cotton grown on the red volcanic soils associated with monsoon forests. Ballard (1925 and 1928) stressed the association between these soils and jassid attack, attributing their connection to unhealthy plant growth due to a deficiency of phosphates and potash. The association of jassid damage in more recent years with a number of soil types has largely discounted this postulate. In some years, very severe damage can be associated with alluvial sandy loams along watercourses, and with the brown clay loams of softwood and brigalow country. As plant growth reflects soil conditions, these must clearly be of some importance in influencing jassid damage. Sloan (1938) suggested this and stated that "the recent increase in the importance of the pest and the extension of the area subject to infestation are probably associated with soil changes brought about by cultivation and cropping practices."

In the case of crops grown on the red volcanic soils, the severe jassid damage experienced is due to an association of two circumstances. Firstly, these soils promote more vigorous plant growth when soil moisture is adequate than do the less fertile forest soils. Secondly, certain of the possible alternate hosts are particularly common on these better soils, which in many instances are closely associated with monsoon forests where winter conditions are less severe than those normally experienced on the lower lying land; these conditions favour pest survival over winter.

Other examples of soil conditions affecting plant growth, and hence influencing the likelihood of jassid attack, may be cited.

Plant competition for soil moisture during periods of poor supply often results in poor growth within fields, but along the edges of these fields or where gaps occur in the stand growth is more marked. In these latter areas, where plant competition is less acute, jassids find conditions more favourable to their development.

Soils planted to cotton for a number of years possess a high rate of nitrification during the early summer months, and good rains induce rapid vegetative growth resulting in large-leaved plants of a dark green colour; these are subject to jassid damage. Crops grown in Rhodes grass-cotton rotation, where the nitrate level is lower, produce slow-growing bushes which carry foliage of a pale green colour, and are less subject to jassid attack.

Adjacent areas of cotton grown on the same soil type but receiving distinctive cultural treatments may present totally different conditions for jassids. This was borne out in an experiment on irrigated and rain-grown cotton at Biloela Regional Experiment Station (Station Records). The variety Miller 39 was planted under irrigation in early October, while the rain-grown cotton could not be sown until early November. By mid-January, the early planted cotton was carrying an appreciable crop of bolls and the plants exhibited the pale leaf colour normally associated with cropping plants. On the other hand, the rain-grown crop had developed slowly and vegetative development was still in progress during February when the increasing jassid populations reached injurious levels. Further growth was suppressed by the jassid in the rain-grown crop, whereas injury was negligible on the irrigated block. Apparently, the physiological condition of the plants on the irrigated area was unfavourable for the pest and did not attract it from the adjacent heavily infested block.

Similarly, small areas within a field may not prove attractive to the pest while the remainder of the crop exhibits symptoms of intense jassid activity. The apparently "resistant" plants in such areas exhibit pale green, coriaceous leaves and possess an open type of growth.

In addition to the influence of soil and climatic conditions on pest populations, the variety of cotton grown will also influence the extent of damage experienced. Certain of the American Upland varieties introduced into Queensland are very subject to jassid damage and this factor has been taken into consideration when choosing varieties for the several cotton districts. Though a particular variety may show promise in a district or in a particular soil type, its degree of susceptibility to jassid injury has to be considered in those districts where jassids are known to constitute a problem. The use of varieties showing some measure of resistance to the pest offsets the risk of jassid injury in such areas, and the planting of the varieties Miller, Farm Relief and Stoneville in preference to the more susceptible varieties Triumph, New Mexico Acala and New Boykin was advocated. However, in years when conditions favour rapid development of the pest, all commercial varieties exhibit varying degrees of damage in jassid areas.

OTHER SPECIES DAMAGING COTTON.

Empoasca terra-reginae Paoli.

This jassid (Fig. 3) was recorded by Sloan (1938) from cotton in the Upper Burnett, Callide and Dawson Valleys, but the damage caused by it was not specified. Throughout these investigations specimens of *E. terra-reginae*, the tomato jassid, were often encountered, but seldom in numbers comparable with *E. maculata*. Their affinity for cotton is markedly less than that of the cotton jassid.

Appreciable populations of *E. terra-reginae* are more usually encountered on young cotton during spring and early summer months, when the harvesting of early summer crops or dry conditions have destroyed their normal hosts. Levels of population per plant may be high at this period. In extreme cases the plants wilt and suppression of growth may be followed by the eventual death of the seedling cotton. However, this latter condition is rarely encountered.

In contrast to *E. maculata*, nymphs and adults of *E. terra-reginae* may be encountered on any part of the plant, and it is not uncommon to find newly-emerged nymphs on the older leaves. Thus, where the insect has migrated from nearby crops (mostly solanaceous) in considerable numbers, the invaded cotton plants do not show injury commensurate with that encountered when smaller populations of *E. maculata* are present. The habit of total plant infestation by the tomato jassid, in contrast to the terminal infestation characteristic of *E. maculata*, results in less pronounced symptoms of plant injury.

Also in contrast to infestation by *E. maculata*, which is more or less evenly dispersed throughout a field, the migrating individuals of *E. terra-*

reginae spread relatively slowly beyond the point of initial entry, where plant growth may be checked to some extent. Despite an initial high level of population of *E. terra-reginae,* subsequent development of the insect is apparently restricted, and it is unusual for this insect to increase in numbers on cotton throughout the season.

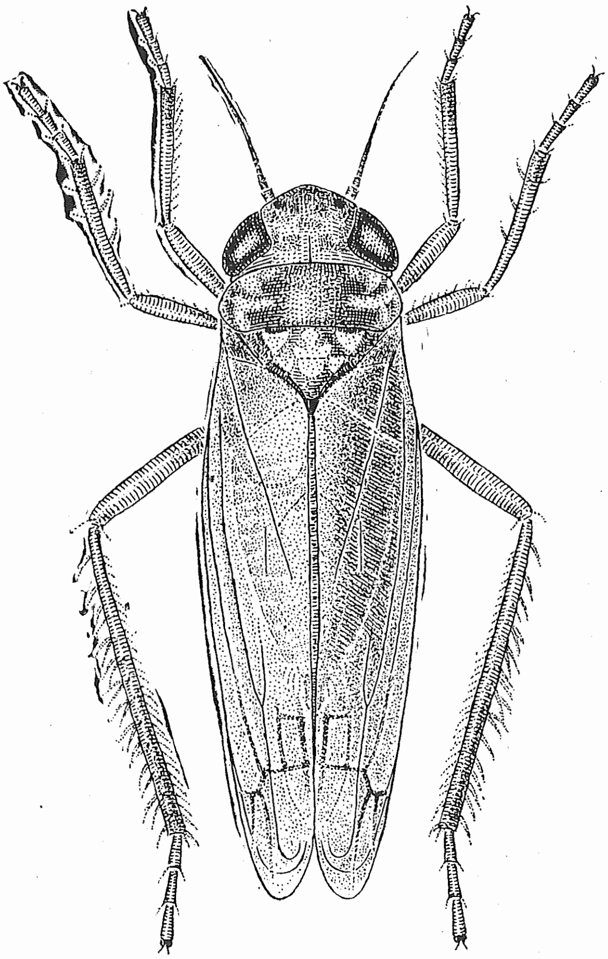

Figure 3.
Adult of *Empoasca terra-reginae* (x30.)
[*Drawing by William Manley.*

The symptoms of injury associated with *E. terra-reginae* are confined to the older leaves of the plant and consist of "white-spotting" of the foliage. Nymphs are occasionally found on the undersurface of the terminal leaves, sometimes among those of *E. maculata,* but damage due to the two species could not be differentiated. However, older leaves which have supported large numbers of adults may approach a pale green or greenish-yellow colour, partly due to the presence of large numbers of the minute whitish areas representing individual feeding punctures. Leaf curl is not associated with the presence of *E. terra-reginae*, and plants infested by this species do not present the characteristic injury symptoms of *E. maculata.*

All evidence suggests that cotton is not a major host of the tomato jassid and that the presence of appreciable populations of this species in a crop is fortuitous. The occasional individuals which may be found in any field of cotton may be regarded as remnants of a migrant population.

Empoasca alfalfae Evans.

This yellowish-green jassid is a pest of various legumes, and is commonly found on lucerne and members of the cowpea group. It has been recorded from cotton in the Gayndah and Ayr districts. In the former district, occasional plants were damaged, and the initial infestation arose as the result of forced migration from legumes in the vicinity.

The habits of this species appear to be very similar to those of *E. maculata,* and the nymphs are responsible for a similar form of leaf injury. Towards the margin of terminal leaves, pale green to chlorotic areas develop which are generally demarcated by the smaller leaf veins. Curling under of the leaf margins may also occur but owing to the few individuals implicated the acute symptoms of leaf injury could not be ascertained. No damage to the leaf veins, as a result of oviposition injury, was noticed.

THE PROBLEM OF CONTROL.

The frequent and serious losses occasioned by *E. maculata,* particularly in localities suited to its development, stress the need for methods of control. Though in itself a serious pest, the cotton jassid is only one of the hazards facing cotton growers. Losses from *Heliothis armigera* may, at times, far outweigh losses due to jassid attack, while even transcending the importance of these two pests, the dependence of cotton growers on suitable seasonal conditions for profitable crop returns must also be considered. The majority of crops in this State are dependent on rainfall for their entire development and growers would be unwise to consider methods of control, however efficient, that would be costly to apply, unless they were assured of adequate crop returns.

Evidence has been obtained that DDT dusts or sprays will effectively reduce jassid populations during the critical period of crop formation. Their use is dependent on the availability and maintenance of costly equipment which, on the present basis of cotton production, the grower can ill-afford. However, some scope for this form of control does exist in irrigated crops where joint control of jassids, *Heliothis* and other cotton pests is desirable.

Of more practical appeal to the cotton grower, though in itself not the complete answer to the problem, is the adoption of cultural measures which can be expected to reduce losses associated with jassid attack. The success of these measures depends largely on the ability to plant crops early in the spring so that an appreciable number of bolls may develop before jassids become active. Though further fruiting may ultimately be depressed, an appreciable amount of seed cotton is harvested from those bolls formed before the late summer. However, dry weather or the ravages of *Heliothis* larvae often interfere with square and boll formation during the early summer months, and the advantage gained by early planting from the viewpoint of jassid control is often nullified. Crops planted in late November or early December are usually particularly susceptible to jassid injury, early boll formation coinciding with the occurrence of peak jassid populations. Should a dry spring have prevented earlier planting, the associated restriction to normal jassid development may enable such crops to produce sufficient bolls to ensure payable yields before jassid populations assume pest proportions.

From a purely cultural point of view, early planting is a desirable feature of cotton growing, for not only is the risk of jassid injury reduced but better overall yields can be expected. However, the dependence of early planting on uncertain weather conditions raises the necessity for a more reliable means of control.

The varietal characteristics of early maturity can be used to reduce losses from the pest, particularly when used to further enhance the advantages associated with early planting. Quick maturing varieties, such as Triumph, tend to escape the effects of jassid injury late in the season by forming the bulk of their crop early and so preventing vegetative development and conditions suited to the pest. Later maturing varieties often revert to rapid growth with the onset of summer rains.

Varieties also differ markedly in their susceptibility to the pest, and despite slower maturity some varieties may be grown with fair success while jassids are active in more susceptible crops. The variety Miller, though slower to mature than Triumph, exhibits some resistance to jassid development and is grown with moderate success in regions where Triumph suffers appreciable damage, particularly when sowing has been delayed until the early summer. This varietal reaction to jassid attack was exploited with some success for a number of years, particularly in those districts where jassids were more prevalent, but the value of this technique has waned as the pest has increased in importance.

It is obvious that the methods outlined above do not constitute a sure method of controlling this pest. However, the tolerance shown by certain commercial varieties does suggest that the exploitation of the tendency on the part of certain plants to resist jassid attack should provide a means of solving the problem. Two avenues of approach are open—firstly, the selection of strains exhibiting resistance to the pest from varieties already under cultivation; and secondly, the adoption of a cotton breeding programme to evolve resistant varieties suited to conditions in this State.

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APPENDIX.

HOST RANGES OF JASSID SPECIES.

The respective hosts of the several jassid species encountered during a search for the alternate hosts of *Empoasca maculata* :—

Species.	Feeding and Breeding.	Adult Feeding only.
Empoasca maculata Evans ..	Cotton(*Gossypium hirsutum* L.) *Sida corrugata* Lindl. .. *Abutilon* sp.	*Amaranthus viridis* L. *Chenopodium carinatum* R. Br. *Clerodendrum tomentosum* R. Br.
Empoasca terra-reginae Paoli ..	Potato (*Solanum tuberosum* L.) Tomato (*Lycopersicum esculentum* Mill.) Silver Beet (*Beta vulgaris* L. *var. Cicla* (L.) Moq.) Cotton .. .. *Trianthema portulacastrum* L. *T. decandra* L.. .. .. *Amaranthus viridis* L. .. *Ricinis communis* L.	*Bidens pilosa* L. *Tribulus terrestris* L.
Empoasca alfalfae Evans ..	Poona Pea (*Vigna sinensis* (L.) Savi ex Hassk) *Pisum sativum* L. .. .. Lucerne (*Medicago sativa* L.) *Crotalaria* spp. .. .. Cotton	Potato
Thamnotettix argentata Evans	*Amaranthus viridis* L. ..	Potato Silver Beet *Trianthema decandra* L. *Crotalaria* spp. Cotton
Erythroneura sativae Evans ..	*Trianthema portulacastrum* L.	Silver Beet Beetroot (*Beta vulgaris* L. *var. crassa* Alef.) Lettuce (*Lactuca sativa* L.) Turnip (*Brassica rapa* L.) *Amaranthus viridis* L.
Empoasca pulcherrima Evans..	*Sida subspicata* F. Muell. ex Benth. *Sida rhombifolia* L.	Cotton
Empoasca malvae Evans ..	*Malva parviflora* L. .. .. *Abutilon* sp.	