

PRESIDENTIAL ADDRESS**Insects and Plant Diseases¹**

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There is virtue in a short title but that must not connote that an attempt will be made to review the whole field but rather to discuss some of our local problems in such a manner as to exemplify the field of study of insects and diseases of plants, at the same time stressing what appear now to be the more fundamental aspects.

The simplest relationship between an insect and a pathological condition of the plant is illustrated by the effect of a large colony of mealybugs at the base of a pineapple fruit (3). This results in cracking between the fruit eyes followed by the ingress of *Nitidulid* beetles and *Drosophila* and subsequent souring of the fruit. In the absence of control measures two factors tend to bring about colonies of mealybugs large enough to produce this condition, first, mealybugs living on the peduncle and green fruit tend to produce more young than those feeding on leaves and second, the fruit develops during a season of rising temperature and drier weather, both favorable to the development of large colonies. This condition of the fruit involves no transmission by the insect primarily involved but the immediate environment is so modified that an insect succession is initiated which results in invasion of fungi and yeasts.

A much more complicated case of an insect in relation to a plant disease is found in leafhopper burn. This in Hawaii is due to *Empoasca solana* DeLong. Although this disease has been merely recorded (12) and not by any means carefully studied it is clearly a case similar to the typical leafhopper burn of potatoes of the mainland and is interpretable as due to a toxic secretion of the insect which produces only local symptoms though not local enough to be limited to the insect's feeding parts. Herford (10)

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has shown that this insect secretes diastase and invertase, the former being associated with yeasts in the intestinal tract.

Studies on the nature of insect secretions are very much to be desired. Why, for example, does *E. solana* produce similar effects on watermelon and castor beans and to a very much milder degree on potatoes while on *Amaranthus* it produces only a stippling of chlorotic spots. Are these differences and similarities due only to plant reactions to an insect's specific secretion or are these secretions as variable as the plant saps from which they are synthesized?

Clear-cut evidence on the relationship between change of host and changed insect secretion is to be found in a consideration of another type of local secretion effect, namely, mealybug green spot (5). That this insect's secretion is toxic is clear from the pathological changes induced in the plant tissue at the point of feeding and the effect of severe cases on the functioning leaf tissue.

In this case it is easily demonstrable that a change of host from pineapple to panicum grass so disturbs the insect's physiology as to completely eliminate the capacity of the insect to produce green spots. A further point of considerable importance lies in the fact that this change is not complete until the emergence of the 2nd generation of mealybugs on the panicum grass.

In the field, both green spotting and non-green spotting colonies are present and although intensity of green spotting by any one colony fluctuates, colonies of non-green spotting mealybugs have been maintained for five years without any green spots appearing, and we are justified in considering this last type as a separate strain.

The evidence is clear-cut in this interesting and unique case that a change of host plant brings about profound changes in the insect's physiology and in addition to this we have concrete evidence on the probable locus of this functional change. *Pseudococcus brevipes*, in common with other insects of the order, possesses an elaborate internal micro-flora which is localized as in other species of the genus *Pseudococcus* in an unpaired organ situated in close apposition with the mid-gut of the insect and known as a mycetome (7).

The two strains, one green spotting and the other non-green spotting, show definite differences in their respective micro-flora and the status of the green spotting strain in this respect is changed to that of the non-green spotting strain when the former is transferred from pineapple to panicum grass (9).

The close correlation between the phenomena of green spotting and symbiosis strongly suggests that symbionts are intimately connected with the insect's nutrition and at the same time they themselves are remarkably susceptible to radical changes in the insect's food.

This whole picture is a most intriguing one, for the vast majority of insects transmitting diseases (apart from those involving the simple transfer of pathogens) are polyphytophagous sucking insects with highly developed internal symbiosis.

The separation of these insect species into separate physiological strains of more or less stability and with varying capacities as related to transmission of plant diseases, may well be brought about by appropriate host plant sequences of the insect.

Returning to a consideration of specific toxic effects brings us to mealybug wilt. This disease, the systemic effect of a toxic secretion of the insect (4), is a type of which very few examples are known and fewer still have been carefully studied. In the writer's approach to the problem, the study of mealybug populations in the field came first and as far as possible this was done on a quantitative basis (1). Such a procedure is highly desirable with any problem in economic entomology and in the case of mealybug wilt proved of particular significance.

"Wilt" was in fact known as "edge wilt" long before its relationship to mealybugs was suspected. These population studies showed clearly that mealybug populations advanced into the field from the edge, being moved from wild vegetation by ants. They showed that movement into the field was much more rapid in beds planted at right angles to the margin than in beds running parallel to the margin and it was these data supplemented by observations on chance plantings throughout the pineapple growing areas that led to the development of a simple but highly effective adjunct to control measures—the guard row planting along field borders (2).

Studies of mealybug populations on planting material both before and after planting helped to explain why infestations were frequently limited to field edges, for it has been repeatedly shown that mealybugs disappear unless ants are in attendance. Exceptions to this occur to a degree which is of economic importance but the generalization is fully supported by the quantitative data.

Finally, the methods of quantitative determination of mealybug colonies have been of primary importance in the development of suitable spray techniques.

Although control of mealybug wilt has become a routine matter of mealybug control as far as plantations are concerned, the relationship between the insect and the disease has already provided, and will continue to provide, an absorbing subject for study.

After preliminary evidence as to this relationship was obtained by J. F. Illingworth (11), the writer was concerned with establishing of conclusive proof. This was accomplished first under laboratory conditions wherein all insects but mealybugs were rigidly excluded, and later under field conditions. As these studies progressed it became increasingly evident that mealybug wilt was in a category for which criteria were essentially lacking, namely the insect secreted toxin disease. Since the tendency under the circumstances was to draw analogies with viruses, the writer has devoted considerable study to this phase of the subject and has listed in Table 1 the principal points of difference between mealybug wilt and viruses as generally understood.

TABLE 1.

COMPARISON OF VIRUS CHARACTERISTICS WITH THOSE OF A
TOXIN AS EXEMPLIFIED BY MEALYBUG WILT

| TOXIN | VIRUS |
|---|--|
| No evidence for multiplication; new tissue arising after bugs are removed is symptom-free. | Multiplication of virus within the host plant typical and without exception. |
| Recovery usual; depends on dosage and length of time dose operates. | Recovery extremely rare. |
| No symptoms ever observed on any other host. | Wide range of host plants usual. |
| Length of colony's feeding time correlated with amount of wilt produced. | Feeding time necessary for virus transmittal is a matter of minutes. |
| Wilt is determined by number of bugs and length of time they feed, i.e., a mass-action phenomenon. | Mass-action not a factor. |
| Sub-wilting populations commonly encountered invariably produce wilt if left to develop. | Non-infectious colony produces no virus symptoms however long it operates or however large it becomes. |
| Capacity to produce wilt is inherent in the insect. | Insect acquires virus by feeding on diseased plant. |
| Vegetative reproductions normal except where mother plant reserves have suffered on account of long continued mealybug feeding. | Vegetative reproductions all carry virus. |
| Control is effected by control of established insect colonies. | No control effected by removal of insect vector. |

These points of difference are not, of course, all of equal rank and further study may bring the two concepts closer together in some one or other respect. The table as given, however, is adequate to separate the categories of virus and toxin and to show that there is nothing in mealybug wilt to indicate that a virus is involved.

From the fundamental standpoint the effect of the insect's host sequence is probably of considerable significance. The toxicity of *brevipex* secretions is clearly governed by the host plant from which the insect comes. Furthermore, in the case of a plant which exhibits as many physiological states as does the pineapple it has been demonstrated that colonies of mealybugs taken from various growth states will show striking differences in toxicity. The obvious conclusion is that the toxiniferous state of a toxicological insect is a direct consequence of the state of the insect's nutrition.

Studies of mass action followed as a logical consequence of the hypothesis that mealybug wilt was due to a toxin. The statistical approach to this aspect of the problem has been of little value (8). Briefly stated, the problem has been to learn what is the "toxic dose" necessary to produce wilt. If one mealybug's feeding for one day is taken as the toxic unit it is apparent that in general the greater the number of toxic units the more wilt results. As is to be expected, data from these experiments rarely graph out as a simple straight line, and although some of the deviations are extremely obscure as to their cause they do suggest that toxin, plant and physical environment are in a rather delicate and easily disturbed adjustment.

Table 2 gives the results from one field experiment on the relationship between number of mealybugs, the length of time they operated, and resulting wilt. No two experiments of this type ever give exactly the same results for the reason that the actual number of mealybugs used and the length of time they are allowed to feed are the only two factors under control.

TABLE 2.
EFFECT OF VARYING NUMBERS OF MEALYBUGS ALLOWED
TO FEED FOR VARYING PERIODS OF TIME

| No. of days | No. of mealybugs | | | | |
|----------------|------------------|---|----|----|----|
| | 1 | 5 | 10 | 25 | 50 |
| 20 | 1 | 0 | 1 | 9 | 8 |
| 15 | 0 | 0 | 1 | 2 | 2 |
| 11 | 0 | 1 | 2 | 2 | 6 |
| 5 | 0 | 1 | 3 | 0 | 3 |
| 2 | 0 | 0 | 0 | 3 | 2 |
| 1 | 0 | 0 | 0 | 1 | 0 |

Each plot contained 20 plants

A toxic effect naturally suggests possible anti-toxic effects. Two lines of investigation indicate that these do exist. One is on the factor of recovery, the other on the accommodation of the

plant to a gradually developing mealybug colony. The first of these is of little if any commercial significance but nevertheless is a constantly recurring phenomenon. As soon as mealybugs are removed from or leave a wilting plant, that plant begins to produce new and apparently normal tissue. The ability of the plant to support a large colony of mealybugs without wilting is of considerable practical importance for in this manner centers of infestation may develop which disperse later, causing quick wilt in the surrounding plants. The only explanation for this phenomenon at the present time is that such colonies develop from one or two individuals and that the plant is able to accommodate itself to the gradually increasing mass of toxin injected into it.

DIAGRAM SHOWING INCIDENCE OF WILT IN EXPERIMENTAL PLOTS

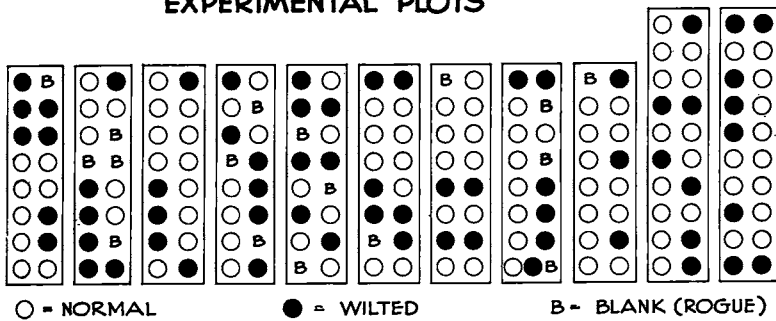


FIGURE 1

The state of our knowledge of mealybug wilt thus far has led to the subject of plant susceptibility and the factors governing it. No definite conclusions are yet available, but one instance can be quoted to indicate what seems to be an interesting lead. It has been the writer's habit to make maps of experimental plots to indicate the position of wilted plants. This has been done because some of the earliest field experiments suggested that the position of plants in a small 20-plant plot affected their susceptibility. Some of the more striking examples of this are shown in Fig. 1. The immediate problem is to determine to what extent this distribution is due to chance and to what extent to the micro-environment. Other subjects of investigation connected with the general problem of

THE STUDY OF MEALY BUG WILT

QUANTITATIVE STUDY
OF MEALY BUG
POPULATIONS

- MOVEMENT FROM FIELD MARGINS
- MEALY BUGS ON PLANTING MATERIAL
- CHECKS ON EFFICIENCY OF SPRAY MATERIALS
- FIELD HISTORY OF COLONIES
- ON PLANTING MATERIAL
- INTERNAL POPULATIONS
- WIND BLOWN INFESTATIONS

CONTROL

BORDER PLANTINGS: GUARD ROWS: INTERNAL POPULATIONS
 OIL EMULSIONS: HIGH PRESSURE SPRAYS: DIESEL OIL EMULSIONS: SUBSIDIARY CONTROL OF ANTS
 BIOLOGICAL: MEXICO · FORMOSA · CENTRAL AMERICA · CANAL ZONE · COLUMBIA · EQUADOR · BRAZIL

RELATIONSHIP
BETWEEN INSECT
AND DISEASE

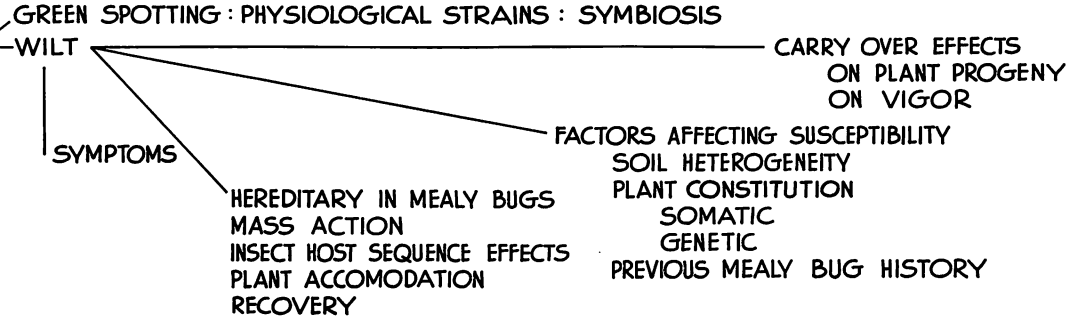


FIGURE 2

plant susceptibility as well as a summary of control methods are shown in Fig. 2.

We now come to a brief discussion of viruses. Pineapple growers are fortunate in that only one virus has been recognized in the field. This virus, commonly called yellow spot, is of very great interest in that it is one of a small group of thrips transmitted virus diseases, its vector is the common cosmopolitan onion thrips and the disease is not known to occur elsewhere than in the islands.

At the time that Linford (13) succeeded in establishing proof of the relationship between the disease and its vector there was considerable fear that the disease would become a limiting factor. Fortunately this fear has not been realized for apart from spasmodic outbreaks of the disease in some sections its status is that of a minor problem.

The reasons for this are at present largely a matter of surmise although attempts are being made to establish, again by quantitative methods, the relationship between field occurring thrips populations, the disease in wild hosts, and in pineapple. The problem is complicated by the fact that the pineapple is not a normal host of *Thrips tabaci* Lind. and the disease only occurs on that plant as a result of a temporary and incidental feeding by the insect. For that reason perhaps, it is possible to find within the confines of a pineapple field, scattered weed hosts of the insect and disease, heavily infested with thrips and infected with virus while the pineapple plants are either free from the disease or showing only an extremely low percentage of infection. The converse does not hold true, that is, no case is known where high percentage of disease in pineapple has not been associated with a similar condition in the weed hosts.

Due to the difficulties of mechanical transmission of this virus many fundamental data are lacking, especially concerning the properties of the virus, which, if available, would enable us to determine the relationships between this virus and others probably allied to it.

What is the original source of the yellow spot virus? This question is put in order to open what is a purely speculative phase of this paper, but one which is of general significance wherever plants are grown and of peculiar interest to Hawaii.

The onion thrips is unquestionably an introduced insect in the islands yet the virus of yellow spot, while allied apparently to spotted wilt of tomatoes and other crops, is not known elsewhere. Two hypotheses are therefore tenable. One is that the insect was viruliferous when introduced here and that the virus is present but not recognized at the point of origin of the thrips. The other is that on being introduced here, the insect acquired the virus from some of the many wild hosts, which, with the natural spread of the insect, was finally communicated to *Emilia sagittata*. This last plant is at present the principal known reservoir of the virus and one of the most favorable hosts for *T. tabaci*.

Either of these hypotheses leads to the same conclusion—that a new economic virus may arise (i.e., be recognized) as a result of the bringing together of potential insect vectors and new host plant sequences.

Another case in point is that of *Commelina nudiflora* mosaic with respect to pineapple. The writer, postulating that any established virus might possibly be capable of infecting pineapple, succeeded in transmitting this virus to pineapple by mechanical means (6). Later, successful inoculation was accomplished using three species of aphids. The disease in pineapple is severe and frequently lethal. It is not yet known to occur in the field although its symptoms on pineapple are so similar to those of yellow spot that it may easily be passing as the latter disease.

The case is quoted here as illustrating how a virus, well established on weeds, may only await the advent of an efficient vector to become a "new" virus on an economic plant.

The constant stream of descriptions of new viruses may not be due altogether to increased interest on the part of biologists but in part at least to the wider distribution of insect vectors and virus host plants attributable to the development of world agriculture and transportation.

It is at this point that the significance to Hawaii will be apparent to all of us. Situated as we are at an ocean crossroads with an increasing volume of traffic and with new and faster methods of transportation it is inevitable that new floras and faunas will meet here and viruses emerge as a result of new combinations of vectors and plant hosts.

This discussion has thus far tacitly assumed that viruses are living entities which cannot arise purely *de novo* and the theory presented deals only with the *expression* of viruses as a result of new host-insect combinations.²

If further study confirms the protein theory of viruses (14) or of some viruses, then true *de novo* genesis of viruses can be considered as possible and the appearance of new viruses or chemical mutants of existing viruses only limited by the factors limiting the arrangement and rearrangement of complex protein molecules.

There is a provocative liason between this last theory and some of the data presented earlier in this paper on insect secretions and the relation of symbiosis thereto. The elaboration of protein virus molecules may well be conditioned by the factors of insect nutrition and secretions, and so-called incubation periods of viruses in insects may perhaps be periods necessary for such elaboration.

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² Since this was written a somewhat similar point of view has been expressed by Leach in "Insect and Plant Diseases", Bot. Rev., Vol. 1, No. 11, 1935.

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