AN ECOLOGICAL APPROACH TO THE CHEMICAL CONTROL OF CAPSID BUGS (HEMIPTERA, MIRIDAE) ATTACKING CACAO IN WESTERN NIGERIA

by

J. R. Gordon Sutherland, B.S.A. (McGill)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The pest status is discussed of three Bryocorine Mirids, *Sahlbergella singularis* Hagl., *Distantiella theobroma* (Dist.), and *Helopeltis bergrothi* Reut., which are of major importance on cacao in West Africa. A chronological review of the literature is given, and terms generally used in cocoa agronomy and in describing Mirid damage are defined. Two new terms are suggested.

Ecological studies are reported of these pests in the cacao environment in Nigeria with particular regard to the immediate effects of their feeding activities upon the plant, and to sequelae which include invasion by fungi, and bark beetles. Preferences in breeding and feeding sites, and reactions and dispersal of the Mirids are examined in relation to seasonal vegetative growth and fruiting.

Sampling methods, observation techniques and experimental procedures used in the ecological investigations and in insecticidal trials are described and a correlation demonstrated between densities of *S. singularis* and rates of incidence of leaf-blast. This species was found to be the most important in abundance, distribution and adaptability.

Results are given of dusting with 5 per cent D.D.T. during three seasons and of spraying with 0.1 per cent D.D.T. introduced into carbide-Bordeaux used for routine control of black-pod disease during two seasons, on plots of from one to forty acres. Decreases in Mirid densities and in damage to vegetative parts were consistent and significant under both forms of treatment, and there was evidence of time and area effects from the formulations tested.

Satisfactory protection was afforded during canopy formation in young cacao, and in regeneration of badly damaged bearing stands, using dusting alone. Fruit setting increased in all dusted plots as compared to the controls, and potential yields as indicated by green pod records were significantly greater in all but one of the former after seasonal treatments over two years.

Although the evidence for improved yields after the treatments reported is not conclusive, continued insecticidal protection with reduced Mirid populations and damage incidences may be expected eventually to produce this effect. A tentative estimate is made of losses due initially to Mirid injury of at least ten per cent of the annual cocoa crop in Nigeria.

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CHAPTER I

INTRODUCTION

The fact has been well established since 1902 that severe damage to cacao plants (*Theobroma cacao* L.) in West Africa may be caused under certain conditions by bugs of the Family Miridae (Capsidae), Subfamily Bryocorinae. The extent of the damage, the areas within which it is likely to occur, and the conditions predisposing attack have been a subject of study since that time in the territories touching on the Gulf of Guinea. Generally, the intensity of effort directed against these pests during any one period has been determined by the currently accepted popular idea of the losses involved, rather than by realistic estimates of the damage caused. Wars, economic depressions, and conflicting theories have tended to obscure the final objective of their control. At no time up to the present has any effective control measure been adopted into general use, although many have been suggested, ranging from pollarding (WARBURG, 1902) through the use of imported parasites, to spraying and dusting with insecticides of various derivations, from kerosene emulsion to chlorinated hydrocarbon dusts, (De BELLEFROID, 1951).

In the interval since 1902 a large volume of data has been built up regarding many phases of capsid bionomics.

It is now known that four species may contribute to the damage of cacao plantings in Sierra Leone, the Gold Coast, French West Africa, Nigeria, the French Cameroons, the Belgian Congo, Fernando Poo, Principe and San Thome' (Figure 1). Three of these species Sahlbergella singularis Hagl., Distantiella theobroma (Dist.), (= S. theobroma Dist.) and Helopeltis bergrothi Reut. are known to attack cacao in Nigeria. The fourth, Bryocoropsis sp.prob.laticollis Schum. has been recorded only once on cacao in Nigeria (ANON, 1950). These species will be referred to below by their valid specific names as now accepted and the common name "capsid" is so well established in British West Africa that it will be retained in this paper. They are well figured by ALIBERT (1951). All geographical references will be according to conventions used in 1953.

Despite repeated warnings over a period of fifty years and the widespread damage and economic losses generally admitted, during the past fifteen years, to have been directly traceable to the feeding activities of this group of capsids, no proportionate effort has yet been made to control these pests. It was for this reason that the present studies were undertaken.

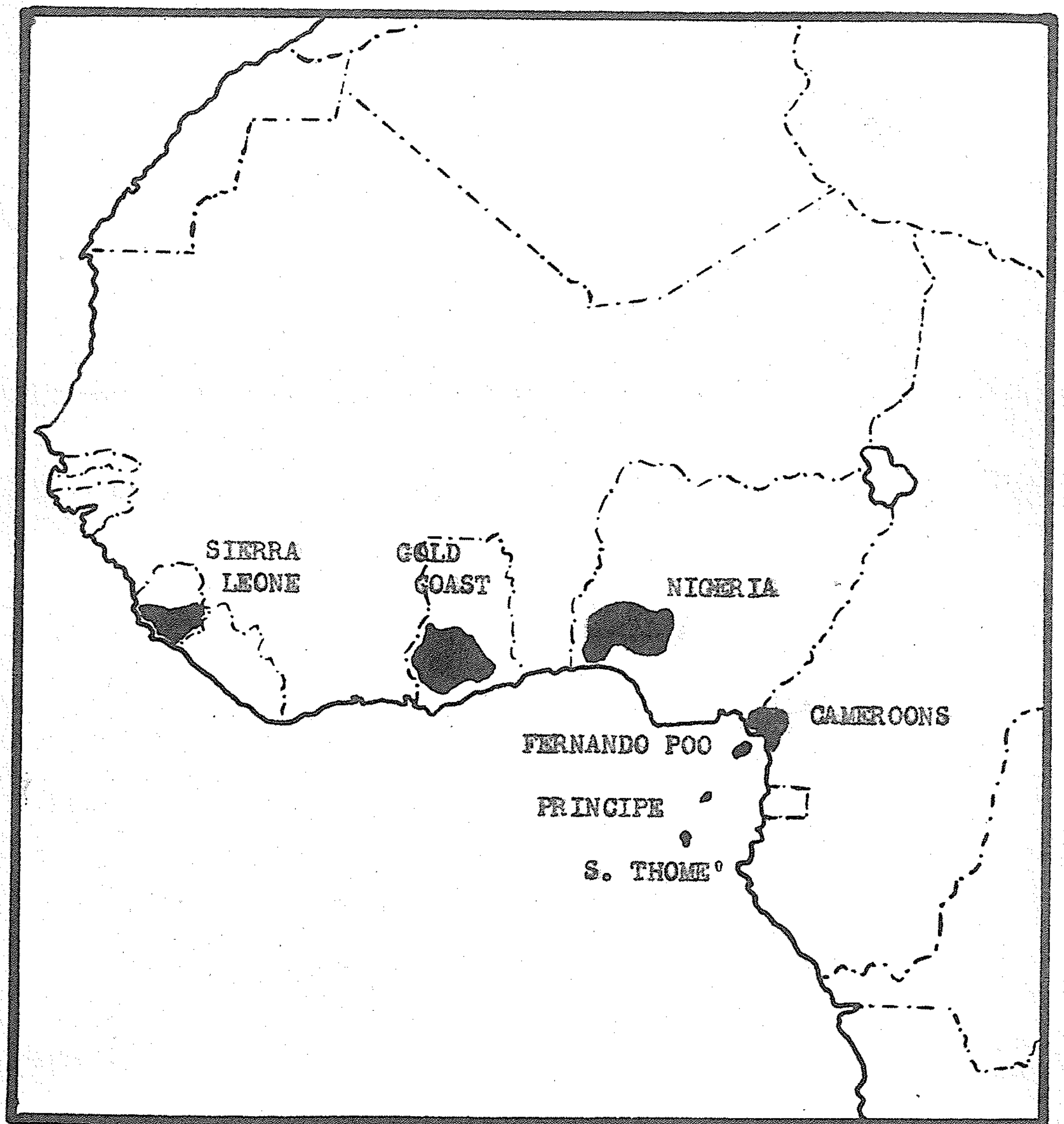

FIGURE 1. Sketch Map of part of Africa Showing Principal Cacao-growing Areas Blocked in Solidly.

CHAPTER II

CHRONOLOGICAL REVIEW OF THE LITERATURE

A brief chronological summary of the more important events leading to our present conception of the cacao capsid problem and its possible solutions, is as follows:-

1895 - Sahlbergella singularis was described from the Belgian Congo by E. Haglund.

1902 - Capsid damage to young cacao trees was reported by WARBURG (1902) from Moliwe Plantation, near Victoria in the Cameroons. He recommended various remedies, including pollarding.

1908 - A capsid, later identified as S. singularis was reported by DUDGEON (1910) to have been observed by Dr. W. M. Graham on cacao in southern Ashanti in "very large numbers ..... on the diseased trees and not on the healthy ones".

1909 - Helopeltis sp.nr.schoutedeni attacking cacao pods in the Gold Coast, was reported by DUDGEON (1910), who remarked that this pest "might become a most formidable enemy to the industry".

1909 - A capsid, later described by Distant as Sahlbergella theobroma was reported by DUDGEON (1910) "ravaging" young cacao in the Gold Coast. He recommended trials of Bordeaux mixture and kerosene - soap emulsions.

1910 - *D. theobroma* was reported by DUDGEON (1910a) to be less plentiful at Bompata (Ashanti) than in the previous year, but *S. singularis* to be "present on almost every tree in badly infested plantations. .... The pest ... had extended to the West of Kumasi". A formula was given for an improved kerosene emulsion for application to the trunks.

1913 - Observations and short notes on the life histories and habits of *S. singularis* and *D. theobroma* were prepared by PATTERSON (1914), who remarked on the types and degrees of damage caused under various conditions. He stated that *Helopeltis* sp. is essentially a pod feeder and noted a wide range of wild hosts common throughout West Africa.

1914 - *D. theobroma* was reported from the Onipe area, south of Ibadan by LAMBORN (1914), for the first time in Nigeria. He also quoted C. O. Farquharson to the effect that a nearly allied species (probably S. singularis) was a serious menace to cacao in Eastern Region.

1914 - S. singularis was said by MAYNE' (1914) to be a cacao pest of primary importance in the Belgian Congo, of greater frequency and more widespread occurrence than any other Hemiptera. He suggested that a first capsid attack might result in a stimulus toward abnormally high fruit production, even over a number of years, followed by a rapid decline and premature death of the plant.

1914 - Successful trials of kerosene emulsion sprays against S. singularis and D. theobroma in the Gold Coast were reported by PATTERSON (1915), who emphasized some of the physical difficulties of treatment which apply equally today.

1915 - A warning was sounded by PATTERSON (1916) against the "fictitious idea of safety" engendered by the increase in cocoa production in the Gold Coast due to large new acreages coming into bearing and despite the "grave position" of capsid damage. The area concept of capsid control was stressed by him for the first time.

1915 - D. theobroma was reported by FARQUHARSON (1916) attacking cacao pods and causing typical bark cankers in many areas of Abeokuta, Ibadan and Ijebu Provinces. (This and Lamborn's 1914 report seem to refer to S. singularis or possibly mixed infestations of Sahlbergella and Distantiella).

1920 - PATTERSON (1920) commented on the after-effects of World War I and the subsequent market depression on the general attitude toward cacao pests. He traced the vicious circle of apathy, neglect and deterioration of the plantings, followed by the formation of a reservoir of infestation and wide and rapid spread of damage from it.

1926 - The life histories and habits of both S. singularis and D. theobroma in the Gold Coast were described in detail by COTTERELL (1927) with observations on their alternative hosts.

1928 - S. singularis was first reported on cacao in Sierra Leone by HARGREAVES (1929).

1929 - A visit to Fernando Poo, San Thome' and the Belgian Congo by COTTERELL (1930) contributed to a definition of the ranges of S. singularis and

D. theobroma; neither was recorded from San Thome', and no specimens of, nor damage attributable to *D. theobroma* were reported from the Belgian Congo or Fernando Poo.

1937 - A considerable divergence of opinion appears to have arisen regarding the etiology of "Swollen-Shoot" and "Dieback" of cacao, the terms often being used together for convenience. DADE (1937) in reporting on this "complex" of diseases in the Gold Coast concluded that the main problem was "drought dieback" due to environmental conditions, and though accepting Cotterell's thesis that *Sahlbergella* and *Distantiella* are involved, maintained that they are "..... only able to damage trees exposed to dessication".

1939 - After a visit to the Gold Coast, VOELCKER and WEST (1940) summed up the prevailing theories regarding "Die-back", drawing attention to the fact that *Sahlbergella* (and *Distantiella*) damage may be expected when breaks in the canopy occur, and that die-back is not simply a water-relations phenomenon.

1939 - *H. bergrothi* was first recorded on cacao in

Nigeria by GOLDING (1941) on pods and shoots, in Ondo Province. *D. theobroma* was recorded on young citrus plants at Ibadan, and on both citrus and cacao planted side by side at Owena, while nearby farmers' cacao showed none.

1944 - An estimate of loss of at least 20% of the annual cacao crop in the Gold Coast due to capsid attack was made by BOX (1944). Furthermore, he stated that these pests contribute largely to the prevention of re-establishment of cacao plantings after swollen-shoot cutting-out operations.

1944 - A new genus *Distantiella* was erected by CHINA (1944) to receive the species originally described as *Sahlbergella theobroma*.

1945 - Studies begun in 1944 at Tafo, Gold Coast, indicated a close relationship between the build-up of capsid populations and the presence of unripe cacao pods, followed by a continued increase on vegetative parts during harvesting in the cases of *Sahlbergella* and *Distantiella* and a rapid decrease in that of *Helopeltis*, (NICOL. 1945).

1945 - A survey by BOX (1945) resulted in extending the known range of *D. theobroma* through the Eastern Region of Nigeria and the British and French Cameroons, though no infestations of cacao were reported. He considered this capsid to have only recently adapted itself to cacao.

1945 - Workers at the West African Cacao Research Institute confirmed the theory of toxicity to plant tissues of the saliva of *Sahlbergella* and *Distantiella*. The maximum flight range of adults of these capsids at Tafo was found to be 240 yards (ANON. 1946).

1947 - CROWDY (1947) showed that capsids alone are capable of killing the green shoots of new flushes, whereas infection by the fungus *Calonectria rigidiuscula* (Berk. & Br.) Sacc. is involved in the die-back of woody stems in the Gold Coast after capsid attack on them.

1947 - SQUIRE (1947) published a general resume of some phases of the capsid problem in the Guinean Region. In it he emphasized his opinion that with the advent of residual insecticides the problem will be solved effectively in plantation cacao, but that this will not be the case in the peasant cultivations of the Gold Coast and Nigeria.

1947 - *Bryocoropsis* sp.prob.*laticollis* was recorded for the first time in Nigeria on *Uvariodendron* sp. (Anonaceae) during 1946 and 1947, and once on cacao underneath a *Uvariodendron* tree, in 1948. This was thought to be an instance of a capsid in its "true ecological habitat", representing together with similar circumstances reported for *D. theobroma*, one of various stages in a change-over of these species from indigenous host plants to cacao (ANON. 1947, 1948, 1950).

1948 - Studies of *Helopeltis* attacking economic plants in the Ivory Coast, appeared to indicate that only *H. bergrothi* attacks cacao (CARAYON & DELATTRE, 1948). Other named forms confirmed as feeding on cacao in West Africa were said to be synonyms.

CHAPTER III

OBJECT OF THE STUDIES AND DEFINITIONS OF TERMS USED

I. OBJECT

The present studies were undertaken with the primary object of developing as rapidly as possible, one or more methods of applying routine insecticidal treatments to farmers' cacao plots in the Western Region of Nigeria, in order to provide effective and economical control of the capsid pests attacking them, particularly those contributing to the condition generally known as "capsid blast" and its sequelae. This involved observations primarily of an ecological nature, including those of the habits and populations of the various capsid and other insect species involved, and of the seasonal shoot, flower, fruit and chupon production of cacao plants in various parts of the Region, as a basis for estimating the most suitable seasons and intervals for the application of treatments and for assessing the effects of insecticidal trials.

II. DEFINITIONS OF TERMS USED

A loose terminology has been developed in British West Africa descriptive of the damage to cacao caused by capsid bugs and other factors acting concurrently with or secondarily to capsid attack. It seems desirable to attempt now to standardize and define certain terms for use in Nigeria with a view to the definitions, at least, being adopted for more general use, (Figures 2 to 6).

Leaf-blast is a condition in which dead leaves persist on cacao trees as if scorched by fire; it is usually caused by the rapid death of twigs owing to the histolytic action of capsid saliva, and consequent failure to produce abcission layers at the bases of leaf petioles. It may be diffuse or intense.

Pincushion is a condition in which the wood of one to four seasonal flushes is devoid of leaves, and sticks out from the remaining comparatively intact canopy like pins in a pincushion; it is characterized by numerous capsid lesions and caused by the death of the wood involved due to capsid feeding, followed by the loss of blasted leaves and failure to produce further flushes.

Leafless twig is a condition often similar in appearance to pincushion, in which one or more seasons' wood is without leaves; it can be distinguished from the latter by the presence of few, if any capsid lesions, by shortened internodes, and by the frequent

FIGURE 2. Average Stand of Cacao Showing Some Pincushion and Leafless Twig.

FIGURE 3. Protected and Damaged Cacao Showing Leaf-blast, Fan-branch and Chupon.

FIGURE 4. Bad Pincushion Showing Some Chupons.

FIGURE 5. Staghead Showing Predominance of Chupon Growth.

FIGURE 6. Pocket Showing Varying Degrees of Damage from Staghead to Intact Canopy with Slight Leaf-blast.

appearance of flushes with numerous shoots growing out of axils of leaf scars, small, etiolated or malformed leaves, and usually rapid defoliation; it is attributed to exposure to high temperature and light intensity and low humidity.

Staghead is a condition of greater deterioration than pincushion, in which little canopy remains, secondary and even primary branches and the trunk are exposed and frequently dead toward the tips and bear characteristic cankers; chupon growth is usually abundant throughout the tree; it is caused by a combination of the effects of exposure, fungus infection, woodborer infestation, and probably other factors.

Pocket is a condition in which a gap in the cacao canopy has been made by some physical or biological agency, and the area invaded by a high density of capsids; in well-shaded cacao the limits of the pocket are usually well defined with a high degree of deterioration of the plants inside it, and little damage to those bordering it; in poorly-shaded cacao, pockets are usually less well defined with concentric rings of decreasing degree of damage from the centre toward the outside, where it assumes the form of diffuse leaf-blast.

It will be convenient also to define briefly certain terms in common use in cacao agronomy, which occur frequently in this paper.

<u>Fan-branches</u> are shoots with the leaves arranged in one plane, characteristic of normal growth beyond the seedling stage.

<u>Chupons</u> are shoots of the water-sprout type with the leaves borne spirally. They are characteristic of regenerative as opposed to proliferative growth, usually basal in origin but in the presence of damage caused by physical or biological agencies may occur at any point on the plant. Originally they are unbranched but eventually branching takes place and normal fan-branch growth follows.

<u>Cushions</u> are the loci on the trunks or primary branches from which the flower petioles arise.

<u>Cherelles</u> are newly set fruit of a size up to the length of the middle finger.

<u>Green pods</u> are fruit longer than the limit for cherelles, which show no sign of the colour of maturity.

<u>Main crop</u> cocoa is harvested during the period September through February, and <u>light crop</u> during other

months of the year (RUSSELL. 1953).

CHAPTER IV

SAMPLING METHODS AND OBSERVATION TECHNIQUES

I. CACAO CULTIVATION IN WESTERN REGION

In the seven Provinces and the Colony which comprise the Western Region of Nigeria, some 500,000 acres (CHIPP 1953) of West African Amelonado cacao are grown in a total area of 45,144 square miles (Figure 7). The average annual production of raw cocoa in Nigeria during the twelve-year period 1941-1953 was about 99 thousand long tons, out of a world production averaging some 671 thousand long tons, (HALE 1953), or 14.75% of the world's total. Only a negligible quantity of cocoa is harvested at present in other parts of the territory, so the figures quoted can be considered to apply to Western Region for all practical purposes. The current value of a crop of this size is approximately £16,830,000 ($46,000,000) at the producer level.

The cacao plant is cultivated near villages at a density of from 600 to 800 trees to the acre, in plots separated from one another by food- or cash-crop plantings or by forest. The cacao stands are usually small, ranging in size from 1/6 acre to 10 acres. Larger holdings are unusual, and it took nearly a month of search to find 70 acres of contiguous plots suitable for use in these studies,

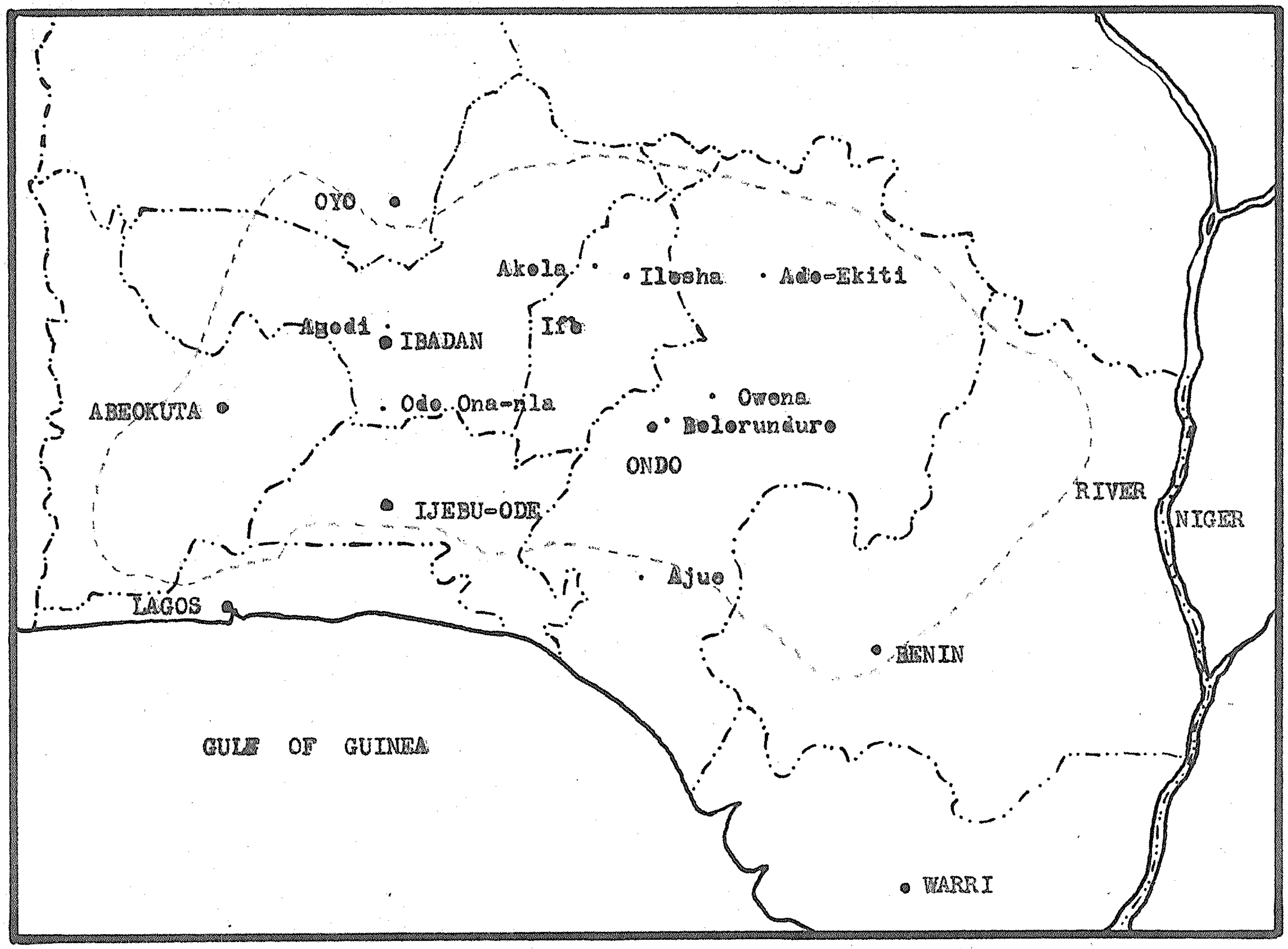

FIGURE 7. Sketch Map of part of Western Region, Nigeria, Showing Principal Cacao-growing Areas indicated by Faint Broken Line; Observation Stations spelt with Lower-case Letters.

despite the availability of considerable information derived from a plant disease survey. It will be seen from the map, Figure 7, that the localities in which cocoa is produced are confined to about one-half the total area of the Region. The acreage under cacao thus represents only about 3.6% of this portion of the Region, and there is considerable dispersal of individual plots and groups of plots throughout it. This fact is of major importance in the ecology of the "cocoa-bush", as this type of native plantation is called, surrounded as it is usually by second growth tropical forest or by derived savannah, both of which have been brought about from the primary forest under different conditions of soil and rainfall, by "shifting cultivation". This latter involves burning off as much as possible of the vegetation from a piece of land, and carrying on primitive farming until the soil is exhausted and the operation transferred to a new site nearby, and the old one allowed to return to its natural cover.

II. PLOT LAYOUTS AND SAMPLING METHODS

In May 1951 these studies began with the selection of eight pairs of cacao plots representative of Amelonado stands found in the principal producing areas of Western Region. Each plot measured one acre, and the trees ranged from 17 to 25 years of age with younger supplies in some cases. Particular care was taken to select pairs of similar vegetative appearance, standing on similar soil, and with similar capsid populations at the outset. The plots were usually side by side and never more than 200 yards apart.

Four of the pairs were observation plots of the Cacao Division, Department of Agriculture; one of each was clean-cutlassed and subjected to cutting-out of black-pod disease, Phytophthora palmivora Butl., under Departmental arrangements, and the other tended by the farmer according to local practice. They were situated near Ife and Ilesha in eastern Oyo Province, near Ado-Ekiti in northern Ondo Province, and near Bolorunduro in central Ondo, (Figure 7). A fifth similar pair, which had reverted to the farmer's control a year previously, was chosen near Ajue in southern Ondo. In addition, pairs were laid out in the Department's experimental cacao farms at Odo Ona-nla south of Ibadan, at Agodi on the northern fringe of Ibadan city, and at Owena in central Ondo Province. In each case where a difference of vegetative condition was evident, the better plot of a pair was designated as control, and the other for eventual treatment with D.D.T. or B.H.C. dust. Random choice was made where no marked difference was found in the general condition of paired plots at the beginning of the studies. One hundred sample trees per acre plot were selected at random and marked permanently.

On 10th November 1951, observations were begun on two sets of larger paired plots, on the same basis as the one-acre plots, except that 300 randomly selected trees were used in each of a 5-acre pair at Odo Ona-nla, and 250 trees in 4-acre plots at Owena. One of each pair of all the above was destined for insecticidal dusting.

On 30th June 1952, observations ended in three of the paired one-acre plots, at Agodi, Ife and Bolorunduro, but were continued at Odo Ona-nla, Ilesha, Ado-Ekiti and Owena, and only D.D.T. dust was used on treatment plots from then on. At Odo Ona-nla a third one-acre plot was adopted as control, the two which had been used previously being marked for dusting at dissimilar intervals. At Owena, the whole of the mature cacao on the farm was designated for treatment, a total area of 10.8 acres. At the same time a control area of equal size was surveyed nearby in farmer's cacao of above average appearance. In each of the last two cases the number of sample trees was 300, while the usual number of 100 was selected in the new plot at Odo Ona-nla.

In addition, in June 1952, spraying trials involving the addition of D.D.T. to a Carbide-Bordeaux mixture used for the control of black-pod disease (THOROLD 1952b) were begun at Odo Ona-nla, in two one-acre plots, each of which had a randomized block layout with seven replications of four treatments, including the controls. Records were kept of all except guard trees in the sprayed and control plots.

By 1st July 1953, observations on these sprayed plots were discontinued and treatments were begun at Owena on the 10.8-acre area which had been uniformly dusted in the previous year, keeping the same sample trees and with 3 somewhat different formulations, as will be seen in a later section.

Also from 1st July 1953, a circular 40-acre tract of almost solid stands of cacao, together with an adjoining control area of 30 acres, was placed under routine observation at Akola between Ife and Ilesha, and a first dusting applied shortly afterward. From July 1953 until the time of writing the dusting trials have been continued at Odo Ona-nla, Ilesha, Ado-Ekiti and Ajue. In a plot of 1 to 10 year old cacao near Ife a non-statistical test was begun in March 1953 of the protective effects of D.D.T. dusting during canopy formation.

Beginning 20th June 1951, records were maintained of observations of the numbers of capsids present by species and stages, on pods and vegetative parts of cacao plants in the selected plots and non-quantitative data were recorded on thrips and borers. The degrees of damage and the presence or absence of fan flushes, chupons and fruits were also recorded. Reliable yield records were available for only five one-acre plots for at least two years before the present observations began.

Life history studies of S. singularis and D. theobroma had already been carried out by W.A.C.R.I. at Owena (ANON. 1947, 1948, 1949, 1950), so it was decided to limit caged breeding to Ibadan. The results for the former species agreed closely with those recorded at Owena in previous years, with a mean total life cycle, including prematurity period, of 51 ± 3 days. The data for D. theobroma were unsatisfactory owing to a very high mortality rate in the cages.

III. INSECT COUNTING TECHNIQUE

The numbers of marked trees per acre in plots of various sizes were the maximum practicable in order to ensure adequate sampling in the presence of low population densities. Counts were made of all capsids observed at seven day intervals from 20th June 1951 until the end of

August; thereafter, counts took place at ten day intervals until 30th November 1953. At no time were collections of capsids made from the test plots.

Squads had been trained previously in the recognition of the nymphal and adult stages of *S. singularis*, *D. theobroma*, and *Helopeltis* spp. and of signs of the presence of thrips. Each squad consisted of four men, and their work had been standardized over a period of six weeks in different types of cacao stands before observations were begun in the experimental plots. Continual exchanges of individuals and entire squads and frequent inspections served to maintain a high standard of accuracy.

The squad leader was responsible for the efficient working of the group, and for recording the data called to him during the examination of each tree. One observer worked from the ground, reporting relevant information to hand height. A second man used a 7-foot ladder and a third a 12-foot ladder, both covering those levels beyond the reach of the previous observer. The group worked in echelon clockwise around the tree, and the leader coordinated the examinations carried out by the observers both horizontally and vertically. Great care was taken under all circumstances to disturb the capsids as little as possible.

The data recorded were:-

(i) numbers of capsids by species, nymphs or adults,

(ii) whether on the pod-bearing areas or vegetative parts,

(iii) presence of damage attributable to thrips, (*Selenothrips* sp.prob. *rubrocinctus* Giard.).

During the early stages of these investigations it was found that several species of pin-hole and shot-hole borers, (Scolytidae, Bostriychidae), were often apparently involved in the further deterioration of trees after capsid attack. Therefore the presence or absence of these borers and of damage caused by them were recorded as well, from September 1951 onward.

IV. RECORDING OF DAMAGE

During 1951-52, injury was recorded simply as pod, chupon or twig lesions characteristic of the three capsid species, where these were recognizable, together with an estimate of the general degree of damage to each sample tree. This was scored: severe 3; moderate 1; negligible 0; and referred to the staghead, heavy blast and light blast conditions respectively. It became clear as the succession of events in damage and recovery was observed in detail that this system of scoring was inadequate. Consequently, the term pincushion was introduced and the scoring values were changed in 1952-53 to:

blasted tree in pocket	5
pincushion and severe blast ...	3
severe blast	2
moderate blast	1
negligible damage	0

No overall correlation was found in either year between numbers of capsids and damage scores. This is not surprising in view of the subjective nature of the scoring method, and of the differential vigour of individual trees and groups of trees, the great variation in soil conditions and water relations which are found frequently in Nigeria over short distances, and the marked susceptibility of cacao to such variations.

On the other hand, in every treated plot there was always abundant visual evidence of improved vegetative condition of the cacao being associated with treatments applied over a suitable period, in contrast to the continued blast effect in untreated cacao nearby. There were considerable differences in degree of improvement, just as there were varying degrees of deterioration. In this there clearly are involved factors other than density of capsid populations.

As the studies continued it became evident that, in addition to the factors mentioned above, the conditions known as staghead, pincushion and leafless twig involve a time factor, possible plant pathogens and secondary insect infestations, and a light-heat-moisture complex referred to as exposure by WILLIAMS (1953a). Therefore, in May 1953 the scoring system was again changed, and the values were assigned as follows:-

Damage negligible	0
Leaf blast, ¼ tree	1
" " ½ tree	2
" " whole tree	3
Leafless twig, no capsid lesions ...	0
" " with " " ...	1
Pincushion, less than ½ tree	2
" more " " "	3

Evidence of the presence or absence of thrips on leaves, and of wood-boring beetles in twigs and branches was recorded and collections of the latter were made from time to time for use in identification and in assessing the seasonal attack rates and damage incidences.

V. RECORDING OF VEGETATIVE GROWTH AND REGENERATION

Vegetative growth was recorded as minor or major fan flushes, depending on whether only damaged portions or the whole canopy of a tree was involved, and regeneration was noted according to the presence of chupons below or above the main branches of each trunk. Records of chupons were disregarded as generally unreliable because of the farmers' tendency to cut them out as soon as possible after appearance except where attempts are being made to re-establish a badly stagheaded plant by training and rooting low-growing chupons. A tree showing no fan flushes was scored 0; minor flushing involving less than half the tree 1; major flushes affecting more than half, 2.

VI. RECORDING OF POTENTIAL YIELDS

It is common experience that cocoa harvesting varies from year to year by locality, usually in well-marked two year cycles, in date of onset, in duration and in yield. SKIDMORE (1929) has shown from studies of rainfall and cocoa yields at Aburi and Asuansi in the Gold Coast that a close association exists between them. In Western Region the development of the cacao pod from pollination to maturity requires from 160-170 days. Pod counts have been maintained thrice-monthly throughout these studies; green pods are defined as those of the length of the middle finger or longer which have not yet begun to show the colour of ripeness. Pods can be considered to fall within these descriptive limits for about 100 days immediately prior to ripening, and in these studies they have been recorded whether defective or not. Such a record constitutes a sample of the yield potential, comparable by six-monthly periods throughout the year, corresponding to light and main crop.

There is some indication in the yield records of Cocoa Division, that the zone in which are situated the observation plots considered in these studies, may be divided into three areas corresponding to differences in the fruiting habits of cacao. The mean annual rainfall varies among and within these as indicated in Table I. In addition, epiphyte ratings (THOROLD, 1952a) are given for the vicinity of each group of plots.

TABLE I

MEAN ANNUAL RAINFALL FIGURES AND EPIPHYTE RATINGS FOR AREAS OF CAPSID CONTROL TRIAL PLOTS

Province	Station	Mean Annual Rainfall (ins.)	Epiphyte Rating
ONDO	Ajue	70	4.6
	Bolorunduro	60	3.4
	Owena	57	3.9
	Ado-Ekiti	58	3.9
OYO	Ilesha	53	3.1
	Akola	55	3.2
	Ife	58	3.2
	Agodi	49	2.9
	Odo Ona-nla	49	3.4

CHAPTER V

OBSERVATIONS ON THE ECOLOGY OF THE CACAO PLANT

I. TYPE OF CACAO AND GROWTH HABITS

Nigerian cacao is almost entirely of the Amelonado strain. It is sensitive to soil and water relations and tends toward leggy growth if planted under a semi-permanent or permanent cover of shade plants. In practice, this type of shade rarely exists now; it is normally cut out as soon as possible as an anti-black-pod measure. Cacao grown under temporary shade is usually more compact in habit and provides a closed canopy readily if low level shade is afforded during the first five to seven years. This results in early and vigorous fan growth as opposed to long stems and small, often etiolated canopies. Usually the height of the canopy bears an inverse relation to the spacing of the trees.

Unfortunately, Nigerian cacao frequently becomes spindly and individual trees have inadequate canopies because cutting out of shade trees is delayed too long. In comparatively few instances are there effective series of shade trees of three or more storeys as in the Gold Coast. For this reason, exposure effects may be expected in most Nigerian cacao plantings, and because in addition much of it is grown in areas which are marginal for soil and rainfall and cannot support regrowth of the tropical forest, the exposure may be both lateral and vertical. Frequently the only visible blast is traceable to the leafless twig condition, which in turn is attributable to exposure. The resemblance to true capsid leaf-blast is usually superficial since there is always some shortening of the internodes and often some abnormality of the leaves. In any case, the blasted condition is temporary, more or less abortive flushes following quickly upon one another, but flushes are vulnerable to capsid attack so that the two types of effect may be combined. This combination of factors has often been seen as the starting point of a pocket along a road or beside a clearing.

Despite the adoption of the amended scoring method in May 1953, total damage scores still failed to show a correlation with capsid populations throughout all the experimental plots, (Figure 9), a situation similar to that found by WILLIAMS (1953a) in the Gold Coast. However, tests were made of monthly moving averages of leaf-blast intensity alone against similarly treated counts of S. singularis of the previous month. Twenty random readings taken at two pairs of dates from each of ten widely distributed treated and control plots, using the $\log_{10}$ transformation, showed a significant coefficient of medial correlation of $\phi = 0.59$, ($P < 0.05$). This is indicative both of the time lapse between capsid attack and the onset of visible effects and of the complexity of the problem. The problem itself becomes of immediate practical interest at the point at which any leaf-blast at all is observed in a cacao planting, and so it has been the aim of these investigations to develop rule-of-thumb control methods, rather than to analyse fully the more complicated question of all the possible factors contributing to the deterioration of cacao after capsid attack.

II. FAN AND CHUPON PRODUCTION

Fan flushes are put forth on Nigerian cacao whenever physical or biological damage occurs which stimulates but is insufficient to prevent this form of regeneration. Chupon growth takes place if the damage is more severe. Periodical flushes involving most of the branches of a tree tend to occur three times a year, in late June and early July, in November and in March. Occasional flushing is present during most of the year, (Figure 9).

The frequency of flushing in cacao appears to depend primarily on shade and temperature relations, (GREENWOOD and POSNETTE, 1950). Their records indicate that weekly mean daily temperatures below 83°F inhibit flushing, and that none of the other environmental factors studied, evaporation rate, soil moisture, and sunshine, influence it. Unshaded cacao was observed by those authors to flush more frequently and with greater intensity than shaded cacao, particularly during periods of relatively low temperature.

No general correlation has been found between the presence of total capsids or of S. singularis and flushes, either contemporaneously or at the approximate life-span of 50 days before or after flushing. Nevertheless there seems to be some local association between the build-up of capsid populations and the June-July and November flush peaks, whereas those occurring in March usually correspond to periods of low capsid densities, (Figure 8). Eggs of S. singularis have frequently been collected on fan flushes and it is thought that the breeding and feeding conditions offered by the November peaks favour the increase of capsid populations during a time when the risk of injury from exposure is great owing to high temperatures and low atmospheric humidities coupled with reduced rainfall and diminishing soil moisture reserves. Conversely the June-July peaks, and to a lesser extent those in March, take place during a period of higher humidity and usually under conditions of increasing soil moisture. Thus the annual

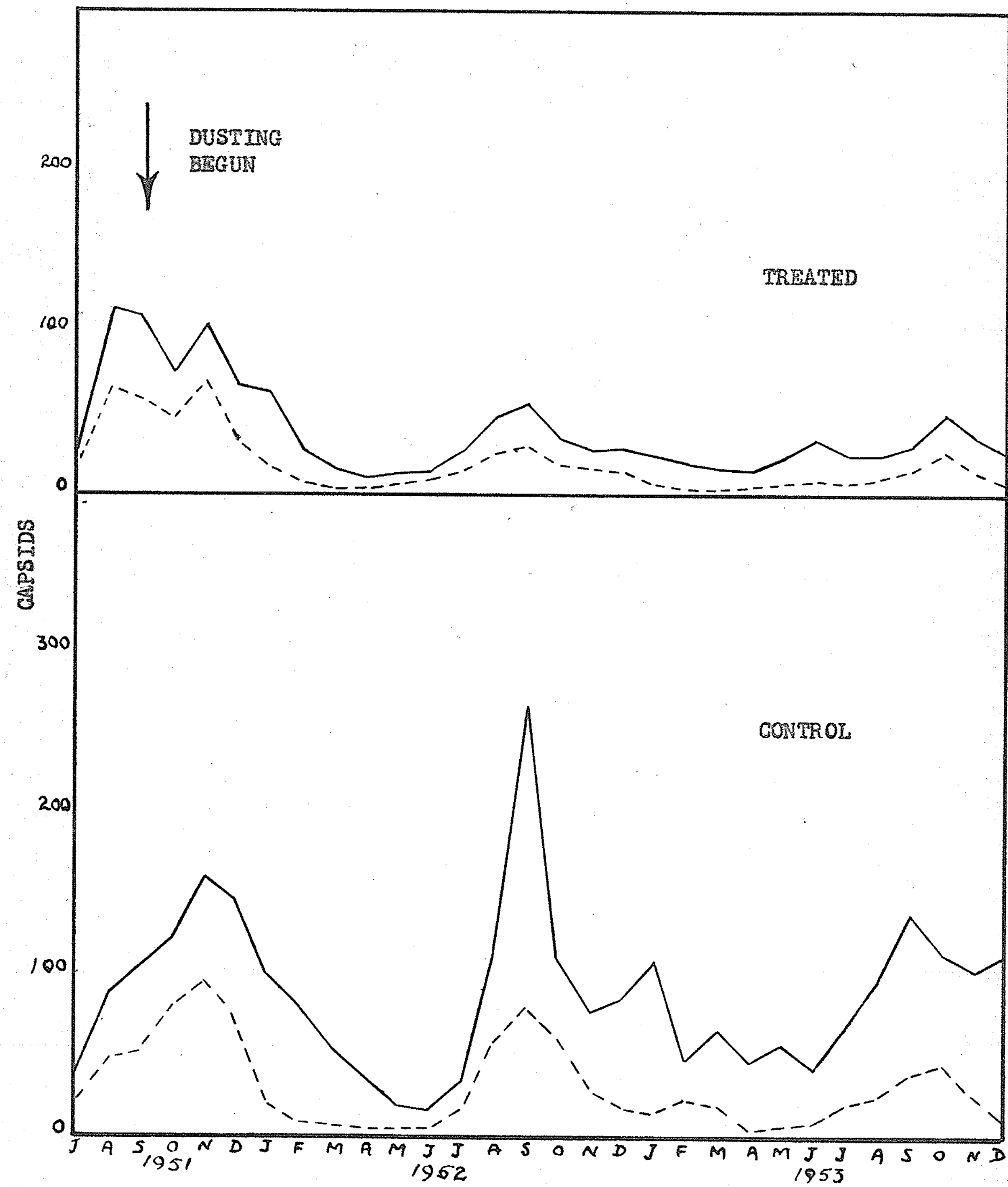

FIGURE 8. Means of Monthly Moving Averages per 100 Trees of S. singularis at Five Stations; Solid Lines indicate Means on Pods and Vegetation, Broken Lines on Pods only.

cyclical decrease in capsid densities coincides approximately with the time of year in which the environment is becoming steadily more favourable for the growth and fruiting of the cacao plant. From July onward, capsid population densities tend to begin their annual rise, sometimes very sharply, although climatic conditions show little change until late October or November, except for a continual increase in moisture content of the soil.

From June to September 1953 only minor flushes were observed in the area Ibadan - Ijebu - Ilesha. This corresponded to a period of overcast skies and low temperatures. Between 20th September and 20th October 1953 general flushing was observed in this triangle, which in every case was comparable with the peak records of the previous two years. The Director of Meteorological Services, Lagos, has provided data from which it seems that in the area and period described, the necessary temperature means to induce flushing were not maintained, whereas in the same area in the months of September and October, they were. This may be reflected in the increases in capsid density shown for 1953 which were more gradual than in previous years, (Figure 8) during the months June to September.

III. FRUITING

Throughout most of the range of cacao in the Region, some flowering takes place in every month of the year. There are, however, great fluctuations in the numbers of flowers and pods present, corresponding to the seasons during which the main and light crop pods are developing, and to the off seasons. In some parts of Ondo Province, pod production is almost continuous, though with noticeable peaks and troughs, while in the Ilesha area there is a tendency in some years toward three distinct harvesting peaks. In the Ibadan area there are usually two well-marked harvesting periods, though in some years the light crop tends to merge into the main crop. There was no correlation found in the course of these studies between the numbers of pods and the numbers of *Sahlbergella* and *Distantiella* present at a given time or as yearly totals.

Observations from March 1952 onward have failed to disclose the presence of the pollinating Ceratopogonids *Forcipomyia* spp. (POSNETTE 1950) in cacao flowers, although one specimen of an undetermined species was taken in a cacao grove at the University College of Ibadan by Dr. Klaas Ebes in the wet season of 1953. The most frequent insect visitors to the flowers seem to be two species of aphids, as yet unidentified, which have been frequently observed to pass between the ripe anthers, sometimes carrying pollen grains on their backs or flanks. These grains were often seen to be rubbed off on the pistil while an aphid was crawling about within the stamen ring, but only rarely do they seem to come to rest directly on the stigma, or very close to it, and no pollen tubes have yet been recorded growing upward from a lower position on the style.

No reduction of the number of flowers set has been observed as a result of the chemical control trials to date. On the contrary, significantly higher numbers of cherelles were recorded from July to October 1953, when fruit-setting virtually ended for the season, in all dusted plots up to 10 acres in extent, than in their paired controls. The data from the 40-acre plot and its 30-acre control at Akola showed no significant difference, but only one chemical treatment had been applied by the end of the flowering season. These observations are far from conclusive, but seem to indicate that either insects play a very limited part in the pollination of cacao in Nigeria, or that those involved in this function are not reduced below effective densities by the insecticidal treatments so far tested in plots of 10 acres or smaller.

Unfortunately, owing to a reduction from June 1952 onward of the original scale of the experimental plan, and a suspicion of theft of ripe pods from some of the remaining observation plots, it has not been possible to get a fully satisfactory series of samples on which to search for a correlation between green pods and final cocoa yields. It has been shown from black-pod studies carried out in the same general area as that under present consideration (THOROLD 1953) that there is a significant correlation between total fruit set and total yield. These figures do not discount cherelle wilt nor premature pod casualties; yet a similar association can be demonstrated between green pods as defined in this paper, and yield over two years in six plots and over one year in one plot. The corner test (TUKEY 1947) shows a significant association, ($P < 0.02$). This will permit valid comparisons to be made between treated and untreated plots, for the purpose of assessing the efficiency and economy of control measures, and eventually of crop forecasting.

CHAPTER VI

OBSERVATIONS ON THE ECOLOGY OF CACAO CAPSIDS

I. HOST RELATIONS

SQUIRE (1947) has summarized the available information on the host plants of the Bryocorine capsids in the Guinean Region. All three of the major capsid pests of cacao have available abundant supplies of wild host material throughout the cacao-growing areas of Western Region and the surrounding territory. It is generally conceded that *S. singularis* and *H. bergrothi* have adopted cacao as a host species comparatively recently, and there are indications that *D. theobroma* has adapted itself even more recently. In addition to its wild hosts, *D. theobroma* has been frequently observed feeding on citrus, particularly at Owena where cacao and a number of citrus plants of various species and varieties are grown a few yards apart.

The age of the cacao plant appears to influence the percentage of *Distantiella* present in mixed infestations, in the Gold Coast, (SQUIRE, 1947). There is little evidence to support this thesis under Nigerian conditions, and it must be considered inconclusive until studies can be made of populations on individual trees of varying ages under more closely controlled conditions than those presently reported.

II. CAPSID POPULATIONS ON CACAO

Unfortunately there are no past records available of capsid population trends throughout the principal cacao producing areas of Western Region. W.A.C.R.I. workers have reported a decline in capsid populations between the years 1944 and 1949 at Tafo, Gold Coast and between 1946 and 1949 at Owena (ANON, 1946, 1947, 1948, 1949, 1950), a station situated in an area of high cacao production in which there was considerable capsid damage.

Reliable local sources consider that there had been a considerable increase in the extent and intensity of "capsid blast" in the area Ijebu - Ibadan - Ife from 1949 to the present time. Certainly during the years 1951-53 farmers' cacao plots in this triangle showed degrees of damage in many instances greater than any seen east of Ife, and no mention is made in the literature of such severe attacks in the former area during the period 1944-49.

It will be seen from Table II that only very small numbers of capsids are involved in attacks on cacao as compared with most crop pests. They are highly destructive in relation to their comparatively low densities, and leaf-blast is frequently seen when only 25 to 40 specimens per 100 trees have been observed using the counting technique described earlier in this report. At Ilesha, populations of less than sixty per 100 trees are sufficient to keep the control plot in a state of diffuse leaf-blast except during the peak flush periods. At Odo Ona-nla, where densities have tended to increase much beyond the average since 1951, populations of over 500 S. singularis per 100 trees have been recorded in untreated plots with the result that they resemble large pockets showing every type and degree of damage.

High population densities of S. singularis may occur at any time between August and February. It is probable that in some localities and some years the populations build up on the pods and the June - July flushes. In these cases there is risk of a high degree of damage caused by feeding on the November peak flushes by capsid populations which are nearing their maxima. If, on the other hand, build-up is delayed, few pods may be present by the time a considerable increase has been achieved and breeding and feeding will be likely to take place principally on fans of the November peak flushes. This will result in population maxima occurring about January, with diffuse blast and the danger of damage by exposure during the dry season.

TABLE II

DISTRIBUTION OF CAPSID POPULATIONS BY SPECIES AND PART OF PLANT ATTACKED; 174600 OBSERVATIONS JUNE 1951 - NOVEMBER 1953

SPECIES	PODS			VEGETATION			SPECIES TOTALS	
	NUMBERS	PERCENTAGES		NUMBERS	PERCENTAGES		NUMBERS	PERCENTAGES
		By Site	By Species		By Site	By Species		
S. singularis	37184	45.8	84.8	44016	54.2	92.3	81200	88.7
D. theobroma	2432	45.7	5.5	2887	54.3	6.0	5319	5.8
H. bergrothi	4251	84.2	9.7	796	15.8	1.7	5047	5.5
SITE TOTALS	43867	-	100.0	47699	-	100.0	91566	100.0

III. RELATIVE IMPORTANCE OF THE SPECIES

Table II shows the relative abundance on pods and vegetation of three species of capsids over a period of 29 months at nine stations. It is evident that S. singularis was observed much more frequently than either D. theobroma or H. bergrothi, and in common with the former of these two shows little preference between vegetation and pods. H. bergrothi shows a marked preference for pods, and its feeding lesions are rarely seen on the vegetative parts of a plant. Little harm is done to the pods by the feeding of these three species.

Of the few D. theobroma recorded on vegetative parts 32.5% were observed at Owena, where there is a citrus planting along the full length of one side of the cacao plots. The remainder were distributed remarkably evenly through seven other stations, and at the ninth none was found.

At Akola in October 1953 H. bergrothi was observed feeding on fan-branches for about fifteen days at a mean density of 9 individuals per 100 trees. This is the only recorded occasion in Nigeria on which attack by this species was severe enough to cause noticeable leaf blast, and it is remarkable because of the small population involved. Although this species has been seen frequently attacking new flushes, it is not usually sufficiently abundant on vegetative parts to effectively injure the plant.

Neither D. theobroma nor H. bergrothi has been observed to cause damage to bearing cacao in Nigeria except in the presence of S. singularis, and degree of leaf-blast has been shown to be correlated with the density of S. singularis populations. In view of these facts, only the last-named species will be considered in the remainder of this report unless otherwise mentioned.

IV. FEEDING AND BREEDING SITE PREFERENCES

Both S. singularis and D. theobroma showed some preference (Table II) for vegetation over pods as feeding sites whereas in the Gold Coast they are reported (WILLIAMS 1935a) to prefer pods and chupons over fans for both feeding and breeding sites. Similarly Williams showed that D. theobroma has a significant tendency to feed on chupons only, while S. singularis feeds readily on either. Since the numbers of chupons which are allowed to persist in Nigerian cacao are negligible except in badly damaged or badly cared-for farms, this may explain the relatively low densities of D. theobroma, and at the same time the readiness with which S. singularis appears to adapt itself to fans for feeding and breeding.

However, a high proportion of breeding seems to take place on pods during certain months of the year. In 432 random observations made in untreated plots without pockets between June 1951 and November 1953, 13,114 *S. singularis* were recorded on pods and 15,161 on vegetation, or 46.4 and 53.6 per cent respectively of the total of 28,275. These percentages correspond closely with those shown for this species in Table II. The pod and vegetation figures were further examined in 2 x 2 contingency tables by totals of adults and nymphs present in three-month periods. Values of χ^2 were significantly large at the 1 per cent level during the months June through November in each of the three years, but not from December through May.

This indicates that during those periods when green pods were present in abundance, breeding took place preferably on pods, as judged from significant increases in the numbers of numphs on those parts. The pod petioles are frequent sites of oviposition. During that part of the year when pods are few in number or small in size, *S. singularis* adults are clearly facultative in choice of both breeding and feeding sites, since for the former purpose fan flushes are used, and for the latter any part of a plant which is not too resistant to a capsid's proboscis.

V. REACTIONS AND MOVEMENTS

Feeding takes place usually between late afternoon and early morning. Both adults and nymphs tend to avoid high temperatures and low humidities by seeking shelter in bark crevices and under pods during the hours of daylight. They are negatively phototactic, and the adults rarely fly. On being disturbed all stages drop to the ground if they are unable to take shelter readily. However, a temperature gradient experiment carried out at Tafo indicated that the females of both S. singularis and D. theobroma tolerate a much greater range of temperature than was generally supposed, and those collected in the dry season seemed to congregate at a higher temperature level than others, (ANON. 1951). This may mean that a higher proportion of adults are normally present on vegetation than is indicated by these studies, since observations were limited to a height of some 18 feet.

In addition to daily movements upon individual trees, and periodical changes of feeding and breeding sites according to the availability of flushes, pods and occasionally chupons, it must be expected that tree to tree migrations will occur as population densities increase in any area. These would normally be brought about in any insect population by competition in the search for food and breeding places. From the reluctance of *S. singularis* adults to fly, it may be concluded that such movements take place through the canopies of contiguous trees, since Williams (1953b) states that migrations across the leaf litter below the trees are infrequent. This type of dispersal together with the comparative absence of chupons may explain the diffuse form of leaf blast which is prevalent in Nigeria.

CHAPTER VII

CAPSID DAMAGE AND ITS SEQUELAE

I. CONDITIONS PREDISPOSING CAPSID INVASION

In Nigeria injury to one or more trees from whatever cause is almost invariably followed by capsid invasion. Minor flushes which are attractive feeding sites, and in the absence of suitable pods also acceptable breeding places, usually follow a low degree of injury in any season of the year as soon as conditions of temperature become favourable. If the original damage is such as to make a gap in the canopy, flushing will be more extensive and the density of the invading capsid population will be greater. Finally, if the injury is such that a large part of the canopy of an individual tree is rendered incapable of producing fan flushes either through mechanical or insect injury or fungus infection, regeneration will take place by means of chupon growth, and the tree will become a focus of capsid infestation for the surrounding area.

Exposure to a combination of high temperature, high light intensity and low humidity seems to bring about the leafless twig condition with its attendant abortive flushes, during the drier months of the year. It is not clear under what circumstances this type of growth is invaded by capsids, but whether or not it is directly attacked, the canopy is usually opened up and deeper invasion follows.

Examples have been seen in Western Region of breaks in the canopy of a cacao planting having been caused by fallen trees, by fire, by exposure on roadsides and the edges of clearings and by capsid injury in plantings where trees were of different heights owing either to a difference of age or to unfavourable soil or water conditions. In addition, in leggy stands with thin canopies, breaks often seem to occur as a result of capsid attack alone without evidence of previous physical injury.

II. DAMAGE ATTRIBUTABLE TO CAPSID FEEDING

There has been considerable disagreement in the past regarding the role played by capsids in bringing about leaf-blast and allied conditions. It was suggested by SQUIRE (1947) that the saliva of *S. singularis* and *D. theobroma* contain histolytic enzymes which give rise rapidly to necrosis involving the medullary rays in the peripheral tissues into which the proboscis has penetrated during feeding.

CROWDY (1947) demonstrated that capsid lesions produced under sterile conditions progress no further than would be expected from the effects of the histolytic action of the saliva alone. In no case were woody stems killed by capsid attack under these conditions, even those in which the stem was completely ringed by necrotic areas surrounding feeding sites. GOODCHILD (1952) has discussed in detail the physiology of capsid feeding and the effects on the tissues at the feeding site.

Leaf-blast and pincushion may appear at any time of the year in Nigeria, though they tend to be much more prevalent as capsid densities increase just before or during the dry season. Leaf-blast rarely persists past a major flush unless the flushing fans are themselves blasted. Pincushion usually continues until a flush takes place low down on the damaged twig and the dead portion is sloughed off.

Crowdy considers that the damage resulting from capsid attack alone is often sufficient to kill green shoots by impeding the flow of nutrients in the vascular tissues, and that death from this cause is so rapid that probably no fungus plays a part in it. He mentions that under these conditions only partial defoliation would occur, since a flushing tree normally carries the leaves of the two previous flushes. He concludes that severe and chronic injury cannot be attributed to capsids or to a fungus alone, but to the two in combination.

Uninfected capsid lesions are said by the same author to heal quickly and cleanly after the early necrosis induced by the histolytic saliva, without the roughening of the bark which characterizes infection by the fungus Calonectria rigidiuscula. In the field they appear at first as soft water-soaked areas, followed by necrosis and sloughing together with active callus formation, and finally a superficial reticulated longitudinal scar involving the cortex, but without discolouration of the deeper tissues at the site.

III. DAMAGE ATTRIBUTABLE TO SECONDARY AGENCIES

The symptoms typical of C. rigidiuscula infection in its various stages are stated by Crowdy to be as follows:-

(i) discoloured areas in the xylem cylinder beneath the cambium, seen as contiguous elongate blotches in peeled stems,

(ii) these lesions later appear in longitudinal section as discoloured streaks in deeper tissue, and in cross-section as broken rings of a similar colour,

(iii) the streaks and corresponding rings are claret-coloured in the early stages at least, and may later become black or even gray-black, the latter probably as a result of contamination by Botryodiplodia theobromae Pat.

(iv) the final stage is marked by a characteristic roughening of the bark, which is always associated with black oval lesions on the surface of a central xylem cylinder.

Unfortunately determinations have not yet been received of fungus material collected from capsid lesions on cacao throughout Western Region. The impression gained from frequent hand sectioning of smaller branches and stems showing leaf-blast and pincushion, is that deep-seated lesions and discolouration are not so frequent in Nigeria, as indicated by Crowdy and Squire for conditions on the Gold Coast, and by the writer's limited observations during a visit to the West African Cacao Research Institute in 1951. This impression is partly borne out by failure to find C. rigidiuscula or other pathogens in newly damaged tissue at Owena (ANON, 1946).

Small wood-boring beetles of the Families Bostrychidae and Scolytidae frequently invade fungus-infected twigs and branches which have become moribund. It is not clear whether these beetles finally cause the death of the affected tissues or whether attack takes place after death. Scolytids have been found attacking apparently live tissue near the sites of fresh capsid lesions. This suggests a relationship in cacao of considerable complexity between capsids, a fungus and boring beetles. So far it has not been possible to get reliable identifications of all the beetles involved.

The Bostrychid, Sinoxylon senegalense Schedl, has been recorded in dead wood on one occasion. Five Scolytids have been identified as attacking dead wood and five others have not yet been determined, all of which have been found in dead wood only. Two identified and one unidentified species have been taken in live wood. Xyleborus morstatti Hag., Hypothenemus pusillus Egg. and Stylotentus ater (Egg.) appear to infest only dead wood, while Stephanoderes solitarius Schedl and Stephanoderes polyphagus Egg. have been observed in live wood on one and two occasions respectively.

The thrips, Selenothrips rubrocinctus has been suggested by W.A.C.R.I. workers (ANON, 1949), as a factor which may help to explain apparent discrepancies between comparatively low capsid populations, and high damage rates in cacao. In the present studies no damage was recorded on shoots, nor were thrips found feeding on them. Feeding injury was confined to the blades, and occasionally the petioles of leaves. Maximum populations, as indicated by leaf injury occurred in all plots between November 1951 and March 1952, and the same trends were repeated in late 1952 and early 1953. These periodical increases in thrips population densities appear to coincide quite closely with capsid population peaks.

The diffuse leaf-blast typical of Nigerian cacao may often progress to the pincushion stage in the presence of high densities of capsids. In this process exposure, beetle attack and fungal infection may play a part and the less vigorous trees in areas of heavy capsid population tend to become foci of infestation, first because of producing numerous minor fan flushes, and later when no longer capable of this form of regeneration, numerous chupons well up in the canopy. Trees showing decreasing degrees of damage are usually arranged in concentric rings about those most severely damaged. The sequence of events may be readily arrested at any time during this phase of pocket formation by cultural or chemical control measures.

If deterioration continues, the trees near the centre of the developing pocket begin to show signs of stagheadedness. Often the trees along the exposed edge of a plot are stagheaded and a roughly semi-circular pocket begins to invade the planting. At this stage only radical measures such as pollarding and training up new chupons together with chemical protection of the new growth and the exposed margins of the pocket, are likely to be successful in preventing the spread of severe damage and in eventually eliminating the pocket.

CHAPTER VIII

EXPERIMENTAL DUSTING

I. EQUIPMENT

Dusting was carried out during the seasons 1951-52 and 1953-53 with Allman "Midget" knapsack dusters, powered by 34cc. petrol motors. The engine is mounted together with a dust fan, the assembly being slung on the chest and abdomen of the operator. Normally, the hopper is suspended on the back of the operator, who also handles the outlet tube. This arrangement was found too heavy and clumsy for use in typical farmers' cacao, so certain modifications were made from time to time.

In the end, three men were used to operate the duster. One of these, the leader of the group, carried a 12-foot flexible metal outlet tube lashed to a pole, and directed the stream of dust up the main stem of each plant, among the branches and above the canopy. The second merely carried the full hopper on a modified A-frame. The third, a partly-trained mechanic, carried the motor-fan assembly, which was connected by a 6-foot tube to a sleeve at the base of the hopper. The other end of this sleeve carried the dust-laden air stream to the near end of the outlet pipe, which was choked from 3 inches to 1½ inches. A new type of impeller with a higher delivery rate was tried out in 1953.

It was found that only two men could not continue to work this apparatus efficiently for longer than two to three fifty-minute periods with ten-minute rest intervals, or five to seven half-hour periods with ten minute intervals. It was therefore decided that the three-man team must continue to be used until a better adapted design of duster could be obtained or developed.

The fully modified Allman dusters were used for the first dustings in July 1953, and a Birchmeier "Mistral" powered by a 50 cc. engine for subsequent treatments. With both machines it was possible to get adequate coverage with 20 lbs. of dust per acre. The Allman still suffered from the disadvantage of requiring three men to carry on work through an 8-hour day, while two men on the Birchmeier alternately carrying and guiding for half-hour periods were able to work the full day. In addition, treatment of nearly an acre per 15 minutes was attained using the Birchmeier, as opposed to about half an acre with the Allman. Both these machines were capable of applying dust satisfactorily under the usual daily conditions of turbulence and wind found in cacao plantings, and during drizzling rains, and were not limited to dawn and dusk operations nor to use in the dry season.

II. INSECTICIDES

During the period 1st July 1951 to 31st December 1953, records have been made in plots of different sizes and under various forms of treatment, by crop seasons as follows:

(i) dusting with D.D.T. and B.H.C. each in four 1-acre plots, 1951-52,

(ii) dusting in 4 and 5-acre plots with D.D.T., 1951-52,

(iii) dusting with D.D.T. in five 1-acre plots, 1952-53,

(iv) dusting with D.D.T. in a 10.8-acre plot, 1952-53,

(v) dusting with D.D.T. in five 1-acre plots, 1953-(to be continued into 1954),

(vi) dusting with D.D.T. in a 40-acre plot, 1953-(to be continued into 1954),

(vii) protection by D.D.T. dusting during canopy formation, 1953-(to be continued into 1954), and

(viii) untreated controls to each of the above.

It was not found feasible to carry on detailed observations for more than five months after treatment had ended in any case.

It was originally intended to carry out dusting trials beginning at the onset of the small dry season in August 1951, in order to take advantage both of recommendations concerning the weather, and what was believed to be a period of low capsid densities (ANON, 1947 et seq.) Late arrival of dusting stores required postponement of the date of the first treatments until 10th September 1951, when work began on the plots mentioned in (i) above. D.D.T. 5 per cent and γ B.H.C. 0.45 per cent dusts were each used on four of the treatment plots, in six applications of 35 pounds per acre up to the end of February 1952. Dustings were spaced at varying intervals in attempts to reduce the already high densities of capsids on most of the plots, and to prevent a recurrence of build-up. The 4 and 5-acre plots referred to in (ii) received four dustings with D.D.T. 5 per cent between November 1951 and February 1952.

No significant difference was found between the effects of D.D.T. and B.H.C. dusts in reducing capsid populations. However, the cost of B.H.C. was some 20 per cent higher than that of D.D.T., and even a dust containing pure gamma isomer gave rise to irritation of the eyes, nose and throat, and hence to undue fatigue. For these reasons it was decided that only D.D.T. would be used in future dusting trials.

In 1952-53, dusting with D.D.T. 5 per cent at 35 pounds per acre was begun in the last week of August 1952, on the plots indicated at (iii) and (iv). Five treatments per plot were applied at 35-day intervals in the period up to mid-January 1953, except on Odo Ona-nla GP which had not been treated during the previous year. This plot received six treatments in the same period, on a schedule based on the appearance of 25 or more S. singularis per 100 trees.

It became evident that the lowest densities of S. singularis tend to occur during the period May to July, (Figure 8), and not in the small dry season in August. Therefore dusting began in the first week of July 1953 on the plots shown at (v) and (vi), using 5 per cent D.D.T. at the rate of 20 pounds per acre, repeated according to the rule-of-thumb of 25 or more capsids per 100 trees. All plots except those at Odo Ona-nla had received two treatments up to 31st December 1953, and they had received six.

III. RESULTS

An analysis of variance was applied to total capsid populations with two treatments and eight sites at thirty day intervals after the first dusting in 1951 and with three observations per interval until March 1952. At all intervals except one in December, reductions in density were highly significant, ($P < .01$); the December interval showed significance, ($P < .05$). An analysis of grand totals over the whole period from 30 days after first dusting until the end of March 1953 gave again highly significant results, ($P < .01$). Results obtained from periodical analyses so far between March 1953 and December 1953 on plots still under observation continue to show significance, ($P < .05$), (Figure 8).

As has been shown, there is a general association traceable between capsid densities during any given period and leaf-blast scores one month later. This has always been reflected in visible vegetative improvement or deterioration of a plot according to fluctuations of capsid numbers, particularly after several dustings have taken place, or after dusting has ceased, (Figure 9). It should be remembered that there are three different systems used in the damage score graph, which though comparable in any period as between treated and control plot means, are not comparable between periods.

Chi^2 tests showed significant increases, ($P < 0.01$) in the rate of fan flushing and the earliness of onset of peak flushes from ten months after the first dusting onward, in all treated plots as compared with their controls, (Figure 9).

In all plots except those at Odo Ona-nla, it was observed that the elapsed time between treatments tended to increase throughout a season and in successive years. At the same time it was evident from comparisons of the vegetative condition of the various spacing-trial stands at Odo Ona-nla and Owena, both those selected for statistical study and others subjected only to casual observation, that initial damage was always greater in any area in open than in close spacings. Similarly, close-spaced cacao invariably responded more quickly to D.D.T. dusting than did nearby cacao planted more openly. Thus the treated plots at Odo Ona-nla, which were in very bad vegetative condition at the outset and are spaced at double the interval of the control, have tended to maintain high capsid populations. Despite a treatment frequency of twice to three times that of any other plot, this tendency continues, and regeneration of the treated plots is proceeding at a much slower rate than in any other case. It should be mentioned that the planting density of these stands is less than half that of the average for farmers' cacao in the Region.

A comparison of the records of one, five and ten acre plots shows that there is a distinct differential between capsid populations and damage scores at the centre and at the periphery of dusted plots, and that the differential increases as the acreage increases. Unfortunately, the results of analyses, though statistically significant were not considered satisfactory, because comparisons were made over very limited periods and not necessarily simultaneously. This reason, among others, contributed to the decision to undertake the larger scale experiments at Akola.

Records of green-pod production have been examined for monthly, three-monthly and six-monthly periods from June 1951 to the end of November 1953. Table III shows the trends of monthly moving averages summed over six-month periods June to November and December to May, corresponding to those in which main and light crop fruits are developing respectively, in four pairs of plots which have been under observation for two and a half years and one other plot for one and a half years. It will be seen from the ratios given that consistent improvement in treated plots as compared to controls was not evident until December - May

1952-53, fifteen months after dusting had begun. An exception is Odo Ona-nla GF which has an open, scanty stand and a long record of poor light crop yields. Consistency was maintained in all plots through June - November 1953, when the main crop of 1953-54 was maturing.

Analyses of variance showed the differences to be significant ($P < .05$) during both these periods, except for Odo Ona-nla GF from December to May 1952-53, as already indicated. The ratios, expressed in terms of percentage increases in potential yields of treated plots as compared with their controls, range from 5 per cent to 44 per cent of those recorded in the first six-month observation period, in which main crop cocoa was developing. In interpreting these results it must be borne in mind that seasonal and annual fluctuations in yield associated with rainfall and other factors do occur, and also that a control plot may continue to deteriorate while the treated member of a pair is improving in relative condition, so that any original superiority is reduced. This appears to be the trend in all plots at the end of 24 months' treatment, but the treatment period has been too short for the data to furnish conclusive evidence, particularly in view of the biennial bearing cycle of the cacao plant.

The non-statistical trial referred to at (vii) was

TABLE III

HALF-YEARLY TRENDS OF GREEN PODS PRESENT PER 100 TREES, BASED ON MONTHLY MOVING AVERAGES

STATION	1951/52		1952/53		1953/54	
	JUN-NOV.	DEC-MAY	JUN-NOV.	DEC-MAY	JUN-NOV.	DEC-MAY
# ODO ONA NLA GS	-	-	2079	985	1789	-
ø " " " GP	6368	2827	9407	2191	7595	-
" " " GF	1732	702	2648	273	2238	-
# ILESHA 2A	5440	6501	7189	2111	6819	-
ILESHA 2A2	4805	11283	15510	5014	7617	-
# ADO-EKITI 2A	3815	2630	4172	179	2268	-
ADO-EKITI 3A	4897	4273	4389	1122	3590	-
# ONDO 7B	1507	2255	4045	511	2458	-
ONDO 7A	2352	3554	5076	952	4806	-

Control Plots

ø Odo-Ona-nla GP was control to GF during 1951-52, and GS control to both GF and GP thereafter.

TABLE III
(continued)

RATIOS BASED ON PLOT FIGURES FOR
THE FIRST OBSERVATION PERIOD,
JUNE TO NOVEMBER 1951 OR 1952

STATION	RATIOS				
	1951 1952	1952/53		1953/54	
	DEC-MAY	JUN-NOV.	DEC-MAY	JUN-NOV.	DEC-MAY
# ODO ONA NLA GS	-	-	.47	.86	-
ϕ " " " GP	.44	1.47	.77	1.19	-
" " " GF	.41	1.53	.39	1.30	-
# ILESHA 2A	1.20	1.32	.32	1.25	-
ILESHA 2A2	2.35	3.23	.44	1.58	-
# ADO-EKITI 2A	.69	1.09	.07	.59	-
ADO-EKITI 3A	.87	.89	.26	.73	-
# ONDO 7B	1.49	2.68	.22	1.63	-
ONDO 7A	1.51	2.16	.27	2.04	-

Control Plots

ϕ Odo-Ona-nla GP was control to GF during 1951-52, and GS control to both GF and GP thereafter.

begun in March 1953 in a planting of badly blasted cacao of sizes varying from year old supplies to 10-year old trees with little canopy, planted amongst inadequate temporary shade. All dead wood was pruned out of the plants and dusting took place at monthly intervals from March until November. By October it was evident that healthy, well-formed canopies were developing on the larger trees, while no capsids could be found on the younger ones, which were growing vigorously although previously they had been blasted and stunted.

IV. COSTINGS

The foregoing data indicate that where it is possible to begin dusting at a time when capsid populations are at a low ebb, fairly uniform plantings of seven years of age or more may be maintained in good condition with a maximum of three to four treatments per year, although badly damaged portions of stands will require a greater number of applications each year until natural regeneration has taken place. Costings per dusting per acre based on experience in 1953 with the 40-acre tract at Akola are as follows:

D.D.T., 5%, 20 lbs./acre	£0. 12. 0d
Labour	0. 1. 6
Share of supervision	0. 1. 0
Petrol, oil, etc.	0. 0. 3
Share of depreciation	0. 2. 0
Share of transport	0. 1. 0
Total per acre/dusting ..	£0. 17. 9

Thus the annual cost of treatment per acre under average conditions where dusting is necessary would range from £2. 13. 3d for three dustings to £3. 11. 0d for four, with additional cost in the event of extensive pockets being present.

CHAPTER IX

EXPERIMENTAL SPRAYING

I. EQUIPMENT

Spraying trials were carried out during the seasons 1952-53 and 1953-54 with the object of testing the effects of an insecticide combined with an anti-black-pod fungicide as an economy measure. Treatments were applied using Four-Oaks pressure sprayers at 120 pounds per square inch, each containing 3 gallons. Operators worked in pairs on parallel adjoining rows, each moving in a semi-circle about a tree in his own row, and then engaging the near side of a tree opposite in his partner's row. The rate of application of one-half gallon per tree was selected to conform to the estimated rate in black-pod control work, using Bordeaux mixture alone. No attempt was made to get canopy coverage, spray being directed only to the height of the highest visible pods. Under these circumstances, the run-off was excessive.

II. INSECTICIDES

From 1st June 1952 until 31st December 1953 records were maintained in spraying trial plots similar to those in the dusting trials, as follows:

(i) D.D.T., D.D.T./Bordeaux and D.D.T./adhesive# in two 1-acre randomized blocks, seven replications, 1952-53, and

(ii) D.D.T., D.D.T./Bordeaux and Bordeaux, 0.82-acre randomized plots, three replications, 1953, to be continued into 1954.

Untreated controls were provided in the block layouts of the former and adjacent to the latter.

The randomized block spraying trial at Odo Ona-nla, indicated in (i) was designed to test the effect of introducing small quantities of D.D.T. emulsion concentrate into carbide-Bordeaux fungicide (THOROLD, 1952b), in comparison with other D.D.T. formulations. Two one-acre plantings were used with seven replications of four treatments in each, twelve trees per plot. D.D.T. 0.1 per cent w/v miscible concentrate in Bordeaux was compared with the same proportion of D.D.T. alone, and with a sticking agent, and with untreated controls. The treatments began on June 12th 1952 and continued at 35-day intervals until January 17th 1953.

YF2732, supplied gratis by Messrs. Plant Protection, Ltd., London, England.

The 0.82-acre plot trials were begun at Owena in June 1953, the work being done by black-pod control spray gangs, incidentally to their routine 21-day schedules. The formulations were the same as those used at Odo Ona-nla in the previous year except that Bordeaux alone was substituted for D.D.T./adhesive. Spraying continued until late November, at which time purely fungicidal treatment is usually suspended owing to decreased relative humidities.

III. RESULTS

The figures in Table IV show that decreases in capsid populations took place progressively in all treatments from July 1952 through March 1953. This is probably due to the area effect of the insecticide on the small 12-tree control plots randomized through three times the number of similar sized treated plots. During this period high capsid densities which continued until May 1953 were recorded in surrounding untreated cacao. Analysis of variance showed a significant difference between populations on controls and all treated plots ($P < .02$) up to March 1953, or for approximately 60 days after the last spraying. Thereafter there was a rise in numbers of capsids in the plots treated with D.D.T. - Bordeaux.

In view of the small plot size and the difficulty

TABLE IV

QUARTERLY TRENDS OF S. SINGULARIS POPULATIONS IN TWO RANDOMIZED BLOCK COMPARISONS OF THREE D.D.T. 0.1% W/V SPRAY FORMULATIONS

TREATMENTS	*S. singularis*: Sums of Monthly Moving Averages — PERIODS: 1952 JULY-SEPT. (a)	1952 OCT.-DEC. (b)	1953 JAN.-MAR. (c)	1953 APL-JUNE (d)	TOTALS
D.D.T.	898	765	425	157	2245
D.D.T. BORDEAUX	931	829	502	577	2839
D.D.T. YF 2732	1003	491	262	170	1926
CONTROL	2601	1970	1509	358	6438
TOTALS	5433	4055	2698	1262	13448

of analysing results satisfactorily, it was decided to modify the experiment in larger plots at Owena during 1953-54, comparing D.D.T. 0.1 per cent w/v in Bordeaux and D.D.T. 0.1 per cent alone, Bordeaux alone and controls. Treatment began in early July 1953 and was continued until the end of November, using the same technique as that applied in frequent anti-black pod spraying.

It is too early to assess fully the results of the Owena trials, but one striking feature is that in the untreated plots and to a lesser extent in those treated with Bordeaux alone, canopies which had been protected by previous years' dustings were beginning to show signs of serious capsid attack by November 1953.

Costings for this type of treatment have not yet been worked out.

CHAPTER X

DISCUSSION AND CONCLUSIONS

West African Amelonado cacao is remarkably uniform in type, but may vary greatly in vegetative condition and fruiting capacity over short distances under the influence of physical factors and capsid attack followed by invasion of fungi and bark-beetles and perhaps in conjunction with damage by thrips. Normal growth is accomplished by fan flushes and regeneration after severe injury, by means of chupons. Fan flushing takes place throughout the year with a tendency toward three distinct peaks at about four-month intervals. Fruiting may occur at any season but in most areas maturity is reached over two well-marked crop periods, and yields are said to follow a biennial cycle.

The three species, *Sahlbergella singularis*, *Distantiella theobroma* and *Helopeltis bergrothi* are characterized by high incidences of damage in relation to population densities by reason of their frequencies of feeding and the histolytic nature of their saliva. Of them, *S. singularis* is the most important in Nigeria from the points of view of distribution, abundance and adaptability, although in one case *H. bergrothi* is reported to have caused severe leaf-blast at densities considerably below those at which the former is usually associated with diffuse leaf-blast. Wild host material is plentiful for all three species in and near the cocoa bush.

The only species which is generally destructive to bearing cacao in Nigeria is S. singularis, and it appears that the times of occurrence of minimum and maximum densities are not as well defined as those reported from the Gold Coast. They seem to vary both in time and intensity by locality and from year to year. The minima usually occur in May or June but may be delayed until August or September, while maxima may take place between August and January. Since, ideally, insecticidal treatment should begin when a species is near its lowest ebb and continue as infrequently as possible until danger of injury is past, these variations will have a profound effect on treatment schedules. Owing to indications of time, spacing and area effects when using D.D.T. dust, it may be expected that large tracts of cacao will need simultaneous treatment in order to obtain the best results in some cases, whereas in others sequential schedules may prove to be satisfactory. An economical solution of this problem will depend primarily upon the early detection of any rise in the numbers of capsids so that available facilities may be switched from place to place according to an integrated programme.

S. singularis seems capable of feeding and breeding interchangeably between fan shoots and green pods in Nigeria, although some preference for pods as a breeding site is shown when they are of a suitable size and abundance. Chupons are of relatively small importance except in badly damaged cacao, and the lack of overall correlation between capsid numbers and those of flushes as well as green pods, indicates that none of these factors is involved directly in the initiation of population increases. The correlation which exists between capsid densities and leaf-blast scores, together with the fact that about half the populations of S. singularis are found in the canopy at any season, and the tendency of individuals to migrate from tree to tree through contiguous canopies, probably means that full canopy treatment will be necessary to isolate and reduce both diffuse and intense blast.

A correlation has been found between the presence of green-pods and yields of cocoa. This should prove to be a useful measure of success in capsid control operations in cases where yield figures are unobtainable or are suspect. It may serve as an indication of the economy or otherwise of insecticidal treatment, but in practice it must be a less valuable index than weight of cocoa harvested.

Dusting and spraying trials resulted in significant decreases in capsid densities in all cases, and damage scores were consistently and significantly reduced in all dusted plots. There are strong indications that protection of young cacao and of regenerative growth in badly damaged older stands can be achieved by dusting alone or by dusting combined with suitable pruning measures. By analogy it is probable that similar results could be obtained by the use of mixed insecticidal and fungicidal formulations with increased economy in areas where routine black-pod control is necessary, provided that some modification of treatment technique be adopted to ensure canopy coverage as well as that of the pod-bearing surfaces. In any event it would simplify matters to be able to depend on a single type of treatment technique in a given area throughout the year and the life of the plant.

The relationships between capsid, thrips and beetle attack, fungal infection and cacao physiology are not yet sufficiently well understood. While it is possible to prevent further deterioration of damaged cacao by insecticidal dusting, and even to bring about a considerable degree of recovery by this means, the final economy of these procedures will probably involve intensive studies of these factors and their interdependence. A definite association has been shown between capsid densities and leaf-blast intensities. An overall correlation between damaging agencies and total damage rates is likely to be revealed only by such investigations.

The fact that monthly cherelle counts on all plots under observation between July and October 1953 showed significantly greater numbers in all treated plots than in their paired controls, is not conclusive evidence of no reduction of populations of pollinating insects. Records were taken in plots of from 1 to 10 acres extent and also at the 40-acre treated plot at Akola. The question of flight range and habits of pollinators arises in conjunction with the distance from the margin of a plot to its centre, and also in relation to the timing, frequency and intensity of treatment. The evidence of the existence of a time-and-space effect of insecticides in reducing capsid populations must be borne in mind when considering pollinating species.

It is to be expected that continued improvement in the vegetative condition and the rate of fruit setting in a cacao plant will be reflected eventually in an increase in yield. Such a tendency is indicated in the green pod figures recorded in these studies with one notable exception which may be explained by a large initial differential in the yields of the treated and control plots and the relatively very poor general condition of the former. The data adduced are therefore not conclusive, although suggestive, and comparative harvesting records over at least two biennial cycles would be necessary to dispel reasonable doubts as to the efficiency of the treatment methods described.

It would thus be premature to attempt a discussion of the economics of capsid control in the light of information at present available. However, this information is sufficient to form the basis of a tentative estimate of cocoa crop losses in Nigeria from causes traceable initially to capsid attack, exceeding ten per cent of the total or at least ten thousand long tons, valued at some £1,700,000, in the average year.

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