I. INTRODUCTION.

The Coccidae are serious crop pests in many parts of the world, and most important among these are the Coccidae of Citrus crops. In view of the fact that in the sub-tropics citrus crops are exceedingly important agricultural commodities, these scale insects rank highly as world insect pests. Quayle estimates that in California citrus insects cost $ 4,000,000 per annum in machinery, materials and labour for control and a like sum for losses in places where control measures are not applied, or are applied and not effective. As the major part of this sum is used in controlling scale insects, the enormous economic importance of the family can well be judged. (21).

Before proceeding to a study of the citrus Coccidae of Trinidad it is worth while to review briefly, the position of these insects in the various citrus producing countries of the world at the present time. When this has been done it will be possible to treat the problems found in Trinidad in the light of the experience of entomologists elsewhere.

The chief citrus producing countries of the world are California, Florida, South Africa, Australia, Japan, Palestine, Egypt, other Mediterranean countries and the West Indies.

Throughout these countries there is a definite range of climatic conditions. Thus in California, South Africa and Australia the climate of the citrus areas is dry and citrus is frequently an irrigation crop. These countries can be taken as representing arid conditions. In Florida, Japan, parts of Queensland, West Indies and coastal districts elsewhere, humid conditions prevail. It will be seen later how/

how important is this preliminary classification in determining which species of scale insects will become pests in any given area.

It is apparent that with a few exceptions the same species of scale insects are present in all the big citrus producing areas. This is doubtless due to the ease with which these insects are transported. Species of polyphagous habit or those which infest mature fruit have been spread relatively more than those which do not have these habits. Silvestri (11) points to S.E. Asia as the home of citrus and suggests that the majority of Citrus scale insects originate there, the exceptions being a few of African or American origin.

The scale insect fauna of China and Japan contains species which are not yet to be found in the species lists of the important citrus areas, - a strong argument in favour of strict plant quarantine in the case of these countries. Insects, which are quite harmless in the oriental region might, on escaping from their parasites, become serious pests in a new country.

With regard to those species which are spread throughout the world, it is of interest to attempt to find the reason for the success of some and the failure of others in any given area. As was mentioned above the main distinguishing factor between the chief producing countries is a climatic one. If the case of the Californian Red Scale (Aonidiella aurantii) be considered, it is found that it is the predominant species in California, South Africa and most of Australia. This species is not however of any importance in Florida or the West Indies, although it is present in these areas. The reason for this difference is clearly climatic/

climatic. Aonidiella aurantii evidently favours hot dry areas.

Chrysomphalus ficus (Florida Red Scale) is the important red scale in the humid areas. The Purple Scale (Lepidosaphes beckii) is the most important species in the world, having a wider distribution than any other citrus insect. It is the chief pest of Florida, but in California it is found to be a pest only in the coastal regions where more humid conditions prevail. In Queensland, Summerville (15) reports a similar state of affairs, noting that the low humidities of the interior are detrimental to this species. As would be expected this scale is important in the West Indies. Glover's Scale (Lepidosaphes gloverii) is similar to Purple Scale in its regions of importance, humid conditions being preferred. The Black Scale (Saissetia oleae) is not important on citrus in Florida but is bad in South California. Quayle (19) considers that it is definitely limited by high summer temperatures.

So much for the effect of climate in determining the important species of an area.

The biotic factors of control must also be taken into account in this connection. The case of South Eastern Asia is interesting. Silvestri (11) considers that the scale insects in this region are indigenous and that a state of equilibrium exists between them and their parasites. It is to be expected that, when any of these insects get away to new countries without their parasites, they will increase in numbers provided that the climatic factors are suitable. The introduction to the new country of the parasites responsible for control in the country of origin should be followed by a reduction of the pest species. If this reduction/

reduction does not take place then the explanation will be, either that the new country is more suitable climatically for the host than the old country, or that the new country is less suitable for the parasites than the old country. Natural control and Climatic control are thus closely linked.

Australia is a country where many citrus scale insects are in equilibrium with their parasites. Several useful predators such as Novius cardinalis and Cryptolaemus montrouzieri have been obtained from this country.

If the success of a scale insect species cannot be attributed to more favourable climatic conditions, then the conception of natural control will provide the answer.

The subject of control of citrus scale insects covers a very wide field. It will be sufficient here to consider the main methods which are being used to combat these pests.

Biological control has gained some of its most pronounced successes in this field. The Cottony Cushion Scale (Icerya purchasi) was controlled in California by the introduction of the Coccinellid beetle Novius cardinalis from Australia. A more recent case is the control of the Citrophilus mealybug (Pseudococcus gahani) in California by the introduction of Coccophagus gurneyi (Compere) and Tetracnemus pretiosus (Timb.) from Australia. This pest was serious over 75,000 acres a few years ago but is now hard to find. (34). Attempts have been made to control the Red Scale (Aonidiella aurantii) in California by introducing Casca chinensis and Comperiella bifasciata from China.

These introductions were based on Silvestri's work in China. These parasites attack Chrysomphalus ficus and Aonidiella aurantii in their country of origin but would/

would not breed on the latter in California. It may be that there is some slight difference in the Aonidiella of these two regions, distinguishable to the parasite if not to systematists. These parasites should, however, prove useful in a country where Chrysomphalus ficus is a pest e.g. Florida. (25).

Another failure has to be noted from Palestine where parasites and predators are not valued highly by Bodenheimer as they are affected by winter and the heat of summer. Cryptolaemus montrouzieri was introduced but could not stand the winter. (23).

As regards chemical control, great advances have been made in the first place in tent fumigation by means of hydrocyanic acid gas. This treatment originated in California in 1886. The method employed in those early days was that known as the "Pot Method". Nowadays liquid hydrocyanic acid gas is used and the whole technique of orchard fumigation has reached a very high degree of efficiency. The most suitable season of the year and the correct atmospheric conditions for fumigation are now fully understood. 20 c.c. of Liquid HCN is the general requirement for each 100 cubic feet in the tent. The average cost for fumigation is about 40 cents for each tree (19).

In Palestine much success has been obtained by the use of Calcium cyanide, as "Calcid", or "Cyanogas".

To use this, a measured quantity of the solid is ground up and blown into the tent and, in contact with water vapour in the air, quickly forms hydrocyanic acid gas. It is a simple, safe and very effective method, as the action is rapid and does not give time for the development of "protective stupefaction" on the part of the insects, which takes place when/

when the dose of gas takes a long time to generate. It also has the benefit of removing water vapour from the air instead of adding it as did the "Pot Method". A film of moisture forming on the leaves absorbs gas and leads to damage of the foliage. (33).

Wolcott has stated that for West Indian conditions fumigation is not suitable owing to the presence of too much moisture, but the "Calcid" method outlined above would probably be found to be suitable.

Quayle (19) (35) has found that Red Scale (Aonidiella aurantii) is in certain cases resistant to fumigation. The resistant stage is usually the second moult, but adult individuals may also be resistant. A special treatment for such cases has been devised. This consists in spraying the trees with a heavy or medium oil emulsion and fumigating subsequently at an interval of from two weeks up to eight months. The spray is chiefly efficient against the scale insects on the outside of the tree next to the tent, while the gas is more effective on the wood. The two treatments work together and the treatment is known as the "Combination treatment". This treatment has been found to be more suitable than two fumigations.

Spraying of citrus fruit trees has also reached a high standard of efficiency in California. Petroleum oils are chiefly used. It appears that insecticidal efficiency and the effect of oil on the trees are governed by the purity of the oil, the heaviness of the oil and the amount of oil deposited on the tree. The oils in use are classified into five grades according to viscosity and "distillation range". This latter figure gives a dependable value for volatility, and, since both insecticidal power and deleterious action

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on the citrus trees are closely correlated with volatility, and not necessarily with viscosity, it follows that "distillation range" is a useful basis of classification. Quayle has found that unsaturated and aromatic hydrocarbons are responsible for the harmful effects on plants of these oils. They can be removed by sulphuric acid and a figure known as the "Sulphonation value" is now required for spraying oils. This is the percentage of oil remaining unchanged after treatment with strong sulphuric acid. For light oils e.g. No.1, this figure must be no lower than 90-92 p.c. and for heavy oils e.g. No.5 it must be 95 p.c..

When sprayed, these oils are combined with an emulsifier and a spreader. The emulsifier is generally potassium fish-oil soap, ammonium caesinate or saponine. In California the spreader is Powdered Blood albumen. This spreader contributes towards the oil-depositing quality, the efficiency and safety of the sprays. Since 1931 Tank mixers have been in use and have been found to be highly successful. The agitators in these machines are working continuously during spraying operations and ensure correct mixing. The combined effect of the agitator and the nozzle brings the constituents of the emulsion to the correct state for application to the trees. (19).

In Florida, where entomogenous fungi are of importance in controlling scale insects, it has recently been proved by experiments that spraying with a fungicide definitely increases the subsequent infestation with scale insects. The use of fungicides is necessary to control Scab (Sporotrichum citri) or Melanose fungi. Watson and Berger (20) state that applications of fungicides must be followed in two months with an oil emulsion in order to control scale insects.

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Hill, Yothers and Miller have more recently worked on this problem and find that copper fungicides such as Bordeaux mixture are the worst in this respect and may reduce natural control of scale insects by entomogenous fungi from 60 p.c. to 20 p.c. It will be seen later how important this is in connection with scale insect infestations in the humid tropics. (26).

With regard to elimination of scale insects, Gardner (27), dealing with the general trend of scale insect problems in the world, makes the point, that the successful elimination of one pest leaves the field open for an attack by another. Problems of this nature are continually occurring and it often appears as if one problem merely leads to another, but the research institutions in the chief citrus countries are proving themselves equal to the task and explanations of abnormal occurrences and new methods of attack are always available.

Cultural measures, embracing all that is best in orchard practice, are tremendously important in connection with scale insects and their avoidance. Frequently, very simple measures of husbandry have a far-reaching effect. In Palestine the planting of citrus trees closer together was found to reduce Red Scale (Aonidiella aurantii) because the shading effect thus induced was detrimental to this species. (27).

The growing of vigorous trees by means of correct management of soil water, soil nutrients and soil reactions, considerably reduces the susceptibility of the host plant to attack by scale insects.

The necessity for strict plant quarantine is still very apparent. It has been stated that, because the main species of scale insect are now spread throughout the citrus areas, it is no longer worth the trouble of imposing strict plant quarantines/

quarantines. Against this it must be said that the spread of these pests is by no means over. In the region of the Orient there are species of Coccidae which are capable of spreading and, once away from their country of origin, they might become troublesome pests. The existing plant quarantines have done much to limit the spread of these pests. Freeborn (28) gives information illustrating this with regard to Florida Red Scale (Chrysomphalus ficus) in eastern Mediterranean countries. This insect is present as a serious pest in Egypt and Syria but the Jaffa district in Palestine lying between the two has been kept free of infestation probably by quarantine measures.

Maxwell-Lefroy (7 pt.II) pointed out the necessity for plant quarantine in the West Indies many years ago. Strict measures were not taken and the result has been the introduction of many injurious forms of insect life.

The above will serve as a short review of the position of the citrus Coccidae as world pests at the present time.

It is the more immediate concern of this dissertation to examine the state of affairs with regard to the West Indies in general and to Trinidad in particular.

It has been mentioned above that in the main citrus producing countries, the climate is dry and the crop is frequently produced under irrigation conditions. The Coccidae are decidedly more troublesome in dry areas such as these, than they are in the humid tropics. The conditions in Florida are probably more akin to those of the West Indies than any other, but in many respects the conditions in these islands are unique. Scale insects rarely become major pests and it is only in the dry season, which comprises the first six months of the year, that they become troublesome.

As in Florida, control by entomogenous fungi is very striking/.

striking and the moist conditions prevalent throughout most of the year give the correct conditions for the development of these controls.

The humid sheltered valleys so characteristic of many West Indian islands form an ideal home for citrus crops both from the point of view of health of the trees and quality of the crop. The West Indian Lime has no equal and the grapefruit of the West Indies is placed beside that of Florida as the best obtainable.

Citrus seems able to stand high humidities, especially when there is no risk of Scab (Sporotrichum citri). In the West Indies, although sour orange stocks are badly affected, Grapefruit and Lime are immune. This is an extremely fortunate circumstance, for it obviates the necessity for fungicidal sprays the effects of which have been discussed above. To maintain a high humidity in the plantation is the aim of the planter in these islands. This ensures control of scale insects and also a succulent fruit such as is not obtained from regions with any marked tendency to dry conditions.

The citrus industry is one of growing importance in Trinidad. Grapefruit is the main crop. In 1926 only 54 boxes were exported, in 1932 the number rose to 11,000 crates and the crop for 1934-35 was nearly 80,000 crates. Oranges and limes are also exported. As the industry is expanding plantings are appearing in situations not quite so suitable as the humid sheltered valleys referred to above. A certain amount of trouble is likely to be met in these cases unless special precautions are taken. In view of the above facts, it is perhaps a suitable time for the study of these pests, for little is known about them under Trinidad conditions. This applies also to certain other pests of citrus e.g. fruit flies.

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In the course of the work covered by this dissertation, the Coccidae associated with citrus in Trinidad, have been listed and an attempt made to assess their economic status.

An examination of the list will reveal the fact that there are present in Trinidad, species of scale insects which are notorious pests in other parts of the world, but which cause no trouble at all. As was indicated above the reason for this may be climatic or it may be due to the influence of natural controlling factors. This question will be discussed under each species later in this dissertation. In a climate such as Trinidad possesses natural control by insects assumes a greater importance than it would in a temperate climate. The reason for this is that the development of insect life is more or less continuous throughout the year, thus allowing the natural enemy to keep pace with its host.

A certain amount of work has been carried out on the natural enemies of citrus Coccidae. No previous work had been done on this subject and therefore no collection was available to help in the identification of species. The list produced in this dissertation must of necessity be regarded as a preliminary one. It is the hope of the writer that subsequent workers may be able, with the help of this list and a collection left in the College Museum, to take up the work with a minimum of delay.