

89.

STUDIES ON THE TOXICOLOGY AND MODE OF ACTION OF
CERTAIN NEW CHLORINATED HYDROCARBON, CHLORINATED
PHENOL AND PHOSPHORUS INSECTICIDES.

With Description of Original Laboratory
Apparatus and Technique designed for the
Evaluation of their Relative Effectiveness.

By

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INTRODUCTION.

Historically the question of pest control is of great antiquity. Man has been fighting insects since his creation and will continue to do so through the years to come. The need for organized large scale control operations against insect enemies is, however, appreciably greater today than in the past. World populations have increased and are increasing, necessitating greater food production and, therefore, more efficient methods of food protection. In addition, depleted soil fertility with the consequent reduction in crop yields, makes it imperative to save the crops from destruction by insects.

Apart from the agricultural aspect of pest control, there is the problem of protecting the ever increasing world populations from the ravages of disease. Hundreds of species of insects, ticks and mites annoy man but of far greater importance is the fact that they may transmit dangerous diseases. During the war period, an incessant battle was waged against lice which carry typhus and relapsing fever; mosquitoes, the vectors of malaria, dengue fever, yellow fever and other diseases such as encephalitis; flies, transmitters of typhoid, dysentery and cholera; fleas which spread plague. In addition, there are other important disease carriers among insects and Arachnids, but those mentioned are of vital importance throughout the world.

A major problem intimately connected with greater food production is the control of serious pests of livestock. These include hornflies, ticks, mites, tsetse flies, mosquitoes and other external parasites of animals.

Confronted with this situation, there is every reason for the entomologist to use every available weapon to control these insect enemies. Chemical control by the use of insecticides is one of the most direct, effective and spectac-

ular methods and is the one with which this paper is concerned. It must be realized, however, that insecticides are only one phase in the war against insects and they must be intelligently applied in order to derive the maximum benefit. Their promiscuous and improper use may lead to other serious problems. There is especial danger in destroying beneficial forms of life by the use of insecticides such as the chlorinated hydrocarbons and there is also the danger of plant injury from their use, either directly or through soil contamination.

Other methods of control should not be lost sight of and should be used to supplement the direct chemical control with insecticides. Soil fertility, crop rotation, seasonal variation and suitability of localities, choice of varieties, silvicultural practice, use of traps, breeding of resistant varieties, use of natural enemies and methods of packing and storing commodities all play an important part in the general campaign.

Prior to the war, arsenic and fluorine compounds, derris, pyrethrum and nicotine were largely relied on for the control of most injurious insects. During the war, however, the diversion of large quantities of inorganic insecticide components to war production and the reduced availability of pyrethrum, derris and nicotine, intensified the search for new insecticides mainly among organic compounds.

As a result of these researches by entomologists and chemists, the past few years have seen the discovery of new insecticides and more effective control methods have been developed not only for the pests of agricultural crops, but for those that affect the health of man and animals.

Among the thousands of chemicals tested, the chlorinated hydrocarbon insecticides D.D.T. (1,1-bis p-chlorophenyl -2,2,2-trichloroethane), B.H.C. (1,2,3,4,5,6-hexachlorocyclohexane), toxaphene, chlordane, the chlorinated phenol,

pentachlorophenol, and the phosphorus compounds " hexaethyl tetraphosphate ", tetraethyl pyrophosphate and O,O-diethyl O-p-nitrophenyl thiophosphate (parathion), have proved to be highly efficient.

Another recent advance, as yet in its infancy, in the insecticide field is the use of systemic insecticides such as bis(bis dimethylamino phosphonous) anhydride and bis dimethylamino fluoro phosphene oxide which are described by Ripper et al. (1950). These materials are carried in the sap rendering the plants treated with them toxic to certain insects. Selenium compounds were previously found to act in this way but they are too dangerous for use in practical pest control.

These insecticides have come to occupy an outstanding position in the field of chemical control of insects so rapidly that there has been insufficient time to investigate their properties thoroughly. Neither their favourable potentialities nor their unfavourable characteristics have been fully evaluated. Further investigations are necessary in order to obtain a working knowledge of their potential usefulness and possible hazards, particularly in respect of their use against insects attacking agricultural crops. Many questions relative to the best formulations to use, the dosages to apply, application schedules, residue hazards, their effect on beneficial insects, plants and soils and their safety to public health and farm animals have yet to be answered more fully before, in many cases, exact recommendations can be made. Research along these lines is in progress and requires not only the aid of entomologists but also that of chemists, toxicologists, veterinarians, agronomists, pharmacologists and plant physiologists and will take years to complete. The field continues to expand rapidly as new chemicals of insecticidal value continue to be found, hence it is obvious that it is impossible to await all research data on all possible applications of new insecticides before

making recommendations as to their use. The procedure adopted is to limit the recommendations for their use to certain specific purposes and broaden them as additional facts become available.

These facts are gradually accumulating and the extent of active research in this direction is very large as is evidenced by the great number of technical papers on the subject which are reaching print in different parts of the world. Exchange of information in this connection is of great value not only to the individual entomologist but to entomology as a whole.

Extensive experiments have been carried out by the writer during the past two years to determine the usefulness, limitations and mode of action of many of the insecticide materials which have given promise of being effective in the control of household and agricultural pests. The results of these researches are embodied in the present thesis and tend to give a clearer picture of the potential usefulness of some of the newer compounds, and broaden the recommendations regarding their practical application.

It is proposed to give first a description of the properties of some of the newer insecticides including D.D.T., hexachlorocyclohexane, toxaphene, chlordane, pentachlorophenol, parathion, "hexaethyl tetraphosphate", and tetraethyl pyrophosphate with some indication of their present or possible fields of usefulness in pest control.

The preliminary step towards selection and ultimate practical use of insecticides is usually laboratory tests to obtain fundamental data regarding their physiological action or to determine their relative effectiveness. For this purpose, standardized apparatus and technique for the accurate evaluation of the toxicity of dusts and sprays and the adhesiveness of insecticides under controlled conditions of temperature and humidity, is required and has been developed by the

writer. The second section of this paper is devoted to a description of three types of original laboratory apparatus.

In the past, insecticides have been applied mainly in the form of sprays, dusts or fumigants, although poison baits and other methods have also been used. One very important factor that has been recognized only in recent years, however, is the possibility of obtaining residual contact effect with insecticides. This phenomenon was first described by Potter with warehouse sprays where pyrethrum was the toxic agent used. This insecticide, as used at present in thin films, decomposes rather rapidly on exposure to daylight so is not likely to have a long lasting residual contact effect, but some of the newer synthetics, such as D.D.T. and other chlorinated hydrocarbon insecticides can be applied in such a way that a film is formed which is toxic to insects coming in contact with it for a considerable period after treatment. It is of direct practical importance to determine the relative efficacy of insecticides with residual effectiveness for the control of household insects. The third section of this thesis describes methods of experimentation and technique designed to obtain such information with certain of the newer insecticides applied as oil sprays and as insecticidal smokes. The use of oil solutions containing the toxic material needs no further explanation, but it may be as well to discuss further the use of smokes as this method of application is not so well known. According to Potter (1948), it is difficult to make a valid distinction, apart from the method of production, between aerosols, smokes and atomised sprays. Toxic smoke produced by burning the insecticide has been used for insect control for some time and the practice of burning nicotine shreds may be mentioned as an example. Brightwell (1942), gives a general summary of the position up to 1942. The advent of D.D.T. and hexachlorocyclohexane has given more scope for this method as the amount of decomposition

of the active ingredients that occurs is considerably less with these materials than with many of the insecticides previously in use. Bateman and Heath (1947), developed techniques for the production of D.D.T. and hexachlorocyclohexane smokes by mixing the insecticides with a pyrotechnic mixture and then igniting them by means of a fuse and ignition mixture. The smoke generators used for the experiments in the present paper were developed by chemists of the Division of Chemical Services, Pretoria, and are based on a sugar-sodium chlorate incendiary mixture.

One of the original features of this thesis is the use of the termite, Trinervitermes havilandi, Hgrn., as a test insect. To the best of the writers knowledge, termites have not previously been used for general insecticide studies. The reasons for the choice of this test animal are given in detail at a later stage.

No paper of this nature would be complete without an attempt to obtain information on the mode of action of the insecticides under consideration. "Mode of action" signifies something different for different people. Those concerned immediately with the practical use of insecticides are most interested in the manner in which the poisons are picked up by the insects and the relative effectiveness of the insecticide materials as fumigants, contact and stomach poisons. It is the main purpose of the fourth section of this paper, therefore, to separate and compare by means of carefully controlled laboratory experiments, the contact, stomach and fumigant actions of D.D.T., hexachlorocyclohexane, toxaphene, chlordane and parathion on three different types of test insects.

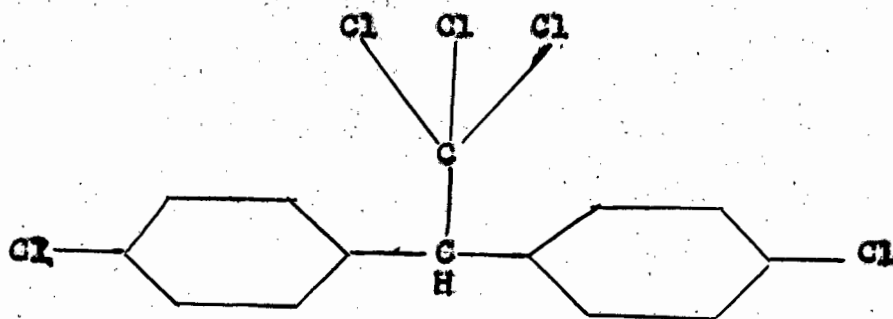
The insect physiologist, however, looks more deeply into the subject and is occupied with the problem of the entry of the insecticides into the insect; and how they intervene in the vital processes in the tissues. This aspect is a problem for the highly specialized insect physiologist and is outside the scope of this thesis. An effort has been made,

however, to review the more recent publications on this highly important and fundamental issue.

We are living in what may be called a chemical age with regard to pest control and it is to be expected that pests will be controlled more and more by synthetic organic insecticides. Even with these great advances in insect control which give cause for optimism in the partial solution of many of our problems, it must be realized, however, that no single insecticide can be considered as an over-all panacea because there is no such product. The specialization and selectivity of insects themselves would seem to preclude even the possibility of such an insecticide in the future. Each insecticide creates its own new problems. For instance there are insects which it fails to kill and thereby festers or builds up. For this reason it is impossible to make general recommendations for any one insecticide without adequate tests being done. It is necessary to treat each pest on its merits and test each of the new compounds against it before arriving at any final conclusions regarding its efficacy. The number of different insects against which many of the new products have been used is rapidly increasing and many of them are common to this country as well as to other parts of the world. South Africa, however, has its own special climatological and ecological characteristics as well as native pests which do not occur in other parts of the world. This entails the repetition, under our own climatic conditions, of tests done in other countries on insects which also occur in South Africa and in addition determining the efficacy of the newer poisons against our indigenous insects. The fifth and final section of this thesis, therefore, gives a detailed account of the results obtained by the writer on the control of some of our more important agricultural pests with certain of the new organic synthetic insecticides.

SECTION I.PROPERTIES OF INSECTICIDES TESTED.I. CHLORINATED HYDROCARBON INSECTICIDES.D.D.T.

D.D.T. normally consists of a mixture of isomers. The proportion of the insecticidally active constituent or para para D.D.T., 1,1-bis(p-chlorophenyl)-2,2,2-trichloroethane, may depend on the conditions of manufacture and may range from 60-90 per cent. The pure para para isomer is a white crystalline substance with a melting point of 107 to 108 degrees C. and a molecular weight of 354.5. It is practically insoluble in water but easily soluble in most organic solvents, is practically non-volatile and decomposes in alkaline media. When the pure compound is discussed specifically it is usually referred to by the abbreviated designation of p,p' D.D.T., but when the term D.D.T. is used without qualification, The commercial (technical) product is indicated. The structural formula of 1,1-bis(p-chlorophenyl)-2,2,2-trichloroethane is given below.



D.D.T. is both a contact and a stomach poison to insects and one of the outstanding properties of this insecticide is its prolonged residual toxicity when

applied under practical conditions. This persistent effect, which is attributable to its great stability to light and chemical action and to its involatility, renders it invaluable for the control of insects over an extended period of time and has afforded a degree of control against a number of insect species hitherto unobtainable with the conventional insecticides previously at our disposal. D.D.T. may be formulated for insecticidal use as a dusting powder, an oil solution, an emulsion, a wettable powder, an aerosol or for use as an insecticidal smoke.

Although toxic to a wide range of insects, D.D.T. will not kill all the important pests. Against some insects it is no better than the chemicals ordinarily used, while against others it has shown little if any effect. In addition, the repeated cases in which various insect pests seem to be developing resistance to D.D.T. and other chlorinated hydrocarbon insecticides presents a serious problem to the economic entomologist. The resistance of house flies to D.D.T. has been demonstrated by Wiesmann (1947), Saccà (1947), Lindquist and Wilson (1948), Wilson and Gahan (1948), King and Gahan (1949), King (1948) and Metcalf and Boyce (1950). Boyce (1949), has reported that the repeated use of D.D.T. on citrus has resulted in citrus thrips developing a resistance to this particular insecticide and he states further that information has been received from Florida, U.S.A., of mosquitoes becoming resistant to D.D.T.

Decker (1946), has shown that owing to the persistence of D.D.T. residues, the normal cleaning and washing processes to which fruit and vegetables are normally subjected after dusting or spraying with insecticides, do not entirely remove the D.D.T. deposits. In general, therefore, in the case of edible crops, the insecticide should be applied in the early part of the season and not just prior to harvesting. A period of three or four weeks should elapse between the time of

application of the insecticide and the harvesting of the crop. The treatment of such crops as potatoes, sweet potatoes, onions etc. involves few or no hazards as the edible portions of the plant are produced below the ground and the treated portion is not used. In the case of some cereal crops, the grain has a protective covering and there is little likelihood that the seeds will be dangerously contaminated. From the residual aspect, there seems no reason why D.D.T. should not be used on shade trees and ornamental plants. The treatment of crops such as fodder plants and lucerne involves a more serious hazard. It is of interest to note that Lehman (1947), states that if D.D.T. intake is greater than seven parts per million in animal food, appreciable storage of the material in the fat can occur. While animals are feeding freely, several times the acutely fatal dose may be stored and subsequently this stored D.D.T. may be mobilised if the animals are starved. Signs of poisoning can then develop in such animals. It has also been found that if animals are given oral doses of D.D.T. it can accumulate in the body fat and appear in the milk (Potter, 1948).

Howell et al. (1947) and Carter et al. (1949), have shown that D.D.T. appears in milk from cows sprayed either with xylene emulsions or suspensions of D.D.T.

In view of these facts, the United States Department of Agriculture recommended in 1949 that D.D.T. and other chlorinated hydrocarbon insecticides, with the exception of the methoxy analogue of D.D.T., should not be used in dairy barns, on forage feed to dairy cattle, on dairy animals or on animals being finished for slaughter. With regard to the use of D.D.T. sprays in dairy barns, however, Harris et al. (1950), produce experimental data which indicates that when good dairy practices are followed, barn sprays applied with simple precautions are not likely to result in milk contamination.

D.D.T. can induce poisoning in man and animals if abused. This, however, is by no means peculiar

II.

-lar to D.D.T., as many other insecticides in general use today are definitely more dangerous in this respect. The major risk would appear to be its cumulative effects and a considerable amount of work has been done on this subject. A summary of the position is given by Cameron(1945), Neal and von Ottingen(1946), Woodland et al.(1948) and Lehman (1949). There appears to be, however, a wide margin of safety in its use as an insecticide. With the low concentrations recommended for the control of insect pests, there is no reason to expect undue danger to man and animals. There is, moreover, no danger of absorbing either dry powders or water suspensions through the skin, but care should be exercised in handling oil solutions, especially if in concentrated form. Inhalation of sprays and dusts should be avoided as much as possible.

There is some question about the safety of heavy applications of D.D.T. to the soil at one time or over a period of several years. The actual effect can, however, only be determined over a long period of time. According to Cullinan (1947), the type of soil involved appears to be an important factor. His more recent work has involved the addition of D.D.T to clay loam, sandy loam, fine sand and acid muck soil. On the lighter soils, 25 pounds per acre of technical D.D.T. depressed or retarded the growth of some vegetables such as cucumbers, squash, beet, spinach, tomato and beans. On acid muck soils, 25 pounds per acre had only a slight effect on the growth of these crops if planted immediately, and no effect if planted two months after mixing the D.D.T. in the soil. The application of 25 pounds of technical D.D.T. per acre to the lighter soils had no effect on maize, turnips, cabbage and radish.

Further published work by Cullinan (1949), indicates that when the pH of acid muck soils is raised from 4.5 to 5.4 by the addition of dolomitic lime, phytotoxicity is apparent at much lower concentrations of D.D.T. It is not

known what changes take place in the soil which may affect the degree of phytotoxicity to plants, but it has been established that the D.D.T. chemicals can be dehydrohalogenated and that plant injury may be quite severe when the p,p', o,p' D.D.T. and the dehydrohalogenated analogues are added to the soil. (Cullinan, 1949). Much is still to be learned regarding how much of the injury resulting from the accumulation is due to decomposition products and how much is due to some by-product or impurity in the chemical. Cullinan, (1949), has established that highly purified D.D.T. preparations are less toxic than some commercial or technical grades.

Evidence that the purified form of D.D.T. does not affect germination of seed comes from a study made by Hopkins and Toole in 1950. These investigators found that purified D.D.T. did not affect the initial stages of germination of cucumber, rye, squash or lima bean seed when planted on special crepe paper impregnated with a large amount of the compound. Their researches showed further, that technical D.D.T. reduced significantly the percentage of germination of the above-mentioned seed and they consider the cause of this to be due to some compound in the formulation other than D.D.T. It was found that after germination had started, the early growth of lima beans, cucumber and rye seedlings was profoundly affected by high concentrations of D.D.T.

As far as our knowledge goes, D.D.T., when applied to the foliage, seems to have an adverse effect on only a few plants; the most important of these are cucurbits, of which many are adversely affected.

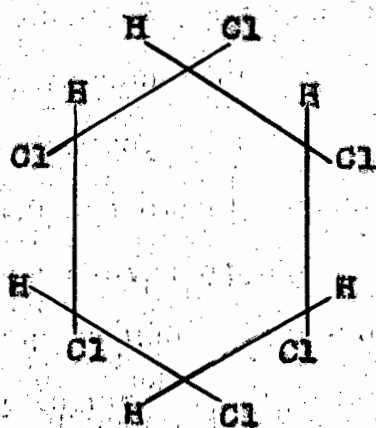
Work done by Wilson and Choudhri, (1946), on certain micro-biological processes in the soil, have thus-far indicated that, in tests with D.D.T. where it was applied much in excess of the quantity which would ever be applied for the control of insects, no injury to micro-organisms will result.

Ammonification, the accumulation of nitrate and the normal concentration of salts in the soil have not been seriously modified. Foster, (1948), also found that soil organisms do not affect the strength of D.D.T.

1,2,3,4,5,6-HEXACHLOROCYCLOHEXANE (B.H.C.)

Like D.D.T., this chemical had been known for many years before its insecticidal properties were recognized. First synthesized in 1825 by Michael Faraday, its structure was determined in 1836. Meunier first demonstrated the existence of two isomers and van der Linden in 1912 proved the existence of two additional isomers. These were named Alpha, Beta, Gamma and Delta. The insecticidal properties were discovered in France in 1941 and independently in England in 1942, where the principal insecticidal action was ascribed to the Gamma isomer and its use against agricultural pests was developed. Recently Kauer et al., (1947), have isolated a fifth isomer which they have designated as the Epsilon isomer. The Alpha, Beta, Delta and Epsilon isomers are reported by Potter, (1948), to have little insecticidal activity.

The structural formula of 1,2,3,4,5,6- hexachlorocyclohexane is



The pure Gamma isomer is a white crystalline solid with a melting point of 112.5 degrees C. and a vapour pressure of 0.03 mm. Hg. at 20 degrees C. It is practically

insoluble in water but freely soluble in acetone and benzene and appreciably soluble in other common organic solvents. It has an odour, unless this is due to traces of impurity, but it is not nearly so pronounced as in the technical product, which possesses a musty clinging smell. The proportion of the isomers in different commercial samples may vary widely according to Haller, (1947), but the following table indicates the most common proportions of the five isomers in the crude chemical and their respective properties. Lindane, the most recent B.H.C. formulation, however, contains approximately 99.5 per cent of the Gamma isomer.

Name of isomer.	Per cent of mixture.	Melting point. Degrees C.	Solubility in CH_3OH . g / 100 g.	Vapour pressure. mm. Hg. at 40 degrees C.
Alpha.	5	157.5-158	2.3	0.06
Beta.	70	309	1.6	0.17
Gamma.	10-12	112.5	7.4	0.14
Delta.	-	138 - 139	27.3	0.09
Epsilon.	3-4	218 -219.3	-	-

Data from Frear, 1948.

In general, B.H.C. is considered for the same uses as D.D.T. but it is also effective against certain insect species poorly controlled by this insecticide. The technical product is more volatile than D.D.T. and sublimes rather easily, (Haller and Bowen, 1947), which probably^{accounts} for its shorter residual duration. Since it is chemically stable at high temperatures it can be volatilized from hot surfaces or vapourized in the form of smokes. It can also be applied as a dust, oil solution, emulsion or ~~or~~ water suspension. It decomposes in the presence

of alkaline materials.

On account of the danger of imparting its unpleasant odour to food plants, it should not be used in soils where root crops are soon to be planted. Taste contamination of fruit and some vegetables has been attributable to applications of B.H.C. A preliminary report by Greenwood, (1947), indicates that this insecticide broadcast at the rate of 2.5 pounds of the crude material per acre for wire-worm control does not contaminate potato tubers. Broadcast applications of 7.5 pounds of the crude material per acre, however, impart a slight taste to tubers boiled in their skins. Stitt and Evanson, (1949), report that soil treatments using B.H.C. definitely cause an off-flavour in fresh peas and pole beans. Results obtained with bush beans were, however, less conclusive. The effect of B.H.C. sprays on the flavour of peaches was investigated by Smith et al. (1949) and independently by Bailly et al. during the same year. The results obtained indicate that the flavour of the fresh fruit is definitely affected by the use of this insecticide and that the flavour of canned fruit is similarly affected.

Rohwer, (1949), states that preliminary experiments indicate that most of the off-flavour caused in products by B.H.C. may result from isomers other than the Gamma. They suggest particularly that B.H.C. formulations should contain the minimum practical quantity of the Delta isomer when they are to be used in situations where plant safety may be involved and the minimum practical quantity of both Beta and Delta isomers when the flavour or odour of the edible portion of the plants may be affected. Odour-free miscible oils, solutions and wettable powders containing B.H.C. are now being produced and it is probable that in the course of time, the objectionable odour will be eliminated from all formulations.

The effect of B.H.C. on soils has not been

fully determined. At the present time substantial data are not available on its permanence and stability under all soil and climatic conditions. As with D.D.T., soil type and character appear to be important factors in determining the toxicity of this product. The data obtained as a result of soil residue experiments indicate that it should be used with caution and that concentrations should be kept at a minimum until a better understanding of the permanent effects is obtained. Cullinan, (1947), reports that B.H.C. is toxic to cucumbers, squash, beet, spinach, tomatoes turnips and cabbage even at fairly low levels in the soil. An application of 2.5 pounds per acre of the Gamma isomer in the top three inches of soil did not appear to injure oats, rice and cowpea seeds and seedlings, but germination and growth was stopped by dosages of 5 pounds or more per acre. Certain field crops and ornamentals were apparently not adversely affected by one application of four ounces of Gamma B.H.C. per acre. Cullinan, (1949), emphasizes that the phytotoxicity of B.H.C. differs greatly from D.D.T. in that all vegetable crops tested appear to be sensitive to it when mixed in the soil in appreciable amounts.

Grayson, (1947), has shown that in small field trials, a soil application of 100 pounds of B.H.C. (30 pounds of Gamma isomer) per acre, greatly reduced germination and early development of peanuts, mealies, cotton and soybeans, whereas 200 pounds of D.D.T. caused no obviously reduced germination or damage to the early development of these crops.

According to Foster (1948), B.H.C. seems to have some fungicidal effect on soil fungi and appears to have a harmful effect on micro-organisms in the soil.

B.H.C. has not been used extensively enough to reach any final conclusions as to its effect on plants in general when applied to foliage at concentrations necessary to obtain satisfactory insect control but, as with D.D.T., it

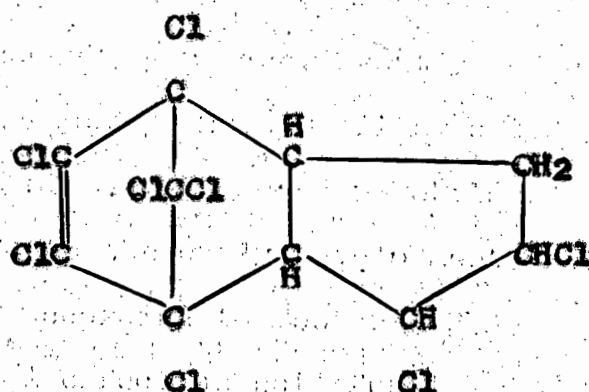
appears to be relatively safe to assume that only comparatively few will be adversely affected. Cucurbits and young maize plants have shown foliage injury and there is some evidence of stunting of tomato plants following its use.

Technical B.H.C. is toxic to mammals, but here as with D.D.T., there should be no hazard if it is used correctly.

CHLORDANE.

This chlorinated hydrocarbon insecticide was reported by Kearns et al. in 1945 under the designation of Velsicol 1068. The chemical name for this compound is 1,2,4,5,6,7,8,8-octachloro-4,7-methano-3a,4,7,7a-tetrahydroindane, which is considered to form 60 per cent w/w of the technical product, the other 40 per cent being related compounds. According to Potter, (1948), all the compounds have an insecticidal action.

Refined chlordane is a viscous, colourless, nearly odourless liquid boiling at 175 degrees C. at 2 mm. pressure. Chlordane,



may show a tendency to crystallize. It is readily soluble in all proportions in most organic solvents such as aromatic, aliphatic and chlorinated hydrocarbons, ketones, esters and alcohols but is insoluble in water. It is completely miscible

in deodorized kerosene commonly used in insecticide formulations. Like D.D.T. and B.H.C., chlordane, in the presence of weak alkali forms a product which is apparently non-toxic and for this reason should be considered incompatible with materials having an alkaline reaction. It has low volatility, being intermediate between D.D.T. and B.H.C. It has longer residual effect than B.H.C. but is, in general, inferior to D.D.T. in this respect.

Chlordane may be formulated as an oil solution, an emulsion, a wettable powder or as a dust. A space spray containing 0.2 per cent chlordane is recommended for flying insects together with a knock-down agent such as pyrethrum, Lethane or Thanite if quick effect is desired. As a space spray it is slightly more effective than D.D.T. against houseflies but is less effective against mosquitoes. As a residual spray for crawling insects, a 2 per cent concentration is recommended. In dust formulations against agricultural pests, an application of one to two pounds of chlordane^{per acre} is suggested. It is more effective than D.D.T. against certain insects such as cockroaches, grasshoppers, aphids, ants and certain species of ticks. It is capable of acting as a contact poison, a stomach poison and as a fumigant to insects.

Brooks and Anderson, (1947), record plant damage on cucurbits and cucumber but as with D.D.T. and B.H.C., its effect on plants and soils has not been fully determined, hence it should be used with caution and at minimum concentration until further information is available. Cullinan, (1949), has found that chlordane mixed with the soil, like B.H.C., causes more root damage than D.D.T. and that chlordane applied to the soil is more toxic to certain seedling plants than B.H.C. Stitt and Evanson, (1949), indicate that bush beans and turnips are adversely affected by the application of 34.8 pounds actual chlordane per acre to the soil, whereas the application of 5

pounds of actual chlordane per acre has no apparent adverse effect on bush beans, pole beans, beets, carrots, cauliflower, onions, squash and Swiss chard. There is some evidence that soil surface treatments cause some off-flavour in the case of peas, bush and pole beans.

Work done by Foster in 1948 suggests that unlike D.D.T., chlordane, in common with B.H.C., has a harmful effect on soil micro-organisms and has some effect on soil fungi.

Some work has been done on the toxicity of chlordane to mammals, (Ingle, 1947), and it appears to have a higher order of toxicity to warm blooded animals than D.D.T. Radeleff, (1949), considers chlordane to be more toxic to young livestock than D.D.T. and urges caution in its use on animals. Howell, (1950), has shown in his experimental work with D.D.T., chlordane, B.H.C., methoxy D.D.T. and toxaphene sprays on cattle, however, that unless they are sprayed more frequently than is necessary, the total organic chlorides present in the milk is not greater than two parts per million, regardless of the insecticide used. Less than 10 parts per million is stored in the tissues.

TOXAPHENE.

The structural formula for toxaphene has not yet been worked out. Chemically this material is a mixture containing polychloro bicyclic terpenes. The approximate empirical formula is $C_{10}H_{10}Cl_8$. An account of the material and its insecticidal properties is given by Parker and Beacher (1947), and Stearns et al., (1947).

The technical product is a creamy coloured waxy solid with a mild piney odour and contains 67 to 69 per cent chlorine. It melts at a range of 65 to 90 degrees C. and is readily soluble in common organic solvents. In solid form

it may be stored for at least a year without deterioration. Solutions can be stored in suitable containers for an equal period of time. It may be formulated in oil soluble concentrates as an emulsion, a water suspension or as a dusting powder.

Toxaphene is similar to D.D.T. in methods of use against common household insects but is somewhat slower in producing paralysis. It exhibits residual toxicity and is a promising contact and stomach insecticide against a number of agricultural pests. It is compatible with sulphurs, Bordeaux mixture, lead arsenate, summer oils and nicotine sulphate. Strongly alkaline materials should, however, be avoided in toxaphene formulations. It is less effective than D.D.T. as a space spray and is inferior to it as a residual spray against insects such as houseflies, mosquitoes and cockroaches.

With regard to phytotoxicity, no adverse effects have been noted on beans, apples, grapes and peaches or on any other plant except cucurbits and potatoes where the damage may be considerable.

It appears to have no fungicidal properties and unlike D.D.T., B.H.C. and chlordane, toxaphene, when applied to the soil, is broken down by soil fungi or bacteria and is rendered harmless in about a year although its initial toxicity is about the same as that of D.D.T. in the soil.

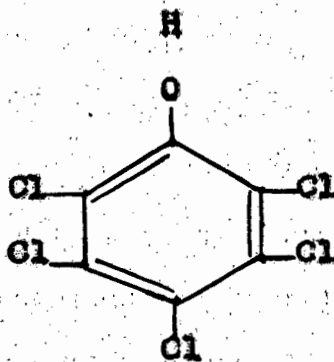
Toxaphene is toxic to mammals as has been shown by Woodland et al., (1948), but according to Potter, (1948) there appears to be no reason to suspect that it is significantly more dangerous than the other chlorinated hydrocarbons used as insecticides. Bushland et al., (1948), report no ill effects from toxaphene to cattle, sheep, goats, hogs and horses when applied as emulsions and wettable powders at concentrations of 1.5 per cent of the technical material. Radeleff, (1949), on the other hand, considers toxaphene to be more toxic than D.D.T. especially to young livestock. This view is supported by the United States Department of Agriculture, (1949), which states

that this material, when administered orally was found to be four times as toxic as D.D.T. to various laboratory animals and in addition, it was more toxic when applied to the skin. Howell, (1950), considers that unless cattle are sprayed with toxaphene more frequently than is necessary for external parasite control, the total organic chlorides present in the milk will not be greater than two parts per million and less than ten parts per million is stored in the tissues. *

2. CHLORINATED PHENOL INSECTICIDE.

PENTACHLOROPHENOL.

Pure pentachlorophenol has the structural formula



It is not a new chemical discovery. Pentachlorophenol was described by Erdman as early as 1841 but it was not until 1935, that Hatfield, in his investigational work with chlorinated phenols, discovered the value of this material as a wood preservative and during the same year Ginsburg published on its toxicity to various insect species. This work was followed up in 1939 by Siegler et al. with tests against the codling moth. It was early established that the use of pentachlorophenol as an insecticide is greatly limited on

account of its very high phytotoxicity, but in 1947, interest in this compound was revived by Weinmann and Decker and detailed studies were carried out against carpet beetles, houseflies and red spider mites. It was found, however, that for agricultural use, even at a dilution of 1 to 16,000, the material was too toxic for use on plants and it is today used mainly for wood preservation against wood-boring beetles, termites and wood fungi.

Pure pentachlorophenol is a colourless, crystalline solid, melting at 191 degrees C; it decomposes at 310 degrees C. The technical grade, which is commonly used for wood treatment, is sold as dark greyish flakes. Pentachlorophenol is soluble in a wide variety of organic solvents including acetone, benzene and many types of oils but it is insoluble in water. It has very low vapour pressure, and one of its most valuable properties is its prolonged residual action.

Pentachlorophenol is toxic to man and warm blooded animals and must, therefore, be used judiciously, especially in oil solutions which is the formulation usually employed for the impregnation of wood and similar materials.

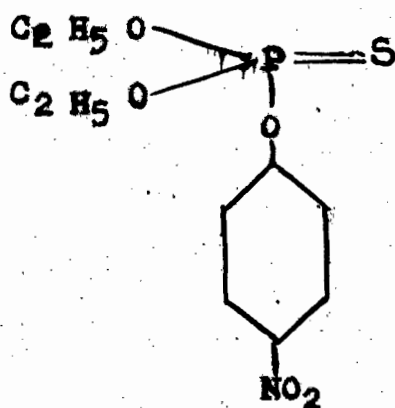
3. PHOSPHORUS COMPOUNDS.

Phosphorus compounds were developed in Germany during the war for plant protection and have since been studied and manufactured in other countries. They appear to have been off-shoots from the work on chemical warfare and those in use are highly toxic to mammals. An account of the position in Germany is given by Martin and Shaw, (1946). These products include some phosphoric acid derivatives which have been shown by the German workers to be taken up from the soil by the plant, which thus becomes poisonous to the insects

feeding on it. This systemic action will not be dealt within this paper, however, since the investigational work carried out by the writer has not progressed far enough for final conclusions to be drawn.

O,O-DIETHYL O-p-NITROPHENYL THIOPHOSPHATE. (PARATHION).

This material which has the structural formula



is one of the newest and most effective developments in the insecticide field. In general, it appears to be more toxic to a wider range of insects and mites than any other chemical now in general use. The compound is a high boiling, yellow liquid having a boiling point of 375 degrees C. or higher. It is only very slightly soluble in water (20 parts per million) but is completely miscible with many organic solvents such as acetone, cyclohexanone, alcohols, esters, animal and vegetable fats. It is only slightly soluble in petroleum ether, refined spray oils and kerosene without the addition of auxiliary solvents. Parathion is stable to hydrolysis in normal waters and is not readily destroyed by oxidation. It has definite residual toxicity.

The compound is compatible with sulphur, fixed coppers, D.D.T., B.H.C., toxaphene, chlordane, rotenone, pyrethrum and lead arsenate. Although the toxicity is not immediately

lost when parathion is used in combination with alkaline materials which contain free lime, the residual toxicity drops rapidly when it is used with hydrated lime, calcium arsenate, Bordeaux mixture or lime sulphur.

At present it is formulated as a dusting powder, an emulsion concentrate and as a wettable powder. Oil solutions and emulsions are not at present recommended by the writer, however, owing to the high degree of toxicity through skin absorption. Parathion is extremely toxic to man and warm blooded animals and operators using the material under conditions involving considerable dust or spray drift should wear protective clothing and respirators. None of the formulations should be handled with bare hands. It cannot be used safely on animals on account of its high toxicity through skin absorption and for the same reason and because of its unpleasant odour, it should not be used for the control of household pests.

As regards phytotoxicity, cucumber and tomato plants have given evidence of being sensitive while beans, peas, cabbage, citrus, rose, carnation, crassula, potato, nasturtium, chrysanthemum and many other plants appear to be able to tolerate quite large dosages. Edwards, (1949), considers that unreacted para nitrophenol is the principal impurity responsible for damage to tomatoes. Recent work done by Scott in 1949 indicates that until more data become available, the use of any parathion formulations on ornamentals should be limited to evergreen and deciduous plants in full growth. Winter applications to dormant plants, deciduous or evergreen, with tight terminal buds and deciduous trees should be avoided until more test work is completed and verified. He found, however, that on the majority of plants, control is safe and satisfactory at 0.02 per cent parathion concentration. Glass, (1949), reports damage to certain susceptible apple varieties. Work done by Pritchard and Beer in 1949, indicates that ferns, poinsettias and African

violet blossoms are sensitive to injury while gardenias have suffered leaf drop by the application of parathion.

For agricultural use, in the case of agricultural crops, parathion should not be applied after the pods of peas and beans or other edible parts of vegetables are formed. Cabbages should not be sprayed or dusted after the heads have started to form and in the case of fruit, a period of approximately thirty days should elapse between the time of application of the insecticide and the harvesting of the crop.

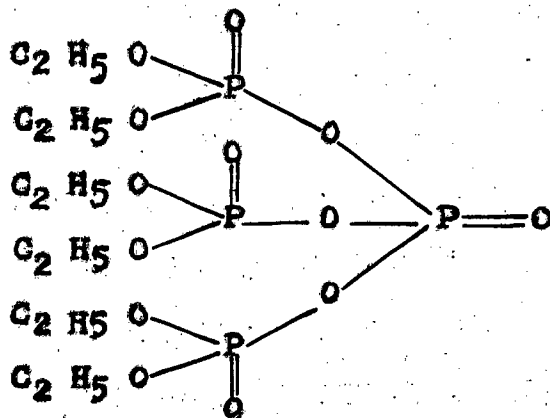
As with the chlorinated hydrocarbon insecticides, the effect of parathion on soils has not been fully determined although work on this project is in progress. Horsfall, (1948), states that preliminary investigations indicate that if the limitations of dosage and timing of applications are strictly observed, there is limited probability of build up of parathion in the soil, of translocation of penetrating spray or dust films or of hazardous dust residues. Chemical analysis of soil has shown 85 per cent loss of parathion content in seven months. Stitt and Evanson, (1949), have shown that soil surface treatments using two pounds of actual parathion per acre seem to reduce the quality of peas, pole beans and bush beans but it is questionable whether it has the same adverse effect on carrots and cucumbers. It is obvious, therefore, that until further data on this subject become available, soil applications of this material should be made with great caution.

" HEXAETHYL TETRAPHOSPHATE ".

In 1938 Schrader described a process for producing " hexaethyl tetraphosphate " by the reaction between triethyl phosphate and phosphorus oxychloride. Bourath investigated its insecticidal properties during the war and a German formulation containing it together with xylene and a wetting

agent was marketed under the name of Bladen. The empirical formula is given by Hall and Jacobsen as $(C_2H_5)_6O_{13}P_4$ and these authors state that it is a non-distillable liquid mixture composed essentially of tetraethyl pyrophosphate, which is the active ingredient, ethyl metaphosphate and triethyl orthophosphate. Pentaethyl triphosphate may also be a constituent of the mixture.

"Hexaethyl tetraphosphate" is a yellowish liquid, miscible in all proportions with water and with many organic solvents including acetone, alcohol and benzene, but not with kerosene or petroleum spray oils. It is hygroscopic and is readily hydrolyzed by water with consequent loss of insecticidal potency; hence it must be applied as a freshly made solution. According to Frear, (1948), the following structural formula has been proposed for the reaction product:-



"Hexaethyl tetraphosphate" is formulated for liquid spraying, for dust application and as an aerosol. As with solutions, the dusts should be applied promptly after mixing. This material, in concentrated form, is extremely toxic to mammals and as it is rapidly absorbed through the skin, it should be handled with great care. For insecticidal purposes, however, it is used in very diluted form hence the main danger

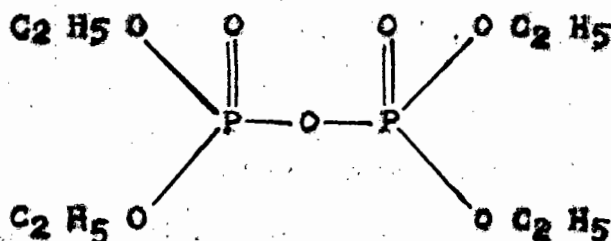
is in the mixing of the material prior to its application. The compound is irritating to the skin and contact with it should be avoided as much as possible. Operators should wear respirators and protective clothing.

" Hexaethyl tetraphosphate " is efficacious in controlling red spider mites, aphids, immature scales, thrips, leafhoppers and mealybugs and in general, it appears to be useful for a number of purposes for which nicotine is used. Its ovicidal effect is, however, poor. The material is effective at cool temperatures as well as at fairly high ones. Since the chemical decomposes rapidly, residues probably will not present a serious health hazard and no residual toxicity can be expected.

Injury has been reported to chrysanthemum varieties and to tomatoes in green-houses but to no other plants. It is not compatible with alkaline materials and should not be applied over fresh residues of Bordeaux mixture.

TETRAETHYL PYROPHOSPHATE.

This compound, which according to Frear, (1948), has the probable structural formula



is a straw coloured mobile liquid having a specific gravity of approximately 1.2. It decomposes at temperatures of 135 degrees C. and above, is miscible with water, acetone, alcohol,

benzene, chloroform, glycerine, toluene, xylene and a number of other organic solvents. It is not miscible with kerosene, petroleum ether and other paraffinic oils.

Tetraethyl pyrophosphate in a relatively pure form is stable at normal temperatures. The compound is hygroscopic, however, and in the presence of water is hydrolyzed rather rapidly with loss in toxicity. As with "hexaethyl tetraphosphate", solutions of tetraethyl pyrophosphate are corrosive to certain materials. It is considered for the same uses as "hexaethyl tetraphosphate" but is in general three times as toxic to insects as this material. It is highly toxic to man and animals and should be handled with great care.

4. MISCELLANEOUS INSECTICIDES.

CRYOLITE. (Na_3AlF_6)

This material was reported on as a stomach insecticide by Marcovitch as early as 1924 and is one of the most promising of the inorganic insecticides in use as an arsenical substitute. It occurs naturally chiefly in Southern Greenland where it is mined for the manufacture of aluminium. It is also made synthetically from bauxite. The natural mineral is, however, superior to the synthetic material on account of its better adhesive properties. Cryolite, largely because of its low solubility, is the safest of the fluorine compounds used in plant protection.

LEAD ARSENATE, SODIUM FLUOSILICATE, PYRETHRUM AND NICOTINE are too well known to warrant any description as regards their respective properties and uses in the insecticide field.

SECTION 2.DESCRIPTION OF ORIGINAL APPARATUS.I. A LABORATORY APPARATUS FOR THE APPLICATION OF INSECTICIDAL DUSTS.

The wide-spread demand for new and improved insecticides and for the evaluation of these insecticides by means of biological assay, has made it imperative to devise standardized methods whereby insecticidal dusts can be quickly and accurately applied. Not only must the powders be uniformly applied, but it should be possible to deposit any desired weight of dust per unit area. When this is achieved, it can be known that insects consuming equal amounts of treated foliage will take approximately equal doses of poison, irrespective of the specific gravities of the powders being tested. Furthermore, it will be possible to ensure that, in the testing of contact insecticides, the test insects will be thoroughly and uniformly dusted over the entire body surface.

With these considerations in view, an apparatus has been constructed which has given satisfactory results and with which an experienced operator can apply dosages accurate to the fourth decimal place of a gramme with reference to a surface area of 28 sq. cms. (the area of the glass slide used for gauging the weight of the dust falling on the exposed foliage or insects.)

DESCRIPTION OF APPARATUS. (Figures I and 2).

The dusting chamber consists of a glass bell-jar (A) 10 inches in diameter and 14 inches high, with a 2 inch opening at the top. It is mounted on a smooth circular rubber mat (B) 16 inches in diameter and half an inch thick. The advantage of the rubber base is that it makes close contact

with the bell-jar and can also be easily cleaned.

The dust receptacle (C) which disperses the dust, is suspended within the bell-jar at a fixed distance from the base. It consists of a glass vessel with a rounded bottom, $2\frac{1}{2}$ inches high and $1\frac{3}{10}$ inches in diameter and is fitted with a securely fitting rubber stopper (D), through which pass four glass outlet jets (E), fitting flush with the bottom of the stopper but extending $\frac{1}{2}$ of an inch through the top and drawn out to fine points. The openings of these tubes at the bottom of the stopper are covered with fine wire gauze having 50 meshes to the inch (F). A fifth tube (G), of slightly larger bore passes through the centre of the rubber stopper and the wire gauze, and projects $\frac{1}{2}$ of an inch into the dust container. This glass tube is connected to a rubber tube (H) passing through a rubber stopper in the top of the bell-jar, and is connected to an air reservoir. Air is released at 5 pounds pressure per square inch and passes through tube (G) into the dust in the dust container, blowing it out through the four outlet tubes and into the bell-jar.

A weighed glass plate (J), measuring 28 sq. cms. is placed on the rubber base of the dusting chamber and is again weighed, after all the dust has settled, in order to determine the dosage. The weight of the dust placed in the dust container depends on the deposit required and will naturally vary to a certain extent with different insecticides. In general however, 0.25 grammes of powder should be put into the container to give an application equivalent to about 10 pounds per acre in the field. With each application, all the dust should be allowed to settle. The same weight of dust in the receptacle will not always give the same deposit on the glass slide; hence the dosage must be calculated not on the weight of the dust blown out of the receptacle, but on the weight that settles on the slide. It is advisable to put slightly less powder in the

DUSTING APPARATUS.

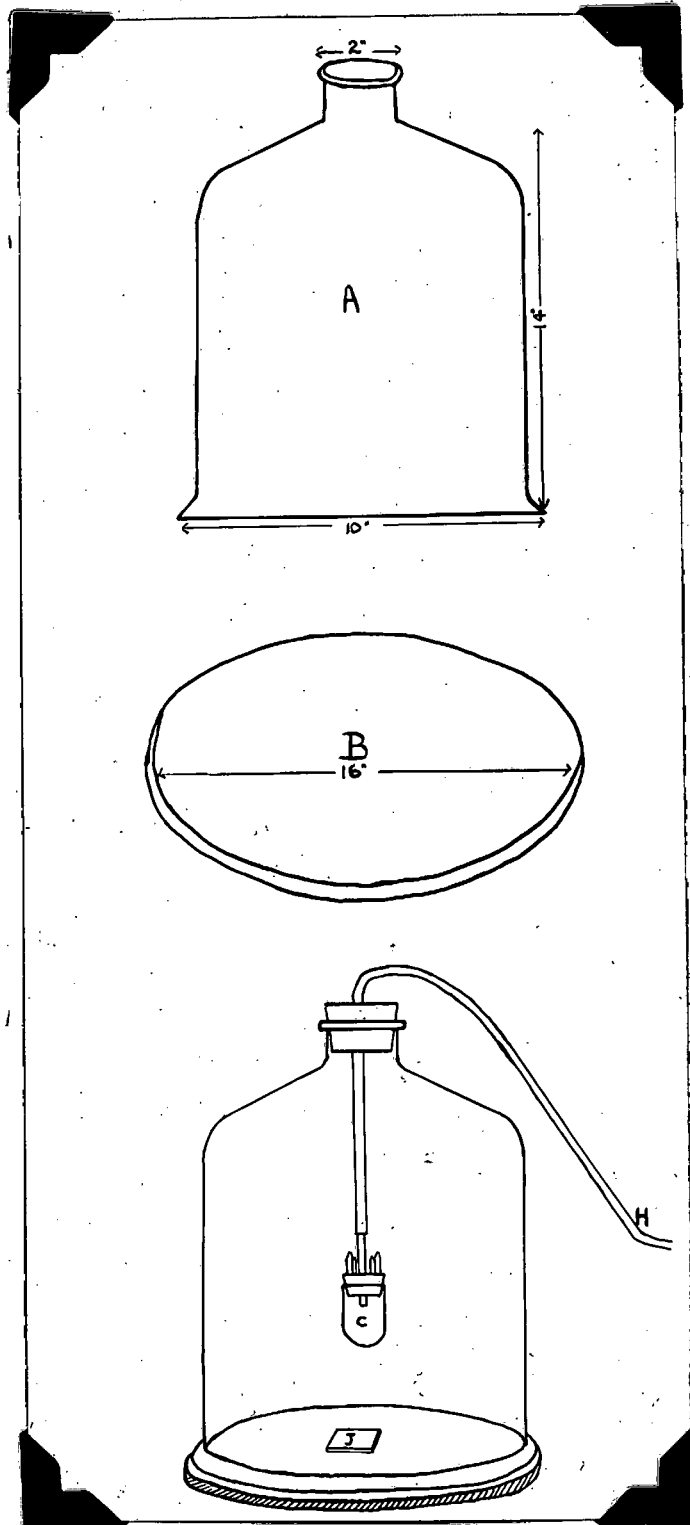


FIGURE I.

DUSTING APPARATUS.

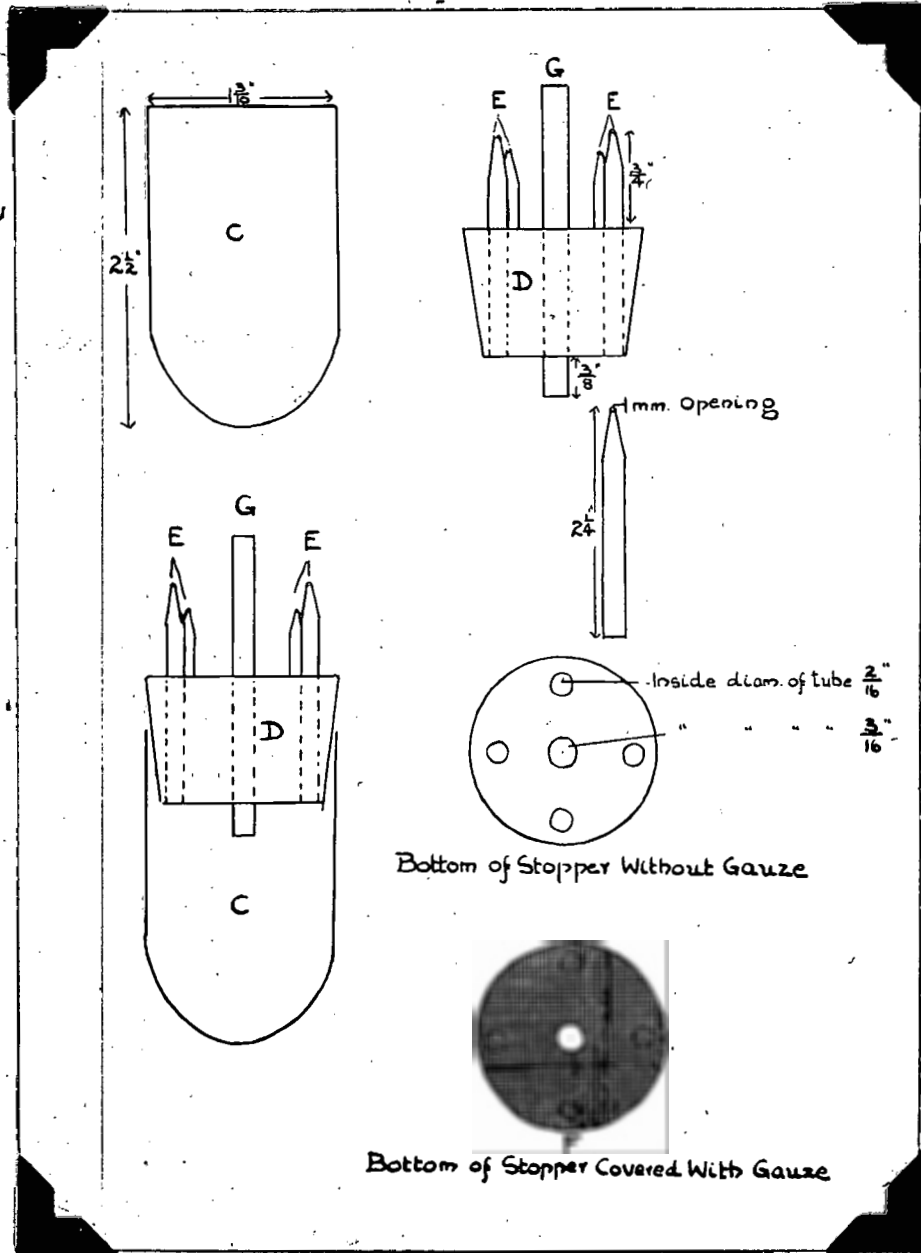


FIGURE 2.

dust container than is considered necessary to give the required deposit on the slide. Then, if on weighing the slide, it is found that the deposit is too light, more insecticide can be added to the container and blown out. This process can be repeated until the required deposit is obtained. An experienced operator will, however, have little difficulty in this respect.

The following is a formula which can be used for calculating pounds per acre from laboratory applications.

$$1 \text{ lb.} = 453.6 \text{ gms.}$$

$$1 \text{ acre} = 144 \times 9 \times 4,840 \text{ sq. in.}$$

Let X be the weight of the dust on the glass slide.

Let Y be the area of the glass slide in sq. in.

$$\text{Then } X \text{ gms.} = \frac{X}{453.6} \text{ lb.}$$

$$\text{which is equivalent to } \frac{X}{453.6} \times 144 \times 9 \times 4,840 \text{ lb. per acre.}$$

$$= \frac{X}{Y} \times \frac{144 \times 9 \times 4,840}{453.6} \text{ lb. per acre.}$$

$$= \frac{X}{Y} (13,828.57) \text{ lb. per acre}$$

If the deposit on the slide is 0.0045 gms. and the area of the slide is 4.16 sq. in., then the application in pounds per acre is:-

$$0.0045 \times 13,828.57$$

$$4.16$$

$$= 14.96 \text{ pounds per acre.}$$

UNIFORMITY OF EXPERIMENTAL PROCEDURE.

An essential part of the laboratory testing of insecticides is uniformity of test conditions and of insect material. In all experiments insects of the same vitality and the same degree of development should be used. When reared

under uniform and optimum environmental conditions, most insects of the same age will develop at the same rate, pass through the same number of instars, complete their development about the same time and, when fully developed will be vigorous and healthy. If, however, unfavourable conditions are allowed to occur, then there will be variation in the size and in the number of instars. The vitality of the insects may also be lowered and consequently their resistance to the insecticides will be affected and unreliable results will be obtained.

A correction for the normal mortality of an insect is applied to results in cases where the insects suffer mortality within the experimental period. A simple mathematical formula used by Abbot, (1925), has proved very satisfactory.

Let X equal the percentage of insects remaining alive amongst untreated individuals.

Let Y equal the percentage remaining alive amongst the treated insects.

Then $X - Y$ equals the apparent percentage killed.

The corrected percentage killed is $\frac{X - Y}{X}(100)$

STOMACH INSECTICIDES.

Leaf sections are placed on the centre of the rubber base of the dusting tower round about the weighed glass plate and dusted with the application required. The sections are then carefully turned over with forceps and the dusting is repeated on the other side. The dusted leaves are then transferred to petri dishes or other suitable containers and fed to the insects, which should be exposed to the treated foliage for a definite period and then transferred to untreated foliage in clean containers. Mortality should be recorded at regular intervals and before, during, and subsequent to their exposure to the poisons, the insects should be kept under constant temperature and humidity conditions.

The leaves should be carefully selected so that they are as uniform as possible and it is advisable to keep them in an atmosphere saturated with water vapour for 12 hours before the commencement of the experiment in order to reduce variation in water content.

CONTACT INSECTICIDES.

In determining the relative toxicity of different contact insecticides, it is preferable to dust the insects only and not the foliage. The insects may be confined in wire gauze cages or in gauze-covered petri dishes during dusting if active, or in open petri dishes if inactive. The wire gauze should have as large a mesh as possible in order to allow free circulation of the dust. Cloth cages should not be used as they tend to interfere with the free passage of the insecticide to a greater extent than is the case with wire gauze. If the insects are confined in cages during dusting, then the glass slide should be covered with the same material as the cage is made of, in order to obtain a comparable deposit on the insects and the slide. Immediately after treatment, the insects should be removed to clean cages containing untreated foliage and kept under controlled temperature and humidity conditions.

RESIDUAL TOXICITY.

For testing the effective duration of insecticides with residual action, surfaces such as glass or unpainted wood may be dusted with the required deposit and the insects can then be confined on the treated surfaces under petri dishes or cages for a definite period. Thereafter they should be removed to clean cages and fed. The test surfaces should be kept under identical conditions for subsequent tests which should be carried out at regular intervals.

2. A LABORATORY APPARATUS FOR TESTING CONTACT SPRAYS.

The apparatus described below is designed for the quick and accurate application of contact sprays and can be used for those with residual or with knock-down action. The apparatus can be adjusted to give any spray required by varying the amount of spray liquid in the reservoir and the spraying pressure. It was found, that for uniformity of results, the apparatus should be operated at a standard temperature and humidity, although standard humidity conditions appeared to be of less importance than standard temperature conditions. The insect rearing room was kept at a temperature of 75 degrees F. and 70 per cent R.H., and it was decided, therefore, to operate the spraying apparatus under the same conditions.

DESCRIPTION OF APPARATUS AND METHOD OF APPLICATION. (Figures 3 and 4.)

The spray chamber consists of a large cylinder made of perspex or glass (A) with an overall length of 36 inches. The cylinder is fitted with a tight cover of the same material (B). The external diameter of the cylinder is 8 inches. There is a hole (C), an inch in diameter in the centre of the cover through which the nozzle (D) of the spray unit is centred. The spray tower rests on a stand (E) fitted with a rubber top, and also provided with levelling screws. The spraying apparatus consists of the spray unit of a de Vilbiss 152 sprayer (F), together with its feed tube (G). The glass container with which it is normally fitted is removed and replaced with a glass centrifuge tube (H) graduated in tenths of a ml. The spray unit fits tightly into this glass container through a rubber stopper (J), the end of the feed tube coinciding with the 0.5 ml. mark on the graduated glass tube. The spray apparatus is fixed in position so that the nozzle (D) is accurately centred in the hole (C) and projects just within the spray tower, the

SPRAYING APPARATUS.

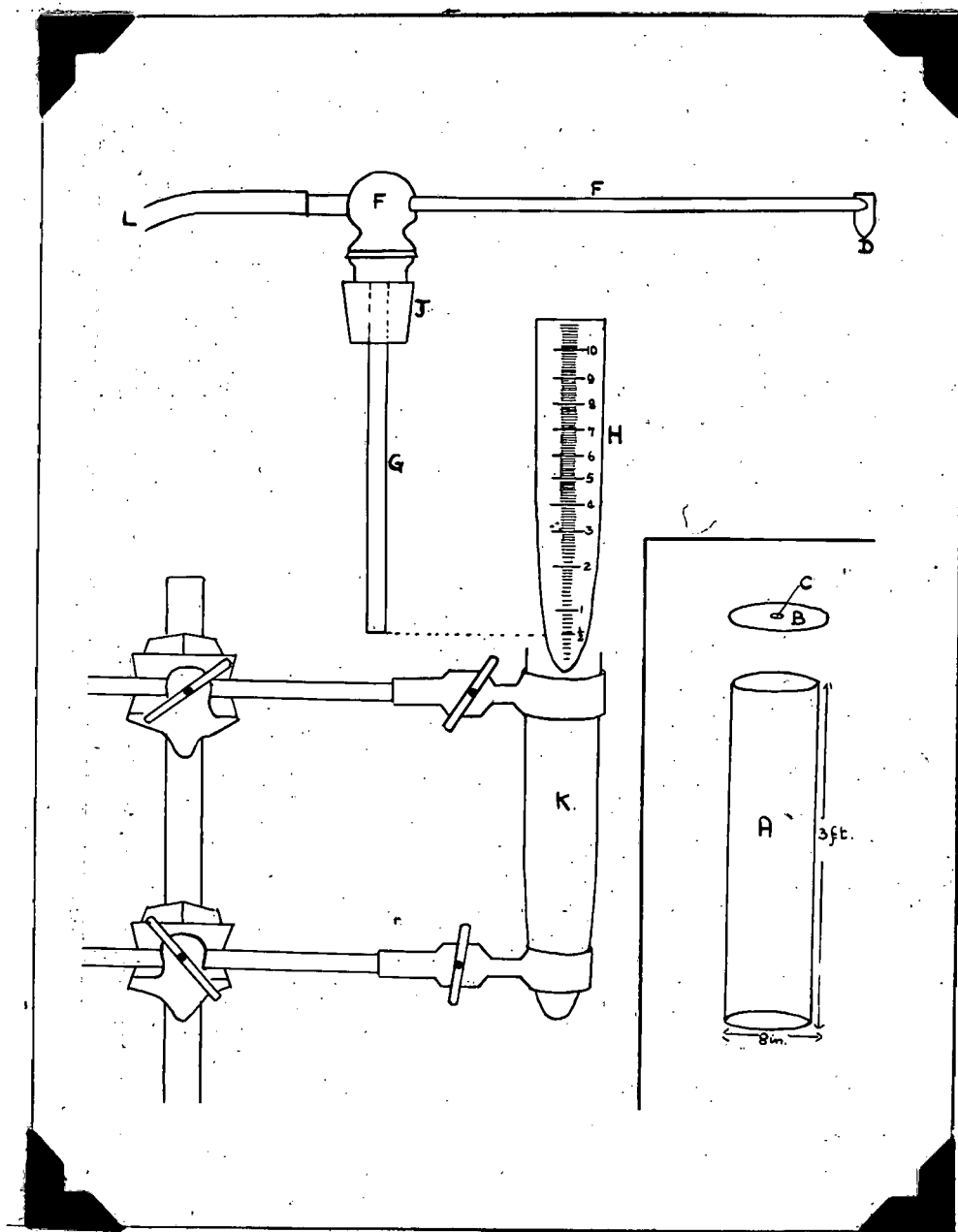


FIGURE 3.

between deposit and the volume of liquid sprayed. Single slides were exposed at different times under the same conditions of temperature and humidity to a spray containing 2.5 per cent para para D.D.T. in kerosene. In every case the slides were exposed to the spray for two minutes and were then removed for chemical analysis. Different volumes of spray were also used.

TABLE I.

Vol. of D.D.T. solution sprayed.	Slide No.	Dosage calculated in mg. per sq. cm.
2.0 ml.	1	0.0187
	2	0.0183
	3	0.0174
1.5 ml.	1	0.0148
	2	0.0145
	3	0.0142
1.0 ml.	1	0.0104
	2	0.0099
	3	0.0098
0.5 ml.	1	0.0044
	2	0.0039
	3	0.0035

In the application of the sprays, the required volume was blown out and the air was allowed to pass for twenty seconds thereafter to ensure that approximately the same amount of spray would remain in the spray gun in every case. This meant that the air was blown into the spray tower for four times as long with the 2 ml. dose as with, for example, a 0.5 ml. dose, where the times required to blow out the insecticide were 10 seconds and $2\frac{1}{2}$ seconds respectively. It is now considered advisable to allow the air current to pass for the same length of time irrespective of the volume applied. There is a certain amount of spray blown out of the tower back through the hole in the cover during the application of the sprays, and the loss of

SPRAYING APPARATUS.

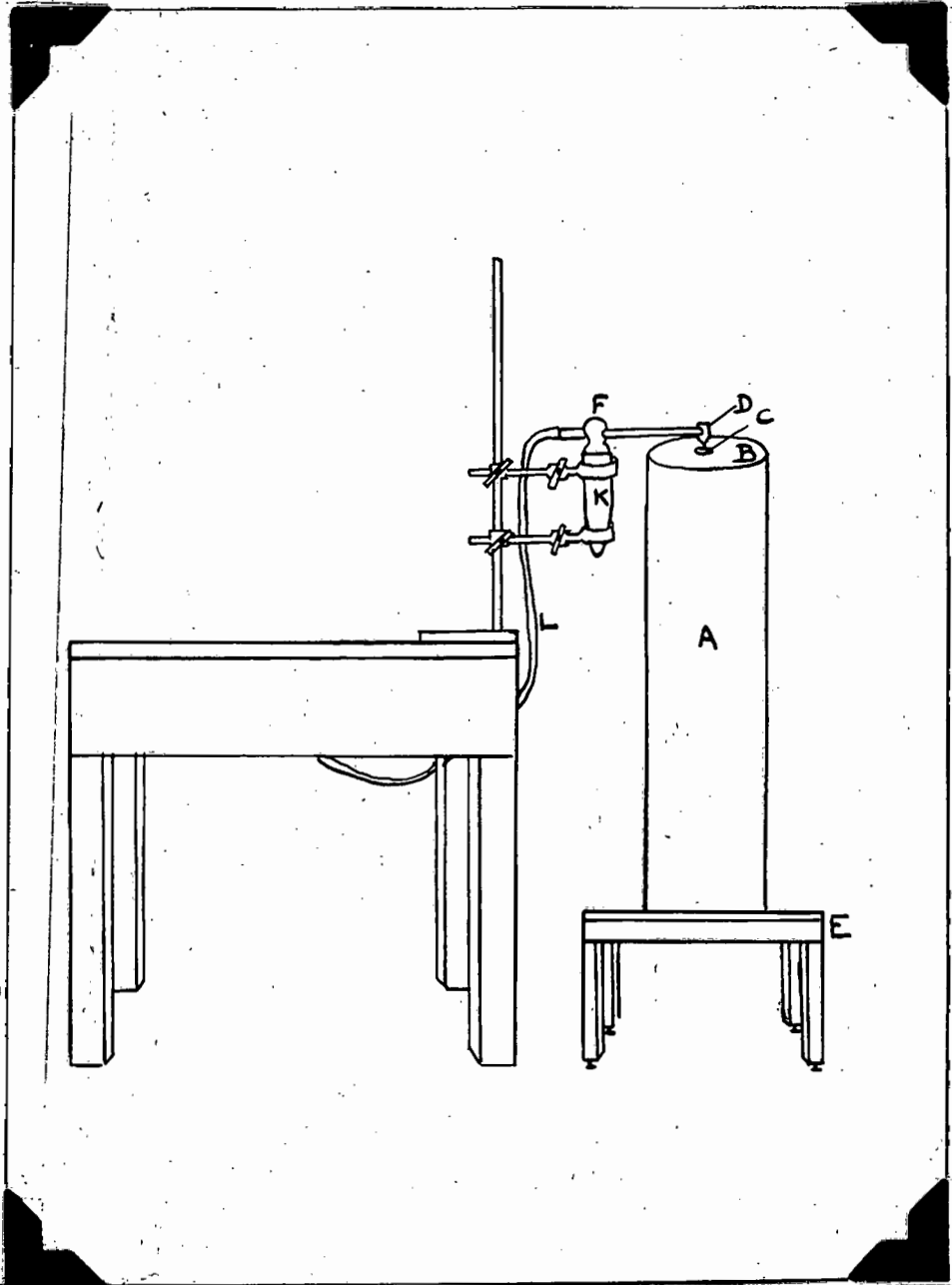


FIGURE 4.

glass container (H) fitting snugly into a metal container (K) which is held in a retort stand and clamped to a table as shown in Fig. 4. The spray unit is connected to an air compressor by means of a rubber tube (L). A pressure of 20 pounds per square inch has been found satisfactory for the application of most sprays. All the insecticide above the 0.5 ml. mark is blown into the spray tower and settles evenly over the rubber base on which it rests. Volumes of 0.1 ml. upwards of spray liquid can be applied. The deposit can be determined by catching and weighing a sample of the spray liquid on the spray table when the apparatus is operated under standard conditions, or else it can be determined by chemical analysis of slides exposed inside the spray tower. In the present paper, the D.D.T. deposit on the slides were determined by total chlorine determination. The sodium reduction method was employed where the chloride derived from the D.D.T. was determined by means of standard solutions of silver nitrate and potassium thiocyanate.

The insects may be exposed in open petri dishes if they are slow-moving, but for active species a covering of open mesh wire gauze should be provided, which will retain the insects without seriously interfering with the passage of the spray. Petri dishes containing filter paper to absorb any excess liquid have proved satisfactory for many species, but for certain insects such as houseflies and mosquitoes, wire cages are more efficient. A four-inch cage composed of a framework of No. 10 gauge wire and covered with wire mosquito gauze has proved to be satisfactory and easily cleaned after spraying.

ACCURACY OF SPRAY APPLICATION.

The following figures will serve to indicate the degree of accuracy that can be obtained and the correlation

insecticide should, therefore, be relatively greater the longer the air passes into the spray tower. This probably accounts for the fact that the smaller volumes applied give relatively higher deposits than would be expected, and this can be correlated with the shorter exposure to the air current with the lower applications. For example, the 1 ml. spray instead of giving a deposit of half that obtained with the 2 ml. spray, gives a somewhat higher figure.

The results given in Table I, however, show that the weight of deposit obtained from the application of a given volume of insecticide under controlled conditions at different times, is sufficiently accurate for practical purposes.

Further evidence of the accuracy of the method was obtained by exposing circular glass slides, 3 inches in diameter, in different positions on the base of the spray tower during the application of the spray. Three separate sprayings were done and three slides were exposed in the same position for each. The average deposit for the three slides in each position was 0.94, 0.89 and 0.94 mg. of D.D.T.

A volume of 0.2 or 0.3 ml. of spray liquid with an exposure of two minutes was found to be a convenient application for testing D.D.T. residual sprays and also for knock-down sprays.

UNIFORMITY OF EXPERIMENTAL PROCEDURE.

As in the case of testing dusts, it is of paramount importance that the physiological state of the insects should vary as little as possible. Insects used in the tests should, therefore, be healthy, of the same instar and age and reared, where possible, under controlled conditions of temperature and humidity. After spraying, also under controlled conditions, the insects should be transferred to clean cages in a constant temperature and humidity chamber, and fed. The knock-down and the mortality should be recorded at regular intervals.

Residual sprays should be tested as outlined for the evaluation of dusts with residual action and natural mortality should be corrected for by means of Abbot's formula.

In spite of all the precautions taken, it will often be found that there is a certain amount of variation in mortality for a given deposit of insecticide, a fact which indicates that there are still uncontrolled factors which have not been recognized or fully appreciated. In order to obtain reliable data, therefore, it is necessary to run a number of experiments at each dosage with an adequate number of test insects. It was found that five replications of each experiment in which 90 test animals were used were usually sufficient.

3. A LABORATORY APPARATUS FOR TESTING THE ADHESIVENESS OF INSECTICIDAL DUSTS.

The adhesive properties of insecticides strongly affect the persistence of the protective coverage of plants and the direct contact coating of insecticides. Adhesiveness is, therefore, of great importance in evaluating the relative effectiveness of different dusts and it is desirable to take it into account in conjunction with toxicity in general insecticide tests. Laboratory toxicity experiments may prove misleading as regards the general efficacy of a dust under field conditions, because as a rule, factors such as adhesiveness for example, are not taken into consideration. It may well happen that, whereas laboratory experiments may show one insecticide to be superior to another as regards toxicity, the efficacy of the two powders may be reversed in the field owing to the greater adhesiveness and, therefore, lower loss due to wind and rain of the less toxic compound.

Many different types of apparatus have been devised for testing adhesiveness, but in the majority of cases

they are designed to give the relative adhesiveness of the insecticides to glass surfaces and not to foliage itself. It is felt, however, that this is not entirely satisfactory and an effort has been made to obtain the relative adhesive values of insecticides on foliage by means of the apparatus described in this section of the thesis.

DESCRIPTION OF APPARATUS. (Figures 5 and 6).

The apparatus consists of a glass bell-jar (A), 5 inches in diameter and 9 inches high, with a $1\frac{1}{2}$ inch opening at the top fitted with a rubber stopper through which passes a glass tube having an internal diameter of $\frac{1}{2}$ inch (B). This tube is 12 inches in length, 6 inches of which project inside the bell-jar.

The bell-jar fits over a vibration unit consisting of a circular metal plate (C), $4\frac{1}{2}$ inches in diameter and $\frac{5}{8}$ inches thick, with a circular hole in the middle 2 inches in diameter. This plate fits on to another metal plate (D), as shown in the diagram, the pegs D_1 , D_2 , D_3 and D_4 fitting loosely into corresponding holes in plate (C). In the centre of plate (D) is a small hole about the size of a pin-head. These two plates when fitted together, rest on top of a yellowwood block (E) to which the foliage is attached. The pin in the top of the block fits into the hole in the centre of plate (D), but does not extend through it. The yellowwood block in turn fits on to a metal spike (F), which is attached to a thick glass plate (G) in order to keep it in position. The foliage is attached to the yellowwood block by means of sealing wax as shown in Fig. 6. The bell-jar fits over the vibration unit and rests on the glass base. The apparatus is clamped in position in a retort stand. A metal plunger (H), $7\frac{1}{2}$ inches long and weighing 70 gms. fits into tube (B).

ADHESIVE APPARATUS.

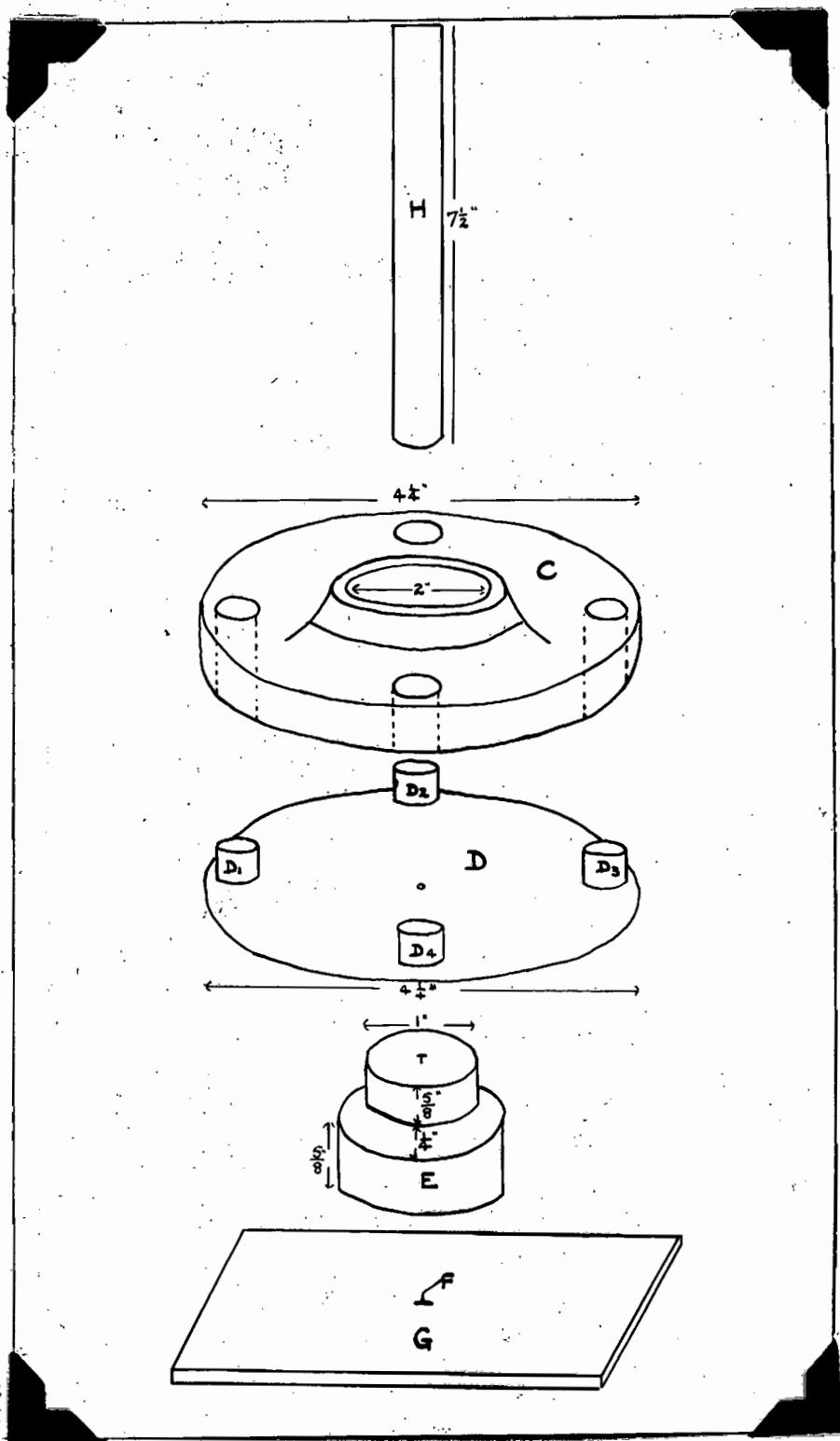


FIGURE 5.

ADHESIVE APPARATUS.

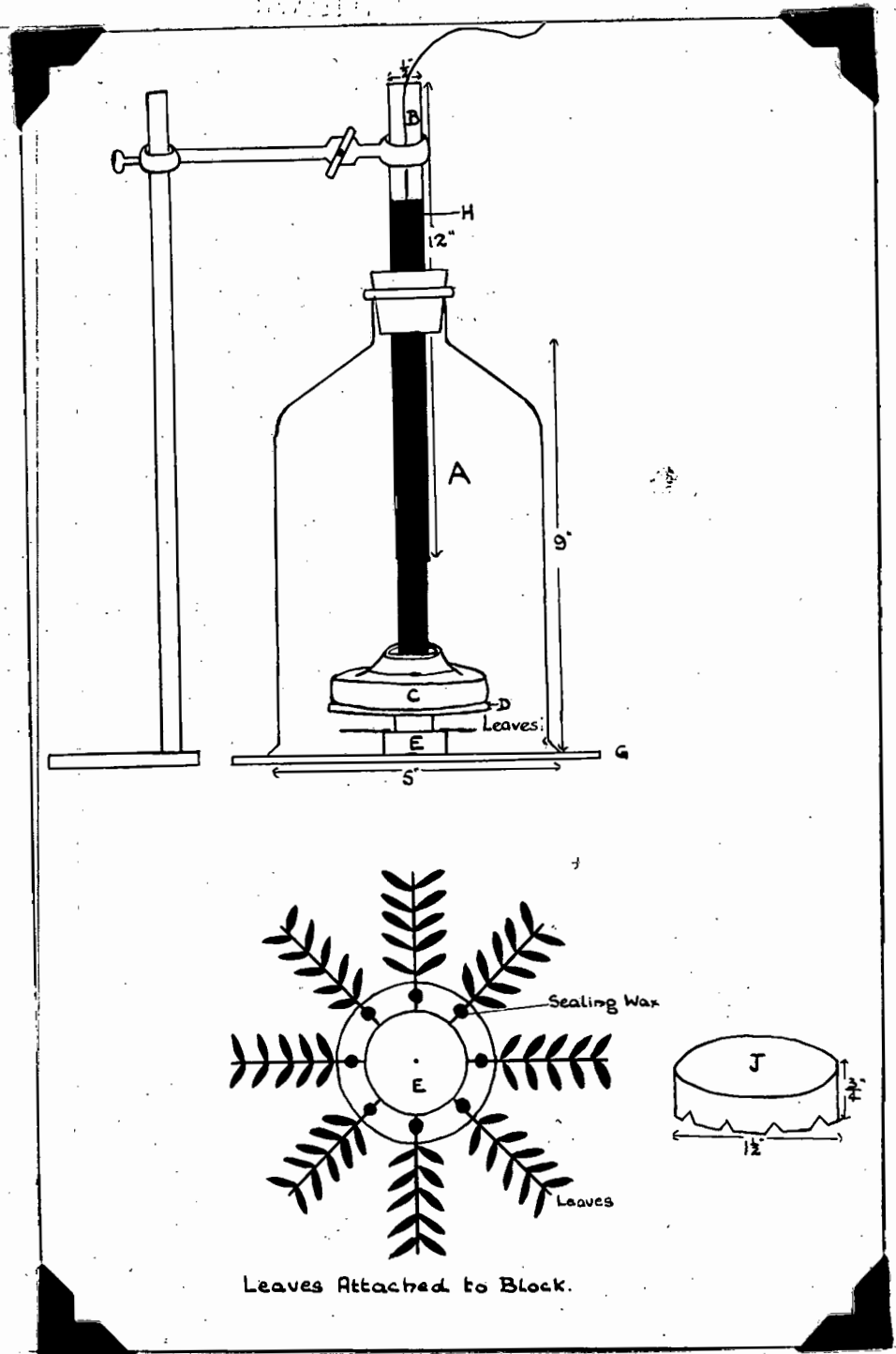


FIGURE 6.

METHOD OF DETERMINING THE ADHESIVENESS OF DUSTS.

The procedure is briefly as follows :-

Foliage dusted with accurately known weights of insecticide is subjected to a standard vibration and the amount of dust thus removed is chemically determined. The tests were carried out with wattle leaves since the apparatus was designed for testing the adhesiveness of different fluorine compounds used in the control of the wattle bagworm, Acanthopsyche junodi, Heyl. The method described will refer, therefore, to cryolite and other fluorine compounds as the insecticides and to wattle leaves as the foliage. It must be emphasized, however, that it can easily be adapted to other insecticides and to other types of foliage.

The leaves were carefully selected in order to have them as uniform as possible in every respect. They were then trimmed to a standard pattern and placed in a desiccator at 100 per cent R.H. and at a constant temperature for twelve hours prior to the experiment so that there would be as little variation as possible in the water content of the different leaf sections. At the end of that time, the leaves were removed from the desiccator and eight were attached equidistantly round each yellowwood block. In all the experiments the leaves were attached in the same positions on the blocks. The blocks themselves were covered with a paper hood (J) during dusting, allowing only the leaves to project, and the dusting was done with the apparatus described in an earlier part of this paper with the required weight of insecticide. A deposit of 0.5 to 0.6 mg. per sq. cm. was found to be a convenient dosage. Three blocks were dusted together and immediately after treatment the paper hoods were removed and the blocks were again placed at 100 per cent R.H. and were removed one at a time for the adhesive test. Each block in turn was fitted onto the metal spike attached to the glass base, and the metal plates (C) and (D) were carefully fitted on top of it. The bell-jar was then placed in

position and centered so that the metal plunger, when released, would strike the centre hole in plate (D) through the hole in plate (C). The plunger was then drawn up so that its top was level with the top of the glass tube (B), and allowed to drop back thirty times on to plate (D). Thirty knocks were found to give a satisfactory vibration. The bell-jar and metal plates were then removed, and the foliage containing the dust was carefully cut at the edge of the yellowwood block with a sharp knife into a petri dish, and the dust knocked off the foliage on to the glass base was carefully swept into another petri dish with a fine camel hair brush. This procedure was repeated with the remaining two blocks. A chemical fluorine determination was carried out with both the powder knocked off and that remaining on the foliage, and the ratio of these two figures gave the relative adhesiveness of the dust. This was expressed as a percentage "knock-off" due to the vibration to which the foliage was subjected. There were three separate replications, each one containing three blocks of dusted foliage for every insecticide.

The following figures in Tables 2 and 3 will serve to indicate the degree of accuracy that may be expected by this method:-

TABLE 2.

Block No.	No. of knocks.	Rate of dust appli- -cation.	Wt. of dry fol- -iage.	Wt. of cryolite knocked off fol- -iage.	Wt. of cryolite remain- -ing on foliage.	Loss of cryolite from foliage.
		Mg. per sq. cm.	Gm.	Gm.	Gm.	%
1	30	0.6	0.61139	0.0117501	0.004212	73.5
2	30	0.6	0.61676	0.009204	0.004136	68.9
3	30	0.6	0.67946	0.012880	0.006440	66.6
4	30	0.6	0.71203	0.009200	0.004370	67.7
5	30	0.6	0.78400	0.0123552	0.007779	61.3
6	30	0.6	0.72260	0.0125 840	0.006405	66.2
7	30	0.6	0.71380	0.0139568	0.005720	70.9
8	30	0.6	0.72194	0.0097146	0.004163	70.0

In Table 3, the relative adhesive value of natural cryolite and four samples of sodium fluosilicate are expressed as percentage loss of dust from the foliage caused by the standard vibration in separate experiments.

TABLE 3.

Insecticides.	NUMBER OF TESTS.						
	1.	2.	3.	4.	5.	6.	7.
	Loss	Loss	Loss	Loss	Loss	Loss	Loss
	%	%	%	%	%	%	%
Natural cryolite	42.5	-	50.0	-	52.1	-	-
Sodium fluosilicate 1.	54.0	28.8	70.3	43.9	61.2	71.5	63.5
" " 2.	55.3	-	74.3	39.7	-	68.1	-
" " 3.	16.0	7.4	21.6	18.9	26.2	-	30.3
" " 4.	-	-	-	-	15.4	13.3	11.7

It will be seen that the actual percentage loss for the same dust varies in different experiments on different days. This is unavoidable, since, whereas the foliage selected for the experiments on one day may be uniform, there is bound to be a certain amount of variation with that collected from day to day, with the consequent variation in adhesiveness to that foliage. The relative adhesive values of the different dusts tested on the same day are, however, fairly constant. It is advisable to run a standard insecticide in every experiment and express the adhesiveness of the different dusts relative to that of the standard.

SECTION 3.RESIDUAL TOXICITY OF CHLORINATED PHENOL AND CHLORINATED
HYDROCARBON INSECTICIDES.

The prolonged residual toxicity of D.D.T. and other chlorinated hydrocarbon insecticides, notably B.H.C., chlordane, toxaphene and the chlorinated phenol, pentachlorophenol, renders them invaluable for the control of household insects such as flies, mosquitoes, bed-bugs, fleas and lice over an extended period of time when applied to the interior surfaces of buildings, and has afforded a degree of control hitherto unobtainable with the conventional insecticides such as derris and pyrethrum which were previously at our disposal. It is well-known, however, that the persistence of D.D.T. residues varies according to the type of surface to which it is applied, and it was considered probable that this would apply to other insecticides with residual action as well.

It is of direct practical importance to determine the most suitable formulations for each insecticide for use on different surfaces commonly used in household construction, in order to obtain the highest degree of insect control. A project was, therefore started with the object of developing a technique for the biological assay of these insecticides on different types of surface. This work is essentially a long-term project involving the determination of the relative duration of residual effectiveness of oil solutions, dusting powders, smokes, water suspensions and emulsions, and will take several years to complete. Certain of the tests undertaken have now been completed, however, and it is considered advisable to present the results already obtained rather than to wait until finality has been reached on the project as a whole.

EXPERIMENTAL MATERIALS.

.....

EXPERIMENTAL MATERIALS.

TEST INSECTS.

Owing to the acute staff shortage at the commencement of the project, it was essential that the test insects should be available in large numbers at all times of the year, but that this should not involve laborious breeding technique. For this reason houseflies, mosquitoes and bed-bugs were discarded. After consulting W.G.H. Coaton, entomologist in charge of termite investigations, it was decided that Trinervitermes havilandi, Hagn. (Fig. 7), should be used as test insects. This species of termite is a grass-feeding, non fungus grower and has, therefore, no complicated food requirements. Provided the insects have contact moisture, they will live under laboratory conditions, feeding on filter paper, for over thirty days without appreciable mortality. In addition, Trinervitermes species are present throughout South Africa and are easily collected in the field where they are concentrated in surface mounds.

The fact that the soldiers are unable to feed without the presence of worker termites makes them ideal test insects for fairly quick-acting contact insecticides when it is necessary to eliminate any stomach effect of the poisons. For slow-acting insecticides, however, they are unsatisfactory owing to natural mortality through starvation.

It is probable that any termite species nesting in surface mounds, and not cultivating fungus, would be equally as satisfactory as Trinervitermes species for use as test animals. Fungus-growing termites are not considered suitable, owing to their complicated food requirements and to the fact that they live in subterranean nests, and are thus difficult to collect.

Adult workers of Trinervitermes havilandi

TRINERVITERMES HAVILANDI, HORN.

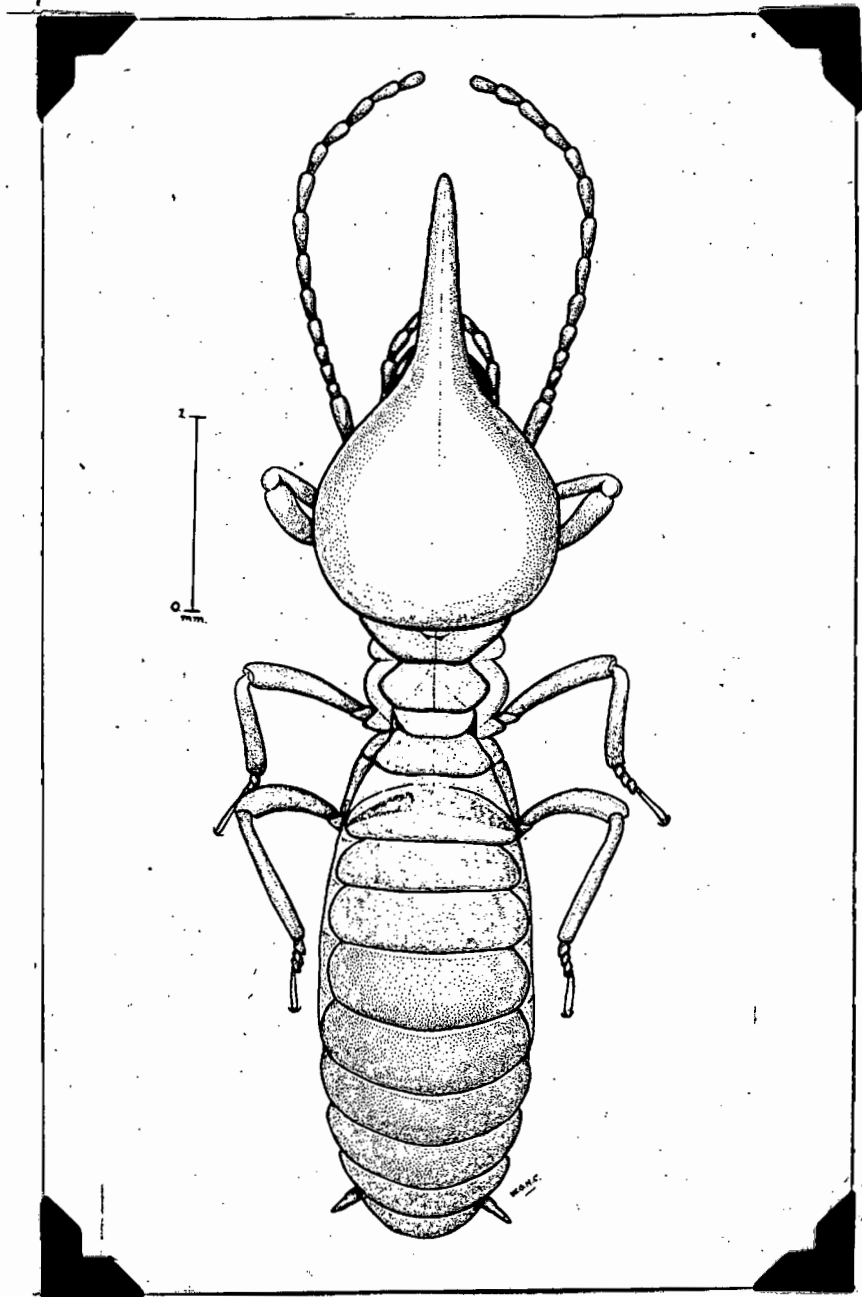


FIGURE 7.

were used as test insects in preference to soldiers in these experiments since it was thought likely that after several months the residual action of the poisons would be slow, and consequently a high mortality through starvation would complicate the interpretation of results if soldiers were used.

INSECTICIDES TESTED.

The insecticides used in this section were D.D.T., chlordanes, B.H.C. and pentachlorophenol. D.D.T. and B.H.C. were formulated as kerosene solutions and smokes, chlordanes as a kerosene solution, and pentachlorophenol as a smoke.

The kerosene solutions contained 2.5 per cent p,p' D.D.T., 2.5 per cent of the Gamma isomer of B.H.C., and 2.5 per cent of pure chlordanes respectively.

Smoke generators were prepared by the Division of Chemical Services according to the following specifications:-

1. D.D.T..... 52 per cent.
Potassium chlorate..... 12 per cent. Total wt.= 400 gms.
Sugar 36 per cent.
2. B.H.C.....52 per cent.
Potassium chlorate..... 12 per cent. Total wt.= 400gms.
Sugar..... 36 per cent.
3. Pentachlorophenol..... 52 per cent.
Potassium chlorate..... 12 per cent. Total wt.= 400 gms.
Sugar..... 36 per cent.

In all smoke generators, from 60 to 70 per cent of the toxic ingredient was recoverable from the smokes.

TEST SURFACES.

The following surfaces were used:-

1. Unpainted wooden blocks.
2. Wooden blocks painted with two coats of white enamel paint approximately two years prior to the application of the insecticides.
3. Wooden blocks painted with two coats of white enamel paint four months prior to the application of the insecticides.
4. Wooden blocks painted with two coats of white distemper four months prior to the application of the insecticides.
5. Wooden blocks painted with two coats of white distemper six hours prior to the application of the insecticides.
6. Wooden blocks painted with two coats of white oil paint four months prior to the application of the insecticides.
7. Glass.
8. An absorbent surface (dry filter paper fitted into the bottom halves of petri dishes having a diameter of 9 cms.).

The wooden blocks consisted of smooth planed Pinus pinaster, each block being four inches square. The termites were confined to these blocks by means of inverted petri dishes, 9 cms. in diameter. The glass surfaces were the bottom halves of petri dishes having the same diameter as those confining the termites to the wooden blocks.

UNIFORMITY OF TEST CONDITIONS.

TEMPERATURE AND HUMIDITY.

A temperature of 75 degrees F. and a Relative Humidity of 70 to 75 per cent was maintained throughout the experimental programme.

TEST INSECTS.

The termites used in the experiments described in this section of the paper, were collected from nests dug up in the field, and only carefully, individually selected

adult workers of approximately the same age, and from the same nest, were used for each exposure to the insecticides in each replication. It is evident, therefore, that the test insects in each separate experiment had been subjected to the same micro-climatic conditions in the field prior to being brought into the laboratory. In order to further eliminate any differences in the physiological state of the material, the termite nests were kept under constant temperature and humidity conditions (75 degrees F. and 70 to 75 per cent R.H.) for 24 hours prior to the commencement of every experiment. The same uniform temperature and humidity were maintained during and subsequent to the exposure of the termites to the different, variously treated surfaces. At the end of the exposure period, the surviving termites were fed on standard filter paper moistened with 0.6 ml. of water, in order to eliminate any differences in diet.

TEST SURFACES.

The same paints and distemper were used for all experiments and there could be little variation, therefore, in the surfaces coated with these materials, or in the glass and standard filter paper surfaces. In order to eliminate, as far as possible, any variation in the smooth-planed Pinus pinaster blocks, these were cut and selected by the Forest Products Institute, Pretoria, from timber from the same tree.

It must be emphasized that in all the tests, contact with the insecticidal residues by the insects was unavoidable, since the termites were unable to climb the glass sides of the petri dishes confining them to the treated surfaces which were all of the same size. It follows, therefore, that in every experiment the insects had the same exposure to the residues.

All the test surfaces were kept under uniform temperature and humidity conditions prior, during and

subsequent to the exposure of the insects to them, in a room where they received no direct sunlight, but were subjected to equal light intensity. Air was kept circulating in the constant temperature and humidity room by means of an electric fan. The surfaces were in no way interfered with during the course of the experiments. Films of dust which collected on them were regarded as a factor that would be encountered under practical conditions.

It may be argued that the mechanical removal of the insecticides due to the movement of the insects must be far greater under these conditions than that encountered in practice owing to the greater concentration of insects on a restricted area for a prolonged period, and that this will affect subsequent exposures of the insects to the residues. This is no doubt true, but it was considered that residue testing should take into account not only the evaluation of the actual toxicity of the insecticides, but also their general efficacy, which would include their ability to withstand mechanical removal. These experiments are, therefore, merely a severer test of what would normally take place in practice.

NORMAL MORTALITY CORRECTION.

Controls were run for all experiments, and all mortality and knock-down figures presented, not only in this section of the thesis, but in all other sections as well, have been corrected for natural mortality by means of Abbot's formula. In view of this, it is not deemed essential to include detailed control mortality figures although it is considered desirable to present the maximum, minimum and average natural mortalities obtained for each series of experiments.

NUMBER OF TEST INSECTS AND REPLICATIONS.

Three surfaces of each type were treated

with each insecticide at the concentration and rate of application described previously in the text. 30 adult worker termites were exposed to each of the treated surfaces, and five replications were run ~~per~~ for each experiment. The total number of test insects used for each type of surface for each of the insecticides was, therefore, 450 for each of the monthly, or in certain cases, fortnightly periods of exposure.

DEFINITION OF KNOCK-DOWN AND MORTALITY.

For the sake of uniformity in observations through-out this thesis, the writer wishes to define the terms " knock-down " and " mortality " as follows:-

An insect was considered knocked down when it had turned on its back, was unable to regain its normal position, and had temporarily or permanently lost all power of co-ordinated movement. Knock-down need not necessarily result in mortality, this depending largely on the type of insecticide used and the length of exposure of the insect to it.

The term mortality is used only in regard to those insects knocked down by an insecticide in which all movement had permanently ceased.

TECHNIQUE.

METHOD I. OIL SOLUTIONS.

The test surfaces were sprayed with the apparatus described on page 36, and the insecticides were applied to give a deposit of 3.6 mg. per sq. foot of p,p' D.D.T., Gamma B.H.C. and pure chlordane, respectively. The treated surfaces were kept under constant temperature and humidity conditions, as previously described, for 24 hours before the insects were confined on them. During the period of exposure, hourly knock-down records were made for a period of six hours. After the termites had been exposed to the insecticides for 24 hours,

mortality records were taken, and the insects were transferred to clean petri dishes containing untreated filter paper moistened with 0.6 ml. of water, on which to feed. Mortality was recorded at 24 hourly intervals until all the insects were dead or had apparently recovered from the effects of the insecticides. Subsequent exposures of fresh batches of termites to the treated surfaces was made at monthly intervals.

METHOD 2. INSECTICIDAL SMOKES.

The determination of the duration of residual toxicity for smokes was done by exposing the test surfaces to them in a room of 1,500 cu.ft. capacity, under controlled temperature conditions for 2½ hours. The surfaces were exposed in a horizontal position at ground level, 3ft., 6 ft., and 8 ft. levels. In addition, surfaces were also exposed to the smokes in a vertical position at the 3 ft. level. After exposure to the smokes, the same testing procedure was followed as that outlined for the testing of spray residues. The actual deposit was not chemically determined, but it was evident that the smoke concentration was considerably too high for the size of the test chamber, and it was considered that smoke canisters of this size could be used effectively in rooms 20,000 to 30,000 cu. ft. capacity.

STATISTICAL ANALYSIS OF DATA.

The question of whether statistical analysis of all data presented in this thesis was necessary was discussed with Government statisticians and statisticians of the University of Pretoria. The opinion expressed by these experts was that in view of the rather obvious differences in mortality and knock-down figures, taken in conjunction with the large number of test animals and replications used, and the uniformity of

experimental conditions and material, it was doubtful whether statistical analysis of all the tables would be necessary. In order to clear up this point, however, it was decided to carry out a complete statistical analysis of one of the most complicated tables, viz., Table IO, which expresses the interaction of three different insecticides, five types of surface, and eleven periods of time. The result of this analysis is given below.

TABLE 4.

TABLE OF ANALYSIS OF VARIANCE.

Variance due to:-	Degrees of freedom.	Sums of squares.	Mean squares.	Variance ratio. F.	Variance ratio requirement. $P=0.001$
Periods.	10.	268389.40	26838.94	4445.0	3.01
Insecticides.	2.	526902.30	263451.15	43632.19	6.91
Surfaces.	4.	176921.90	44230.47	7325.35	4.62
Surfaces x Insecticides.	8.	141835.40	17729.43	2936.31	3.27
Periods x Insecticides.	20	101751.40	5087.57	842.59	2.33
Periods x Surfaces.	40	91760.50	2294.01	379.93	1.61
Insecticides x Surfaces x Periods.	80	65969.06	824.61	136.57	1.44
Error	660	3985.34	6.038		
Total	824	13777515.30			

The following figures for Standard Error and Significant Difference were obtained when considering the three main treatments, namely, insecticides, periods of time and surfaces, separately.

TABLE 5.
INSECTICIDES.

2.5 per cent Gamma B.H.C.	10.785 per cent.
2.5 per cent pure chlor-dane.	12.886 per cent.
2.5 per cent p,p' D.D.T.	65.414 per cent.

Standard error = 0.148 per cent.

Significant difference = 0.411 per cent. ($P = 0.05$).

The corresponding figures for periods of time and surfaces respectively, were :-

PERIODS OF TIME.

Standard error. = 0.283 per cent.

Significant difference. = 0.784 per cent. ($P = 0.05$).

SURFACES.

Standard error = 0.1913 per cent.

Significant difference = 0.530 per cent.

The next step was to analyse the interactions between the various treatments. The results of this analysis are presented in Tables 6, 7, 8 and 10.

TABLE 6.TABLE OF INTERACTION OF PERIODS AND INSECTICIDES.

Periods	2.5 per cent Gamma B.H.C.	2.5 per cent pure chlor- -dane	2.5 per cent p,p' D.D.T.
24 Hours	80.396	80.0	79.956
1 month	17.12	31.31	79.864
2 "	1.756	6.88	79.052
3 "	3.124	3.476	78.892
4 "	4.10	3.704	76.20
5 "	3.168	3.740	75.568
6 "	2.50	3.160	71.360
7 "	3.296	3.036	54.108
8 "	1.716	3.428	53.972
10 "	1.188	1.764	50.696
12 "	0.264	1.232	19.892

Standard error = 0.491 per cent.Significant difference = 1.3621 per cent. (P= 0.05)TABLE 7.TABLE OF INTERACTION OF INSECTICIDES AND SURFACES.

Insecticides	Enamel %	Distem- -per %	Wood %	Glass %	Filter paper %
2.5 % Gamma B.H.C.	1.196	14.718	11.751	11.774	15.464
2.5 % Pure chlordan.	1.534	15.745	12.638	12.298	22.216
2.5 % p,p' D.D.T.	2.122	79.121	64.722	88.713	92.304

Standard error = 0.3314 per centSignificant difference = 0.9186 per cent. (P= 0.05).

TABLE 8.
INTERACTION OF PERIODS AND SURFACES.

Periods	Enamel %	Distemper %	Wood %	Glass %	Filter paper %
24 Hours	0.66	100.0	99.93	100.0	100.0
1 month	0.29	56.71	37.53	40.0	79.08
2 "	0.22	35.66	34.95	35.9	39.46
3 "	1.75	35.21	34.55	34.65	36.32
4 "	1.09	36.99	32.64	35.31	33.97
5 "	2.41	35.06	31.36	34.43	34.20
6 "	3.06	33.17	22.41	35.10	34.63
7 "	3.29	18.51	11.30	33.29	34.33
8 "	1.53	22.86	9.08	29.53	35.53
10 "	1.67	21.83	8.12	25.53	32.25
12 "	2.2	5.81	4.87	9.61	13.7

Standard error = 0.6344 per cent.

Significant difference = 1.7585 per cent. ($P = 0.05$)

It will be seen from this analysis that the variance is exceedingly small. The experimental error never exceeds 3.05 per cent for any of the main treatment effects or for any of the interactions. It is the considered opinion of the statistician concerned, that this proves beyond any doubt that the number of test animals and the number of replications, under the conditions outlined for this experiment, are more than adequate and give significant and reliable results. Moreover, as all other experiments described in this thesis have been carried out with an equal or greater number of test insects, and replications, under the uniform and controlled conditions described in this section of the paper, it is considered unnecessary to analyse the other tables statistically, especially in view of the fact that in the conclusions drawn, differences

even greater than the minimum significant differences required statistically, have not been considered significant for practical purposes. The relative efficacy of the various treatments, too, is so marked that a clear picture is given without the aid of statistics. This decision was taken after the remainder of the tables and the set-up of the experiments had been examined by the statistician in question.

It is of interest to record that the conclusions arrived at by the writer, prior to the analysis of Table IO, have in no way had to be modified as a result of it.

In support of the above opinion, it may be mentioned that the specifications laid down by the S.A. Bureau of Standards, Pretoria, stipulates that provided controlled and uniform laboratory conditions are employed, five test groups of 30 insects shall be used in triplicate for each insecticide, making a total of 450 test animals. This specification is based on sound statistical information.

RESULTS.

SPRAY SOLUTIONS. (Method I, page 55).

RELATIVE EFFICACY OF SPRAY SOLUTIONS ON DIFFERENT TYPES OF SURFACE.

The comparative duration of residual effectiveness of D.D.T., B.H.C. and chlordane solutions at different intervals on various types of surface, over a twelve months period, are presented in Tables 9 and IO.

In these experiments the enamel paint and distemper were applied to the wooden blocks four months prior to the application of the insecticides.

The results demonstrate that:-

- a. B.H.C. produces a markedly quicker rate of knock-down than either D.D.T. or chlordane on all the test surfaces

when the insects are confined on them 24 hours after the application of the insecticides.

- b. The initial mortality produced by the three insecticides on freshly sprayed surfaces is of the same order, but neither B.H.C. or chlordane can compare with D.D.T. as regards duration of residual toxicity.
- c. At the concentration and rate of application used, B.H.C. and chlordane are relatively ineffective on all the test surfaces one or two months after the application of the sprays, whereas D.D.T. remains highly toxic on filter paper, and causes appreciable mortality on distemper and glass after 10 months.
- d. Neither D.D.T., B.H.C. or chlordane are effective on enamel painted surfaces under the conditions of these tests, even when the insecticides are freshly applied. B.H.C. is the only insecticide to produce a knock-down effect on enamel paint 24 hours after the application of the solutions. These results tend to confirm those presented by the writer in a previous publication (Petty, 1946), where it is stated that the toxicity of surfaces treated with flat, enamel and oil paints, oil varnishes and oil stains is unsatisfactory when D.D.T. solutions are applied to them a month after the surfaces are painted.
- e. It is of interest to note that a high percentage of insects knocked-down by contact with B.H.C., subsequently recover on their removal from the sprayed surfaces. This is well illustrated in Table 9, where 92.5 per cent of the termites were knocked-down when exposed to the enamel paint 24 hours after it had been sprayed with B.H.C. solution. In spite of this high percentage knock-down, however, the final mortality is only 2 per cent (Table 10). Recovery of the

TABLE 9.
Deposit :- 3.6 mg. of insecticide per Sq. Foot.

Time after spray application.	Type of surface.	Percentage Knock - down at Hourly Intervals.																	
		2.5% Gamma B.H.C.						2.5% Chlordane.						2.5% para para D.D.T.					
		1 Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	6 Hrs.	1 Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	6 Hrs.	1 Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	6 Hrs.
24 hours.	Enamel.	14.9	59.1	71.6	84.1	89.3	92.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Distemper.	100.0						16.6	39.9	52.2	63.3	77.7	78.9	15.4	41.0	52.8	76.7	87.9	94.6
	Wood.	73.3	87.8	100.0	-	-	-	0.0	0.0	1.3	10.0	20.8	40.1	2.2	29.4	47.4	73.3	80.0	80.8
	Glass.	100.0	-	-	-	-	-	0.6	1.6	27.4	49.9	75.8	84.1	32.7	61.6	85.9	94.1	99.1	100.0
	Filter paper.	100.0	-	-	-	-	-	1.6	10.0	37.4	54.9	69.1	76.0	0.0	24.9	32.4	44.1	47.3	61.6
1 month.	Enamel.	0.0	1.3	3.3	3.3	3.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Distemper.	0.0	1.3	7.3	18.3	24.9	33.3	0.0	0.0	10.0	10.0	10.0	10.0	0.0	0.0	0.0	0.0	3.3	3.3
	Wood.	0.0	0.6	1.3	20.0	2.6	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	3.3
	Glass.	0.0	1.3	3.3	7.3	7.3	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.6	67.7	93.2	93.2	100.0
	Filter paper.	0.6	2.6	3.3	7.3	10.1	24.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	4.9	4.9	4.9	4.9
2 months	Enamel.	No knock - down.						No knock - down.						0.0	0.0	0.0	0.0	0.0	0.0
	Distemper.	"						"						0.0	0.0	0.0	0.0	0.0	4.9
	Wood.	"						"						0.0	0.0	0.0	0.0	0.0	0.0
	Glass.	"						"						0.0	3.3	6.6	30.0	53.3	77.7
	Filter paper.	"						"						0.0	0.0	3.3	7.4	12.4	12.4
4 months	Enamel.	"						"						No knock - down.					
	Distemper.	"						"						"					
	Wood.	"						"						"					
	Glass.	"						"						0.0	1.6	6.6	26.6	56.6	66.6
	Filter paper.	"						"						0.0	0.0	0.0	7.4	12.4	12.4

TABLE 9. (Continued).

Deposit :- 3.6 mg. of insecticide per sq. foot.

Time after spray application.	Type of surface.	Percentage Knock - down at Hourly Intervals.																	
		2.5% Gamma B.H.C.						2.5% Chlordane.						2.5% para para D.D.T.					
		I Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	6 Hrs.	I Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	6 Hrs.	I Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	6 Hrs.
6 months.	Enamel	No knock - down.						No knock - down.						No knock - down.					
	Distemper	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Wood	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Glass	"	"	"	"	"	"	"	"	"	"	"	"	0.0	15.8	25.0	38.3	38.3	54.9
	Filter paper	"	"	"	"	"	"	"	"	"	"	"	"	0.0	0.0	0.0	7.4	17.2	23.3
8 months.	Enamel	"	"	"	"	"	"	"	"	"	"	"	"	No knock - down.					
	Distemper	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Wood	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Glass	"	"	"	"	"	"	"	"	"	"	"	"	0.0	0.0	0.0	5.1	12.4	26.6
	Filter paper	"	"	"	"	"	"	"	"	"	"	"	"	0.0	0.0	0.0	13.3	19.1	21.6
10 months.	Enamel	"	"	"	"	"	"	"	"	"	"	"	"	No knock - down.					
	Distemper	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Wood	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Glass	"	"	"	"	"	"	"	"	"	"	"	"	0.0	0.0	0.0	3.3	4.1	6.6
	Filter paper	"	"	"	"	"	"	"	"	"	"	"	"	0.0	1.6	10.0	10.0	10.0	13.3
12 months.	Enamel	"	"	"	"	"	"	"	"	"	"	"	"	No knock - down.					
	Distemper	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Wood	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Glass	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	Distemper	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"

Average control knock-down :- 0.65 per cent. Control knock-down range :- 0.0 to 3.3 per cent

TABLE IO.

Deposit = 3.6 mg. per sq. foot.

Time after spray appli- cation.	Insecticides. 2.5 per cent concentration	Percentage		Final Mortality.		
		Enamel	Distem- per.	Plain wood.	Glass	Filter paper.
24 Hours.	Gamma B.H.C.	2.0	100.0	100.0	100.0	100.0
	Chlordane.	0.0	100.0	100.0	100.0	100.0
	p,p' D.D.T.	0.0	100.0	98.0	100.0	100.0
1 Month.	Gamma B.H.C.	0.6	34.1	3.3	8.6	39.1
	Chlordane.	0.0	36.6	9.3	11.3	98.6
	p,p' D.D.T.	0.0	100.0	100.0	100.0	99.3
2 Months.	Gamma B.H.C.	0.6	3.3	2.0	2.6	0.6
	Chlordane.	0.0	6.6	3.3	6.6	21.9
	p,p' D.D.T.	0.0	96.6	100.0	100.0	96.1
3 Months.	Gamma B.H.C.	2.6	3.9	2.6	1.3	5.3
	Chlordane.	1.3	3.9	1.3	3.3	7.3
	p,p' D.D.T.	1.3	97.5	98.6	100.0	96.6
4 Months.	Gamma B.H.C.	0.6	9.1	3.9	4.6	2.6
	Chlordane.	2.0	8.3	3.9	1.3	3.3
	p,p' D.D.T.	1.3	94.1	90.0	100.0	95.9
5 Months.	Gamma B.H.C.	1.3	6.6	6.6	1.9	1.9
	Chlordane.	2.6	7.4	8.6	1.3	3.3
	p,p' D.D.T.	5.9	93.3	81.3	100.0	97.7
6 Months.	Gamma B.H.C.	0.6	0.6	5.3	3.3	2.2
	Chlordane.	3.9	3.9	1.6	1.6	2.6
	p,p' D.D.T.	3.9	94.9	60.0	100.0	98.6
7 Months.	Gamma B.H.C.	2.6	4.6	2.6	4.6	3.3
	Chlordane.	3.3	2.6	2.6	2.6	2.6
	p,p' D.D.T.	4.6	51.6	27.9	91.9	98.6
8 Months.	Gamma B.H.C.	2.6	0.6	2.6	0.0	3.9
	Chlordane.	1.3	4.6	2.6	3.3	4.6
	p,p' D.D.T.	1.3	63.3	21.9	85.9	98.6
10 Months.	Gamma B.H.C.	0.0	0.6	1.9	0.0	3.3
	Chlordane.	1.3	0.6	2.6	0.0	1.9
	p,p' D.D.T.	3.3	64.9	17.3	75.9	94.1
12 Months.	Gamma B.H.C.	1.9	0.0	0.6	0.0	0.0
	Chlordane.	3.3	0.0	1.9	3.3	0.0
	p,p' D.D.T.	4.6	17.6	11.9	26.6	39.5

Average control mortality= 1.6 per cent.

Control mortality range= 0.0 to 6.6 per cent.

Standard error = 1.0989 per cent.Significant difference = 3.0461 per cent.

termites after sufficient exposure to cause knock-down on surfaces treated with D.D.T. or chlordane rarely if ever occurred. A study of Tables 9 and 10 will show that, in the case of D.D.T., complete mortality is obtained even when no knock-down is recorded after six hours exposure to the insecticide.

- f. The most prolonged residual toxicity with D.D.T. is obtained on filter paper, but it is also highly effective on glass, distemper and unpainted wood, the latter surface, excluding enamel paint, being the least satisfactory from the residual aspect.
- g. Best results with B.H.C. are obtained on filter paper and distemper. As with D.D.T., filter paper is superior to distemper. This is especially evident with chlordane.

It is of interest to note that in the course of subsequent experiments, when the volume of D.D.T. spray solution applied to the different surfaces was increased ten times, practically no mortality was recorded on painted wood when the insects were exposed to it 24 hours after the application of the spray. It was also found that D.D.T. incorporated in distemper and painted on wooden blocks, was markedly less toxic than a D.D.T. solution in kerosene sprayed on the distempered blocks when the same concentration of D.D.T. was used in both cases.

EFFECT OF SURFACE ON THE FINAL RESIDUE DISTRIBUTION.

The ineffectiveness obtained with sprayed enamel paint may be attributed to the dissolution of the insecticides by the oils present in the paint. It is also possible that the insecticide solvents may have softened the paint in such a way as to make the poisons unavailable to the insects

by causing most of the spray to be absorbed and the insecticide to be deposited under the surface. Clapp et al. (1947), found that this occurred when linoleum was sprayed with D.D.T. emulsions and oil solutions, with consequent poor toxicity to mosquitoes exposed to it. Results obtained by Barnes, (1945), indicate that wood painted with oil paint approximately a month prior to the application of D.D.T. oil sprays was not markedly toxic to Cimex lectularius, L. Gahan et al. (1945), state that for mosquito control, oil painted surfaces treated with D.D.T. are unsatisfactory both from the knock-down and mortality point of view. They consider that the insecticide is in some way made unavailable to the insects. It is of interest to record that West and Campbell (1946), found that oil paint and synthetic enamel containing D.D.T. did not prove insecticidal to flies at all. Their explanation is that D.D.T. particles are coated with an adsorbed oil or resin layer, built up to appreciable thickness which prevents close contact between the D.D.T. and the insects. Gilmour (1946), has done a considerable amount of work on incorporating D.D.T. in paints of a number of different types, and in his opinion it is important, in order to be toxic, that solid D.D.T. should be present in excess of what might be dissolved in the oil paint solvent. This view is supported by Monro et al. (1947).

A possible explanation for the superiority of filter paper over the plain wood and distempered surfaces is that the comparatively rough, fibrous surface of the paper may tend to hold the crystals on the surface, whereas the smooth planed wood, and possibly the slightly rougher distempered surface to a lesser degree, are penetrated by the spray solutions to a greater extent than the paper, and a larger amount of the spray deposit remains beneath these surfaces and is thus not available to the insects. This theory is supported by the work of Clapp et al. (1947), where they found that fabrics, wall

paper and rough wood were more satisfactory for prolonged D.D.T. residual toxicity than smooth planed wood. Parkin and Hewlett (1946), have shown that rough surfaces such as sacking, retain droplets of insecticidal sprays suspended from the projecting fibres so that the amount of insecticide available for transference to the insects is probably greater on rough than on smooth absorbent surfaces,.

The fact that a considerable proportion of D.D.T. solutions and emulsions sprayed onto smooth planed wood is absorbed into the wood and is thus of no value biologically, is clearly demonstrated by Schmitz and Goette (1948). These workers consider that the D.D.T. which remains within 0.001 of an inch of the top surface includes all that is available biologically, whereas all the D.D.T. which penetrates further than this is of no value. By chemical analysis, they were able to show that only about 38 per cent of the D.D.T. applied in emulsion and about 30 per cent of D.D.T. applied in kerosene solutions were deposited within 0.001 of an inch of the top surface.

The longer duration of residual effectiveness of B.H.C., D.D.T. and chlordane on filter paper than on glass, which is non-absorbent, is not easily accounted for. A possible explanation is that filter paper is a relatively soft material, and although a high percentage of the insecticidal deposits are retained on the rough, fibrous surface, a certain proportion of them are absorbed by the material. The constant movement of a large number of insects over the paper over a period of several months, while tending to gradually remove the surface insecticidal deposits, also removes fibres on the surface of the paper, thus causing the insecticidal deposits below the surface to become available to the termites. In the case of the harder surfaces, such as glass, the insecticides are gradually removed without further deposits becoming exposed. In support of this

theory it is interesting to record that microscopic examination of filter paper which had been exposed to termites at monthly intervals over a period of twelve months, showed clearly that much of the fibrous surface had been removed.

RESIDUAL TOXICITY AS AFFECTED BY AGE OF PAINT AND DISTEMPER.

The results presented in Tables 9 and 10 show that the persistent toxicity of B.H.C., D.D.T. and chlordane varies according to the nature of the surface to which they are applied. The question then arose whether or not the age of the painted or distempered surfaces would exert an influence on the duration of residual effectiveness of these insecticides.

To elucidate this point, tests were undertaken with wooden blocks coated with distemper and with enamel paint of different ages.

The test surfaces were:-

1. Wooden blocks coated with distemper six hours prior to the application of the insecticides.
2. Wooden blocks coated with distemper four months prior to the application of the insecticides.
3. Wooden blocks coated with enamel paint one month prior to the application of the insecticides.
4. Wooden blocks coated with enamel paint two years prior to the application of the insecticides.

The results are summarized in Table II.

TABLE II

(Deposit = 3.6 mg. per sq. foot).

Time after spray application.	Insecticides.	Percentage Final Mortality			
		Distemper.		Enamel Paint.	
		6 hours	4 months	1 month	2 years
24 Hours.	Gamma B.H.C.	73.1	100.0	0.0	76.6
	Chlordane.	37.4	100.0	0.0	83.7
	p,p' D.D.T.	33.3	100.0	0.0	97.3
1 Month.	Gamma B.H.C.	17.6	34.7	0.0	2.6
	Chlordane.	11.9	29.3	0.0	3.3
	p,p' D.D.T.	11.3	100.0	0.0	23.3
2 Months.	Gamma B.H.C.	4.6	2.6	0.0	0.0
	Chlordane.	4.6	6.6	0.0	0.0
	p,p' D.D.T.	3.9	100.0	0.0	10.0
6 Months.	Gamma B.H.C.	2.6	4.6	0.0	0.0
	Chlordane.	1.3	1.3	0.0	0.0
	p,p' D.D.T.	1.9	94.1	0.0	5.4
8 Months.	Gamma B.H.C.	1.9	5.3	0.0	0.0
	Chlordane.	3.3	3.9	0.0	0.0
	p,p' D.D.T.	3.3	74.7	0.0	7.6
10 Months.	Gamma B.H.C.	0.6	1.9	0.0	0.0
	Chlordane.	1.9	3.3	0.0	0.0
	p,p' D.D.T.	3.3	63.3	0.0	5.4

Average control mortality = 2.2 per cent.

Control mortality range = 0.0 to 3.3 per cent.

The following conclusions can be drawn from a study of the figures given in Table II:-

- B.H.C., chlordane and D.D.T. solutions are considerably less effective on fresh distemper than on old.
- B.H.C. is more effective than D.D.T. or chlordane on freshly applied distemper.
- D.D.T. has considerably longer effective residual duration than either B.H.C. or chlordane on old distemper.

This confirms the results obtained in previous experiments which are presented in Table IO. In both series of experiments, B.H.C. and chlordane are relatively ineffective after one month, whereas D.D.T. causes appreciable mortality after ten months.

- d. Surfaces painted with enamel paint two years prior to the application of B.H.C., D.D.T. or chlordane solutions are considerably more toxic to termites than freshly painted surfaces, but the residual effect disappears rapidly, very low mortalities being obtained even with the most effective insecticide, namely D.D.T., one month after the application of the sprays.
- e. D.D.T. is more toxic than B.H.C. or chlordane on old painted surfaces which have been freshly sprayed.
- f. Freshly painted surfaces (one month), are apparently non-toxic even when the insects are exposed to them as soon as 24 hours after the application of B.H.C., D.D.T. or chlordane.

EFFECT OF SURFACE ON THE FINAL RESIDUE DISTRIBUTION.

The reason for the higher toxicity obtained on the old than on the freshly painted surfaces is fairly obvious. It appears safe to conclude that in the case of the old paint, the surface has hardened in the course of time and the paint solvents will have tended to dry out. Consequently less of the insecticide materials will be absorbed and deposited under the surface than in the case of freshly painted wood. It is apparent, however, that even after two years a sufficiently high proportion of the insecticides is still absorbed to make the painted surfaces unsatisfactory for prolonged residual toxicity. Similar results were obtained by Barnes (1945), Lindquist et al. (1945), Gahan et al. (1945), Clapp et al. (1947) and other workers.

It is more difficult to account for the longer residual duration of B.H.C., D.D.T. and chlordane on old than on freshly applied distemper. A reasonable assumption would seem to be, that for some reason, the spray solutions are absorbed to a greater extent by fresh distemper, thus making less of the spray deposits biologically available to the insects. The greater hardness of the old distemper may partly account for the lower penetration through this material.

COMPARATIVE RESIDUAL EFFECTIVENESS OF SOLUTIONS CONTAINING PURE AND IMPURE D.D.T.

Laboratory experiments carried out to determine whether sprays containing pure D.D.T. have a longer residual action than those made up with the impure material, showed the reverse to be true.

Solutions were made up with D.D.T. of 100 per cent purity, 66.6 per cent and 24 per cent purity respectively. Two solutions in kerosene were made up with each grade, one containing 3.5 per cent of p,p' D.D.T., and one containing 3.5 per cent of actual material. In these tests Trinervitermes havilandi workers were again used as test insects and the test surface was glass. The technique for exposing the insects to the treated surfaces was the same as that followed in testing the residual toxicity of the chlorinated hydrocarbon insecticides, B.H.C., D.D.T. and chlordane on different types of surface, except for the fact that the termites were exposed for six instead of 24 hours, and subsequent exposures were made at fortnightly instead of monthly intervals.

The results of these experiments are given in Tables I2 and I3.

TABLE 12.

Time.	Percentage Mortality.				
	3.5 per cent p,p' D.D.T. and 3.5 per cent material. 100 per cent purity.	3.5 per cent p,p' D.D.T. 66.6 per cent purity.	3.5 per cent material. 66.6 per cent purity.	3.5 per cent p,p' D.D.T. 24.0 per cent purity.	3.5 per cent material. 24.0 per cent purity.
24 Hours.	96.7	100.0	98.3	100.0	98.3.
2 Weeks.	46.2	69.1	37.5	90.0	33.3
1 Month.	33.2	65.3	25.0	96.1	11.1

Average control mortality = 2.2 per cent.

Control mortality range = 0.0 to 3.3 per cent.

Further experiments were carried out with D.D.T. of 86 per cent, 73 per cent and 18 per cent purity. The results of these tests are presented in Table 13.

TABLE 13.

Time.	Percentage Mortality.		
	3.5 per cent p,p' D.D.T. 86 per cent purity.	3.5 per cent p,p' D.D.T. 73 per cent purity.	3.5 per cent p,p' D.D.T. 18 per cent purity.
24 Hours.	95.5	100.0	100.0
2 Weeks.	62.5	55.5	98.3
1 Month.	36.6	42.5	86.6

Average control mortality = 3.3 per cent.

Control mortality range = 0.0 to 6.6 per cent.

From the data presented in Tables 12 and 13, the following conclusions can be drawn:-

- a. D.D.T. solutions containing the same percentage of p,p' D.D.T., whether made up with pure or impure material, are approximately equally toxic 24 hours after the application of the spray.
- b. It is clearly evident that the effective residual duration is definitely more prolonged with kerosene solutions containing impure D.D.T. than those made up with the impure material.
- c. As might be expected, the solutions containing 3.5 per cent of the total impure D.D.T. material have not the same residual efficacy as those containing 3.5 per cent of p,p' D.D.T.

DISCUSSION OF RESULTS.

Although the data presented show clearly that kerosene solutions containing impure D.D.T. have markedly longer duration of residual efficacy than those containing the purer material, it is not possible at this stage to give an explanation of this with any great degree of certainty. Work now in progress by the writer, however, indicates that one of the main factors is the greater adhesiveness of the insecticide to the sprayed surfaces due to the impurities present. The difference in crystal formation and structure too, appears to play an important role in the superiority of the solutions of lower D.D.T. purity. The results of these researches will be embodied in a scientific paper in the near future upon the completion of the project.

INSECTICIDAL SMOKES. (Method 2, page 56).

Smoke generators are well suited for the dispersal of insecticides, especially in inaccessible localities. On ignition, a dense white cloud is produced which deposits a thin

insecticidal film over exposed surfaces and penetrates into cracks and crevices. They have been found particularly well suited for the disinfection of dwelling houses, ware-houses, lofts, sewers etc., and have also been used successfully out of doors under favourable weather conditions for the control of pests such as the tsetse fly.

Trials have shown that D.D.T., B.H.C. and pentachlorophenol smokes have immediate killing effect on a variety of insects, but up to the present, their residual effect has not been fully investigated.

RELATIVE TOXICITY OF SMOKES ON HORIZONTAL AND VERTICAL SURFACES.

In the first series of experiments designed for the determination of the duration of residual toxicity of D.D.T., B.H.C. and pentachlorophenol smokes, the test surfaces used were unpainted wooden blocks exposed at different levels and in horizontal and vertical positions in the test chamber as described on page 56. The only surfaces in the vertical position were those at the three foot level, the remainder lying horizontally. The results are presented in Tables 14 and 15.

The evidence presented in these Tables shows that:-

- a. In general, Where D.D.T., B.H.C. and pentachlorophenol smokes are applied within enclosures, such as the room used in these experiments, there is a very much lower deposition of the toxic materials on vertical than on horizontal surfaces. This is readily explained by the fact that in relatively still air, the smoke particles tend to settle straight down and the heaviest deposition will thus be on the top of the horizontal surfaces. It follows, therefore, that prolonged residual toxicity will not be obtained on walls and other vertical surfaces.

This conclusion is supported by Yeomans et al. (1949) in their studies on the behaviour of aerosol clouds in relation to deposition of particles on insects and on surfaces in different positions. They state that in enclosed spaces, even if air currents occur which tend to interfere with particles settling straight down, practically all deposition is on horizontal surfaces or upon horizontal protrusions from vertical surfaces. Busvine and Kennedy (1949), have shown this to be the case too, in their work with insecticidal smokes against the bed-bug, Cimex lectularius.

- b. As judged by the mortality figures given in Table 15, D.D.T. appears to be slightly more effective on vertical surfaces than B.H.C. or pentachlorophenol.
- c. As a surface or residual treatment, B.H.C. smoke does not possess the lasting property exhibited by those of D.D.T. or pentachlorophenol against termites. B.H.C. remains effective for slightly over four weeks, whereas D.D.T. and pentachlorophenol smokes retain their toxic properties for at least eighteen months on horizontal surfaces.
- d. D.D.T. smoke has a longer effective duration than pentachlorophenol, although up to eighteen months, there is only a slight difference in the actual mortalities produced by the two materials on the test surfaces. The main evidence regarding the loss of toxicity by pentachlorophenol is found in Table 14, where the knock-down figures are given. Here it will be seen that up to four months, pentachlorophenol causes a more rapid rate of knock-down than D.D.T. ; at five and six months their rate of knock-down becomes equal, but thereafter, the toxicity of pentachlorophenol deteriorates rapidly in relation to that of D.D.T. as is evidenced by its rate of knock-down.
- e. There is some evidence that horizontal surfaces exposed to

TABLE 14.
Percentage Knock-down after 6 Hours Exposure.

Time after exposure to smokes.	Benzene hexachloride Potassium chlorate Sugar				D.D.T. Potassium chlorate Sugar				Pentachlorophenol Potassium chlorate Sugar			
	Ground level. Horizontal.	3 ft. Vertical.	6 ft. Horizontal.	8 ft. Horizontal.	Ground level. Horizontal.	3 ft. Vertical.	6 ft. Horizontal.	8 ft. Horizontal.	Ground level. Horizontal.	3 ft. Vertical.	6 ft. Horizontal.	8 ft. Horizontal.
24 hours.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1 month.	100.0	6.6	100.0	97.5	96.6	4.9	95.0	93.3	100.0	0.0	100.0	100.0
2 "	13.3	0.0	11.6	3.3	91.6	0.0	91.6	89.9	100.0	0.0	100.0	100.0
3 "	13.3	0.0	8.3	3.3	66.6	0.0	53.3	34.9	100.0	0.0	100.0	100.0
4 "	10.0	0.0	3.3	3.3	57.6	0.0	50.0	36.6	100.0	0.0	100.0	100.0
5 "	0.0	0.0	1.6	0.0	66.6	0.0	63.3	37.5	60.0	0.0	66.6	40.0
6 "	3.3	0.0	10.0	6.6	54.0	1.6	55.7	40.0	60.0	0.0	60.0	51.9
7 "	3.3	0.0	6.6	6.6	48.3	0.0	48.3	48.1	33.3	0.0	37.4	27.5
8 "	Discontinued				40.0	0.0	44.9	31.4	3.3	0.0	0.0	0.0
12 "	"				86.6	3.3	83.3	73.3	0.0	0.0	3.3	0.0
14 "	"				41.7	0.0	34.9	31.4	6.6	0.0	4.7	3.3
16 "	"				30.0	0.0	33.3	24.1	0.0	0.0	0.0	0.0
18 "	"				34.6	0.0	33.7	26.1	0.0	0.0	0.0	0.0

Average control knock-down :- 1.1 per cent.

Control knock-down range :- 0.0 to 3.3 percent.

TABLE 15.
Percentage Mortality after 24 Hours.

Time after exposure to smokes.	Benzene hexachloride 52% Potassium chlorate 12% Sugar 36%				D.D.T. 52% Potassium chlorate 12% Sugar 36%				Pentachlorophenol 52% Potassium chlorate 12% Sugar 36%			
	Ground level. Horizontal.	3 ft. Vertical	6 ft. Horizontal.	8 ft. Horizontal.	Ground level. Horizontal.	3 ft. Vertical	6 ft. Horizontal.	8 ft. Horizontal.	Ground level. Horizontal.	3 ft. Vertical	6 ft. Horizontal.	8 ft. Horizontal.
24 hours.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1 month.	93.3	13.3	100.0	93.3	100.0	38.3	100.0	100.0	100.0	8.3	100.0	100.0
2 "	44.9	13.3	53.3	35.0	100.0	16.7	100.0	100.0	100.0	10.7	100.0	100.0
3 "	44.9	8.3	65.0	15.6	100.0	9.9	100.0	100.0	100.0	3.3	100.0	100.0
4 "	23.2	0.0	34.1	17.4	100.0	13.3	100.0	100.0	100.0	3.3	100.0	100.0
5 "	18.3	0.0	18.3	13.3	100.0	8.3	100.0	100.0	100.0	7.6	100.0	100.0
6 "	4.9	3.3	13.3	10.0	100.0	15.0	100.0	100.0	100.0	6.6	100.0	100.0
7 "	3.3	0.0	4.6	6.6	100.0	3.3	100.0	100.0	100.0	0.0	100.0	100.0
8 "	Discontinued.				100.0	10.0	100.0	100.0	100.0	20.0	100.0	100.0
12 "	"				100.0	10.0	100.0	100.0	100.0	20.0	100.0	100.0
14 "	"				100.0	13.3	100.0	100.0	90.0	6.6	100.0	100.0
16 "	"				100.0	6.6	100.0	100.0	93.3	6.6	96.6	96.6
18 "	"				100.0	3.3	100.0	100.0	96.6	3.3	100.0	93.3

Average control mortality :- 2.7 per cent. Control mortality range :- 0.0 to 3.3 per cent.

the smokes at ground and six foot levels receive a heavier insecticidal deposit than those at the eight foot level. This is indicated by both knock-down and mortality figures.

It will be noted that in Table 15, there is a sudden drop in mortality on the surfaces treated with pentachlorophenol at eight months, followed by a rise in mortality for subsequent exposures. No explanation can be found for this or for the relatively high knock-down figures obtained with D.D.T. in Table 14 after twelve months.

Microscopic examination of glass plates exposed to the smokes at the same time as the test surfaces revealed that, in the case of D.D.T. and pentachlorophenol, the deposits were in the form of minute droplets, whereas the B.H.C. deposit consisted of finely divided solid particles.

INFLUENCE OF DIFFERENT SURFACES ON RESIDUAL EFFICACY OF D.D.T. SMOKES.

The second series of tests with insecticidal smokes was done with D.D.T. alone and was undertaken with the object of determining the relative effectiveness of smoke deposits on different types of surfaces exposed at different levels.

The surfaces were unpainted wooden blocks and blocks painted with oil and enamel paints and distemper respectively. The paints and distemper were applied to the blocks four months prior to their exposure to the insecticides, and they were placed in a horizontal position at ground, six foot and eight foot levels. The mortality figures obtained are given in Table 16. The conclusions to be drawn from the data presented in this Table are:-

- a. The persistence of toxicity of D.D.T. smokes is markedly of shorter duration on oil and enamel paints than on unpainted wood or distemper. In the case of the oil and enamel painted surfaces, the D.D.T. deposit becomes ineffective within a month, whereas the wood and distemper

surfaces remain highly toxic for a period of at least two years.

- b. As with D.D.T. solutions, the residual effectiveness of the D.D.T. smokes is of longer duration on distemper than on wooden surfaces.

TABLE 16.
Percentage Final Mortality.

Time after exposure to smokes.	<u>Ground Level.</u>				<u>6 Foot Level.</u>				<u>8 Foot Level.</u>			
	Oil	Enamel.	Distem- per	Wood.	Oil.	Enamel.	Distem- per.	Wood.	Oil	Enamel.	Distem- per.	Wood.
24 hours.	66.6	60.0	100.0	100.0	70.0	63.3	100.0	100.0	60.0	69.4	100.0	100.0
1 Month.	6.6	10.0	100.0	100.0	6.6	6.6	100.0	100.0	10.0	6.6	100.0	100.0
2 "	3.3	0.0	100.0	100.0	0.0	6.6	100.0	100.0	0.0	0.0	100.0	100.0
3 "	0.0	0.0	100.0	100.0	0.0	0.0	100.0	96.6	3.3	0.0	100.0	100.0
4 "	Discontinued.		100.0	100.0	Discontinued.		100.0	100.0	Discontinued.		100.0	96.6
8 "	"		100.0	93.3	"		100.0	100.0	"		100.0	96.6
12 "	"		100.0	100.0	"		100.0	100.0	"		100.0	100.0
16 "	"		100.0	100.0	"		100.0	100.0	"		100.0	100.0
20 "	"		100.0	91.4	"		100.0	90.0	"		100.0	95.7
24 "	"		96.6	80.0	"		100.0	93.1	"		97.3	78.8

Average control mortality :- 2.2 per cent. Control mortality range; 0.0 to 3.3 per cent.

SECTION 4.COMPARISON OF FUMIGATION, CONTACT AND STOMACH ACTIONS
OF NEW ORGANIC INSECTICIDES.

The evaluation of the relative efficacy of certain of the newer synthetic insecticides is comparatively simple, but as some of these materials act as stomach and contact poisons while others, in addition, exhibit fumigation properties, the investigation of their mode of action presents difficulties, especially in practical experiments where these are not completely separable.

It is well known that B.H.C. acts as a stomach poison, as a contact agent or as a fumigant and that D.D.T. and chlorinated camphene or toxaphene combine both contact and stomach actions. It has also been demonstrated that chlordane shows both contact and stomach toxicity, and more recent work by Sun et al. (1948), has established its value as a fumigant. The new synthetic insecticide, parathion, has both contact and stomach actions but little information is available ^{regarding} its fumigation properties, although Hoffman and Lindquist (1949), included this material in some preliminary tests to determine the fumigating properties of several new insecticides against the housefly, Musca domestica, L.

It is considered important for practical considerations to determine not only the role each of these modes of action plays in relation to the efficacy of each of the insecticides mentioned above, but also to evaluate the relative toxicity of each material as a fumigant and as a contact and stomach poison. Detailed laboratory investigations have, therefore, been undertaken with a view to obtaining information on these points.

Before presenting the results of these experiments, however, other aspects of the mode of action of

insecticides will be briefly discussed. Firstly, the manner in which the poison is picked up should be considered. The work of David and Bracey (1946), has shown how, in the case of space sprays, the insecticidal mists are picked up by the insect. Movement is necessary for the impaction of the droplets. This takes place particularly on the beating of wings, and the insecticide is transferred to other parts of the body when the insect cleans itself. According to Wigglesworth (1946), the final site of entry remains to be investigated.

For residual toxicity, the properties of residual films are important. Parkin and Green (1947), describe how the toxicity of supersaturated D.D.T. solutions in oil increase greatly when they crystallize following mechanical movement over them. The stimulus for crystallization of the supersaturated residue may be any form of mechanical agitation, including the movement of insects over the treated surface. If the stimulus is absent, crystallization may take several weeks. Barnes (1946), found that large particles of D.D.T. in distemper are the most effective for prolonged residual toxicity, and McIntosh (1947), that in water suspensions, large elongated crystals gave the highest kills.

In the second place, there is the question of the entry of the insecticides into the insect and the problem of how they intervene in the vital processes of the tissues.

According to Wigglesworth (1948), there is no really clear evidence just where insecticides such as D.D.T. enter through the cuticle. Hayes and Liu have found that entry through the feet is much more rapid in Musca than in Epilachna or Blattella, and this is correlated with a thinner tarsal cuticle and the presence of thin walled chemoreceptive sensilla. Hurst (1945), states that the toxicity of an insecticide may be related not only to its molecular structure, but also to the carrier in which it is dissolved, since this may alter the

permeability of the insect cuticle and modify access to the internal tissues. The relative susceptibility of insects to insecticides such as D.D.T. depends only partly on the permeability of the cuticle but more fundamentally on the stability of the internal tissue receptors that regulate the internal balance in oxidative metabolism. Dresden and Krygaman (1948), contend that for efficient penetration through the chitinous insect cuticle, an insecticide should have a high solubility in lipoids and a specific adsorption by chitin is favourable. The fact that B.H.C. is often more toxic to insects than D.D.T. is ascribed by these workers to a difference in the rate of penetration.

Wiesmann (1946), states that the penetration of D.D.T. is dependent on the structure and chemical composition of the cuticle and the lipophilic properties of D.D.T. In the parts that are not permeable, resistance is due to the high sclerotin content of the exo- and endo-cuticle, and in the larvae that are resistant to D.D.T., the epicuticle is polymerised to form a complete and impenetrable covering for the whole body. Unlike the sites that are unpermeable, the penetrable ones, including even the sense organ pores, not only have an epicuticle that contains lipoids, but also either have very thin unpigmented and flexible exo- and endocuticles containing little or no sclerotin or, as in the sense organ pores, lack these layers entirely. Penetration through the small organ pores and the intersegmented skin is due to the presence of lipoids.

Bot (1949), working with D.D.T., B.H.C., chlordanes and toxaphene against the fly Calliphora erythrocephala, Meig., and the cockroach, Periplaneta americana, L., states that the sense organs do not play an essential part in the penetration of these insecticides. By demonstrating that a water soluble and a fat soluble dye penetrates the cuticle, he emphasizes that it is dubious whether the efficiency of the

insecticides can be attributed to the fact that their chemical structure should be considered as the main factor for easy penetration. This worker stresses that not only the spot of application but also the size of the treated area on the insect play an important part. He concludes that D.D.T., B.H.C., chlor-dane and toxaphene can be conveyed through the body of the insects by the nervous system, but that this method of transportation is considered secondary to transportation by the haemolymph. It is probable that all insects with malphigian tubes can excrete the insecticides from the haemolymph by means of them. Ladger and Martin (1944), consider that transport along the nerves is probable.

According to Wigglesworth (1948), the most ^{obvious} effect of D.D.T., after absorption, is on the nervous system, causing over-excitability and inco-ordination. He states that the study of muscle - nerve preparations in Crustacea by Welsh and Gordon has shown that D.D.T., like many other substances, produces repeated volleys of impulses, causing tetanic contraction in the muscles. The most obvious explanation of death from D.D.T. poisoning, therefore, appears to be the exhaustion of reserves following upon excessive activity. Work done by Roeder and Weiant (1946), on the cockroach supports this theory. Lord (1949), concludes from his experiments with Oryzophilus surinamensis that insects treated with D.D.T. do not die as a direct result of D.D.T., but that the life of the insect is shortened because of its increased activity which follows from the action of this material.

Tobias et al. (1946), have shown that the course of poisoning is not altered by anaesthetics that suppress the movements, or by the administration of glucose. The action of D.D.T. on the nervous system is largely determined by the lipid solubility of the molecule. If the chloroform residue is replaced by something water soluble, it becomes inactive.

They conclude that these changes are not critical in the cause of death. Lord (1949), however, argues that they do not consider the possibility that the hyperactivity of the insect may be closely associated with the cause of death and that they have not presented any evidence which makes this suggestion unlikely.

Welsh and Gordon consider that it is mainly a question of adsorption in the nerve fibre. These authors explain the significance of halogenation on a physical hypothesis, arguing that it is a question of obtaining a molecule of high density that will not be too mobile after adsorption.

Wigglesworth (1948), considers that in the case of D.D.T., there is a great reduction in activity if the chlorine atoms on the benzene rings are moved from the para position, which suggests that the shape of the molecule is important. Martin and Wain (1944), have shown that up to a point, there is a rough parallel between the activity of chemicals related to D.D.T. and the ease of dehydrochlorination, and they have, therefore, suggested that these substances owe their activity to the release of hydrochloric acid when adsorbed at the sensitive intersurface. Wigglesworth is of the opinion, that although there are exceptions to this rule, the hypothesis has provided a useful guide in the search for chlorinated ring compounds with insecticidal properties.

Dresden (1949), in summarising the action of D.D.T. states:- " D.D.T. is a poison that penetrates the integument of Arthropods in a specific manner, and then, just as in the case in Vertebrates after injection or oral administration, by a specific reaction on the synapsis, causes a prolonged state of general facilitation, followed by an irreversible block of those synapses. The integrative action of the nervous system is thus rendered impossible, in consequence of which the animal, as a dynamic whole, dies ".

Published insecticidal data on the mode of

action of parathion and related phosphorus compounds are more fragmentary than that dealing with the mode of action of the chlorinated hydrocarbon insecticides. Recent work by Metcalf and March (1949), and Metcalf (1950), has, however, provided valuable information on this subject. These investigators, using the American cockroach as the test insect, have shown that parathion is readily absorbed by the cuticle and that the toxicity of the material is about the same whether it is applied topically or injected. They also conclude from results obtained from " in vivo " studies with parathion, that the symptoms of bees poisoned with it can be directly correlated with the extent of inhibition of bee brain cholinesterase, and that the enzyme is almost completely destroyed at the point of death.

EXPERIMENTAL MATERIALS.

TEST INSECTS.

The test insects selected for these experiments were the Melyrid beetle, Astylus atromaculatus, Bl., the eucalyptus snout-beetle, Gonipterus scutellatus, Cyl. and the termite Trinervitermes havilandi, Hggn. In studies on the contact action of the poisons, termite soldiers were used because they are unable to feed without the aid of worker termites, thus eliminating the stomach effect of the poisons. Workers were, however, used for fumigation tests. Owing to the rather specialized food requirements of Trinervitermes havilandi and Astylus atromaculatus, it was found to be impossible to eliminate entirely the contact action of the materials under consideration and still induce the insects to feed, hence in the case of these insects, the tests were confined to the contact and fumigation actions of the insecticides. This difficulty was not experienced with Gonipterus scutellatus.

INSECTICIDES TESTED.

The insecticides were tested as dusts at

concentrations commonly used for practical application in preference to each containing the same percentage of active ingredient.

Fumigation Action.

10 per cent B.H.C.
10 per cent D.D.T.
10 per cent chlordanes.
10 per cent toxaphene.
2 per cent parathion.

Stomach and Contact Actions.

5 per cent B.H.C.
5 per cent D.D.T.
5 per cent chlordanes.
5 per cent toxaphene.
2 per cent parathion.

1 per cent parathion dust was included in the experiments on the contact action of the poisons.

UNIFORMITY OF TEST CONDITIONS.

TEMPERATURE AND HUMIDITY.

As in the previous section of this thesis, a temperature of 75 degrees F. and a Relative Humidity of 70 to 75, per cent was maintained throughout the experimental procedure. Air was kept circulating by means of an electric fan.

TEST INSECTS.

The test insects were kept under constant temperature and humidity conditions for 24 hours prior to the commencement of every experiment. The insects used in the tests were carefully selected in order to eliminate differences in the physiological state of the material as far as possible. With Gonipterus scutellatus and Astylus atromaculatus, large numbers of these beetles were isolated in tubes with food for 24 hours before each experiment, and an effort was made to select only those which had fed normally during that period, for inclusion in the tests. In the case of termites, only those from the same nest were used in each experiment.

After exposure to the poisons, the surviving

insects were transferred to clean petri dishes containing filter paper moistened with 0.6 ml. of water, and were fed on flower petals and pollen in the case of Astyus atromaculatus, and young gum leaves in the case of Goniapterus scutellatus. The termites were fed on standard moistened filter paper. Soldier termites, being unable to feed themselves, were placed with workers from the same nest from which they were originally selected.

EXPOSURE OF INSECTS TO THE INSECTICIDES.

In the fumigation tests, the desiccators in which the insects were confined to the toxic vapours were all of the same size, as were the petri dishes containing the insects and those holding the insecticides. Freshly prepared insecticide material was used for each replication.

For the evaluation of the contact effect of the poisons, the test surfaces used were dry, standard Whatman No. 1 filter paper accurately dusted with the various insecticides under consideration. The same area of dusted surface was exposed for each insecticide. The insects were, in general, unable to climb the sides of the glass rings confining them to the poisons, which were dusted at the same rate of application as the filter papers and they were thus automatically confined to the treated surfaces. An observer was present throughout the exposure period, however, to prevent any isolated individual insects from climbing off the treated papers.

To eliminate the contact action of the insecticides, the sandwich method was employed for determining the stomach action of the various poisons, and the leaf discs comprising the poisoned sandwiches were cut to a standard size with a cork-borer. The poisons were dusted onto the leaf discs at a standard rate of application. To avoid shrinkage of the leaf discs during the course of the experiment, the sandwiches were placed on moist filter paper in the closed tubes containing

the insects.

NORMAL MORTALITY CORRECTION.

Controls were run for all experiments and all knock-down and mortality figures have been corrected for natural mortality by means of Abbot's formula.

NUMBER OF TEST INSECTS AND REPLICATIONS.

The number of test insects and replications used are given in detail later in the text, when the different methods of experimentation for fumigant, contact and stomach actions of the insecticides are described. In no case were there less than 450 insects used for each insecticide.

TECHNIQUE.

METHOD I. FUMIGATION ACTION.

To compare the fumigation action of B.H.C., D.D.T., chlordane, toxaphene and parathion, 10 gms. of each material at the concentrations previously given on page 88, were spread evenly over the bottoms of petri dishes in tightly closed desiccators. Freshly prepared material was used for each replication, and the petri dishes were covered with large mesh wire gauze. After 48 hours, three petri dishes 9 cms. in diameter, each containing moist filter paper and 20 worker termites, were placed one above the other in each desiccator in order to obtain information on the fumigating action of each material at three different levels in each desiccator. Two desiccators were used for each poison and the experiment was replicated twelve times. The number of test insects used for each insecticide at each of the three levels was, therefore, 480. The insects were confined to the petri dishes by means of wire mosquito gauze so that they were unable to come in contact with the toxic materials. The termites, being more susceptible to the effects of the insecticides than the other test insects,

were exposed to the toxic vapours for 30 hours, whereas the beetles were given a 72 hour exposure. Knock-down was recorded in the top petri dish in each desiccator at hourly intervals for the first six hours, and again at the end of the period of exposure, when the first mortality records were made in all the dishes and the insects were transferred to clean containers and fed. Subsequent mortality was recorded at 24 hourly intervals.

METHOD 2. CONTACT ACTION.

The test surfaces used in all contact experiments were Whatman No. 1 filter papers dusted with the various insecticides at the rate of 0.11mg. per sq. cm. for Gonipterus scutellatus and Astylus atromaculatus, and 0.06 mg. per sq. cm. in the case of Trinervitermes havilandi. The dusts were applied with the dusting apparatus described in a previous section of this thesis. The insects were not dusted but were confined to the treated filter papers for one hour by means of conical glass rings, 1 inch high, open at both ends, and having a diameter of 7 cms. and 5 cms. at the bottom and top respectively. After an hour, the insects were transferred to clean petri dishes and fed. Subsequent to the period of exposure, hourly knock-down records were made for six hours and mortality was recorded at 24 hourly intervals. Two groups of 20 insects were used for each poison in each of the experiments and there were twelve replications. The total number of each type of test animal used for each insecticide was, therefore, 480.

METHOD 3. STOMACH ACTION.

As stated previously, only the eucalyptus snout-beetle, Gonipterus scutellatus, was used in these tests. To eliminate the contact action of the insecticides, the sandwich method was employed. Leaf discs cut with a cork-borer, were

dusted with the insecticides at the rate of 0.22 mg. per sq. cm., and the sandwiches were made by placing untreated leaf discs painted with starch paste over the dusted ones. The beetles were isolated in small celluloid tubes, 2 inches long by $\frac{1}{2}$ inches wide, each tube containing a leaf disc resting on moist filter paper to prevent shrinkage. Three groups of 20 beetles were used in each experiment for each insecticide. There were twelve replications. The results obtained, therefore, are based on a total of 720 insects for each insecticide. After 24 hours exposure to the treated leaf discs, the beetles were removed to clean petri dishes and fed on undusted foliage. Mortality was recorded at 24 hourly intervals.

RESULTS.

FUMIGATION TESTS. (Method I, page 90).

A. TRINERVITERMES HAVILANDI. Hggn.

The results obtained indicate that the fumigation action of chlordan is markedly superior to that of any of the other insecticides tested, both as regards rapidity of action and the final mortality produced. B.H.C. and parathion take second and third place respectively in order of efficacy, and cause similar final mortalities although parathion is slower in producing knock-down. Toxaphene is more toxic than D.D.T., but both these materials exhibit poor fumigating properties.

The results are summarised in Tables I7 and I8.

TABLE 17.

Relative Efficacy of Different Poisons as Indicated by Knock-down.

Insecticides	Length of exposure	Percentage Knock-down.						
		1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	30 hours
10% D.D.T.	30 hours.	0.0	0.0	0.0	0.0	0.0	0.0	4.4
10% B.H.C.	"	0.0	0.0	0.0	0.0	5.7	7.5	51.1
10% Chlordane.	"	0.0	0.0	0.0	1.7	8.5	12.5	100.0
10% Toxaphene.	"	0.0	0.0	0.0	0.0	1.6	3.3	3.5
2% Parathion.	"	0.0	0.0	0.0	0.0	0.0	0.0	27.4
Control.	"	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 18.

Relative Efficacy of Different Poisons as Indicated by Mortality

Insecticides.	Length of exposure	Percentage Mortality after 96 Hours.			
		Top dish.	Middle dish.	Bottom dish.	Average percentage mortality for three levels
10% D.D.T.	30 hours.	3.3	3.3	2.2	2.9
10% B.H.C.	"	100.0	12.3	15.6	42.6
10% Chlordane.	"	100.0	100.0	100.0	100.0
10% Toxaphene.	"	4.4	5.6	26.6	12.3
2% Parathion.	"	100.0	7.7	17.7	41.1
Control.	"	1.3	0.0	2.1	1.1

A study of Table 18 indicates further, that in the case of B.H.C. and parathion, the highest concentration of toxic vapour occurs at the top of the desiccators whereas with chlordane, it is distributed at effective concentrations throughout the enclosed space. There is some evidence that

toxaphene produces best results at the lower level.

B. ASTYLUS ATROMACULATUS. Bl.

The fumigation action of the different insecticides under consideration on Astylus atromaculatus is given in Tables 19 and 20.

TABLE 19.

Relative Efficacy of Different Poisons as Indicated by Knock-down.

Insecticides,	Length of exposure	Percentage Knock-down.						
		1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	72 hours
10% D.D.T.	72 hours.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10% B.H.C.	"	0.0	0.0	0.0	0.0	0.0	0.0	23.3
10% Chlordane.	"	0.0	0.0	0.0	5.0	5.0	13.3	100.0
10% Toxaphene.	"	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2% Parathion.	"	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Control	"	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 20.

Relative Efficacy of Different Poisons as Indicated by Mortality

Insecticides.	Length of exposure	Percentage Mortality after 96 Hours.			
		Top Dish	Middle dish	Bottom dish	Average percentage mortality for three levels
10% D.D.T.	72 hours.	0.0	0.0	0.0	0.0
10% B.H.C.	"	20.0	5.0	5.0	10.0
10% Chlordane.	"	100.0	100.0	100.0	100.0
10% Toxaphene.	"	0.0	0.0	5.0	1.6
2% Parathion.	"	10.0	0.0	5.0	5.0
Control	"	0.0	0.84	1.0	0.58

The mortality and knock-down figures clearly demonstrate the superiority of chlordanes over the other insecticides which is even more marked than with Trinervitermes havilandi. In general, the order of efficacy is the same as with termites, although, with the exception of chlordanes, their degree of effectiveness is considerably lower. The conclusions drawn regarding the levels at which each insecticide is most effective against termites, is confirmed in the tests with Astyus atromaculatus.

C. GONIPTERUS SCUTELLATUS, Gyl.

Tables 21 and 22 show that although the fumigation properties of chlordanes are superior to those of the other insecticides, Gonipterus scutellatus is more resistant to this material than the other test insects. B.H.C. and parathion again fill second and third places respectively, but there appears to be no significant difference between the effectiveness of D.D.T. and toxaphene.

TABLE 21.

Relative Efficacy of Different Poisons as Indicated by Knock-down.

Insecticides.	Length of exposure.	Percentage Knock-down.						
		1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	72 hours
10% D.D.T.	72 hours.	0.0	0.0	0.0	0.0	0.0	0.0	3.6
10% B.H.C.	"	0.0	0.0	0.0	0.0	0.0	0.0	72.8
10% Chlordanes.	"	0.0	0.0	0.0	0.0	6.6	13.3	78.4
10% Toxaphene.	"	0.0	0.0	0.0	0.0	0.0	0.0	4.7
2% Parathion.	"	0.0	0.0	0.0	0.0	0.0	0.0	17.2
Control.	"	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 22.

Relative Efficacy of Different Poisons as Indicated by Mortality

Insecticides.	Length of exposure.	Percentage Mortality after 96 Hours.			
		Top dish.	Middle dish.	Bottom dish.	Average percentage mortality for three levels
10% D.D.T.	72 hours.	8.3	8.3	7.1	7.9
10% B.H.C.	"	96.6	45.7	47.8	63.4
10% Chlordane.	"	96.6	93.3	87.3	92.4
10% Toxaphene.	"	5.0	5.0	8.3	6.1
2% Parathion.	"	37.3	20.0	20.2	25.8
Control.	"	1.3	2.1	1.3	1.5

As in experiments with Trinervitermes havilandi and Astyus atromaculatus, the toxic vapours of B.H.C. and parathion are most effective at the top of the desiccators, while that of toxaphene produces the highest mortality at the bottom of the containers. In the fumigation tests with termites and the Melyrid beetles, no conclusions could be drawn regarding the most effective level for maximum efficacy with chlordane, since all the insects were killed at the three levels. With Gonipterus scutellatus, however, owing to the greater resistance of these insects to the toxic effect of chlordane and the consequent lower mortalities obtained, it is clearly indicated that although highly toxic as a fumigant at all three levels, chlordane, like B.H.C. and parathion, has the greatest effective concentration of toxic vapour at the top of the desiccators.

CONTACT TESTS. (Method 2, page 91).

The results obtained on the contact action of the various poisons with Trinervitermes havilandi, Astyus

atromaculatus and Gonipterus scutellatus are presented in the form of two graphs, I and 2, which indicate the average percentage knock-down and mortality figures respectively obtained in the twelve replications.

A. TRINERVES HAVILANDI, Hagn.

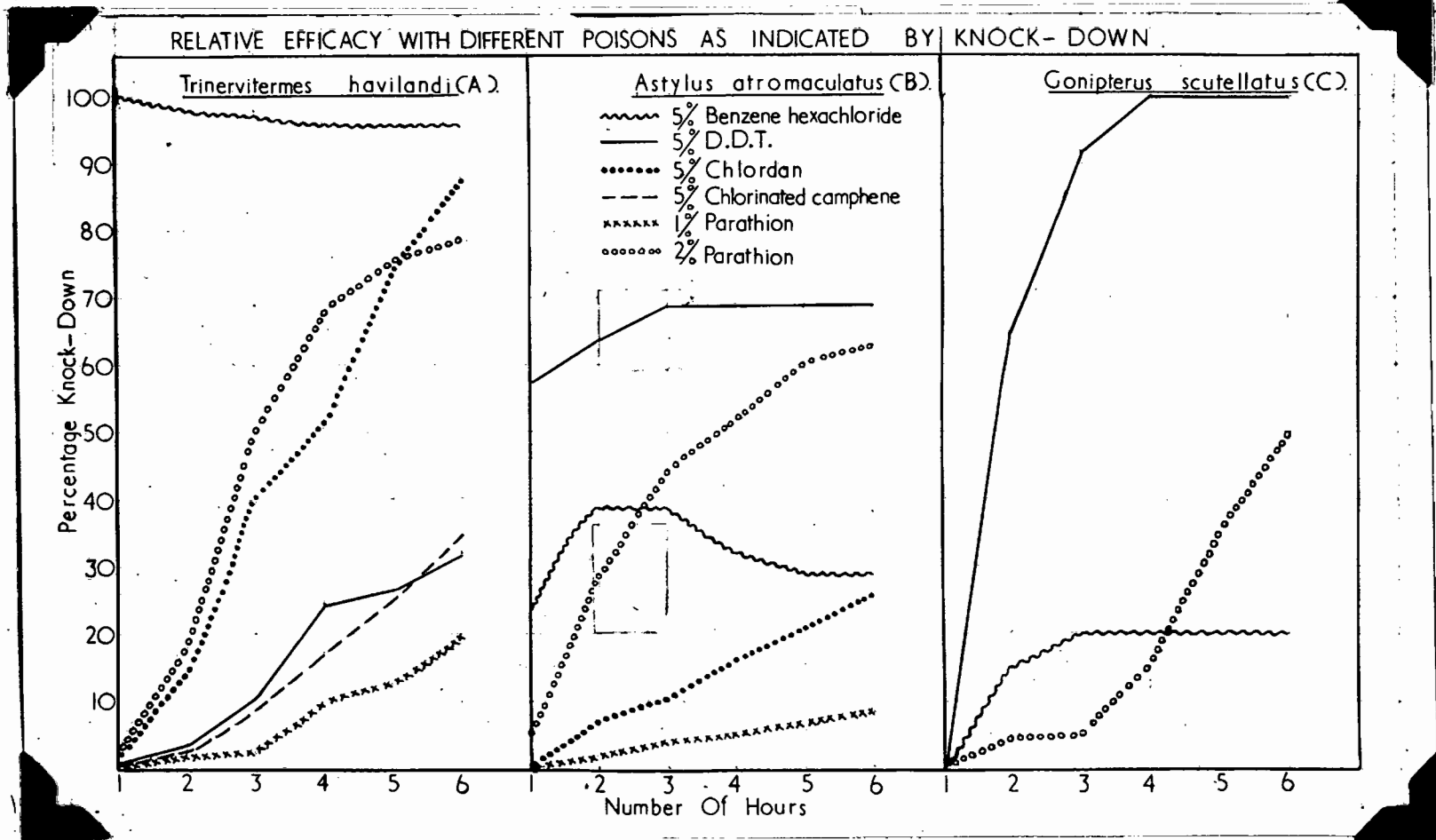
It is evident from a study of Graph I A, that B.H.C. is far superior to the other insecticides in producing rapid knock-down. Chlordane, although rather slower in action than 2 per cent parathion in the initial stages of the experiment, eventually surpasses it to take second place. D.D.T. and toxaphene produce rather similar results and are superior to 1 per cent parathion. The three last named insecticides are, however, obviously inferior to the first three mentioned.

In considering the final mortalities obtained (Graph 2 A), it is at once obvious that the rate of knock-down produced by the different insecticides is not necessarily a true index as to their final efficacy. B.H.C., although more rapid in action, is in no way superior to chlordane with regard to the final mortality produced. 2 per cent parathion is inferior to D.D.T. although it causes a quicker knock-down than this material. Toxaphene and 1 per cent parathion are considerably less toxic than the other insecticides to Trinervitermes havilandi.

B. ASTYLUS ATROMACULATUS, Bl.

It is at once apparent in studying Graph I B, that from the purely knock-down point of view, D.D.T. possesses the most rapid toxic action followed in order of merit by 2 per cent parathion, B.H.C., chlordane and 1 per cent parathion. Toxaphene exhibits no knock-down action for the first six hours of the experiment.

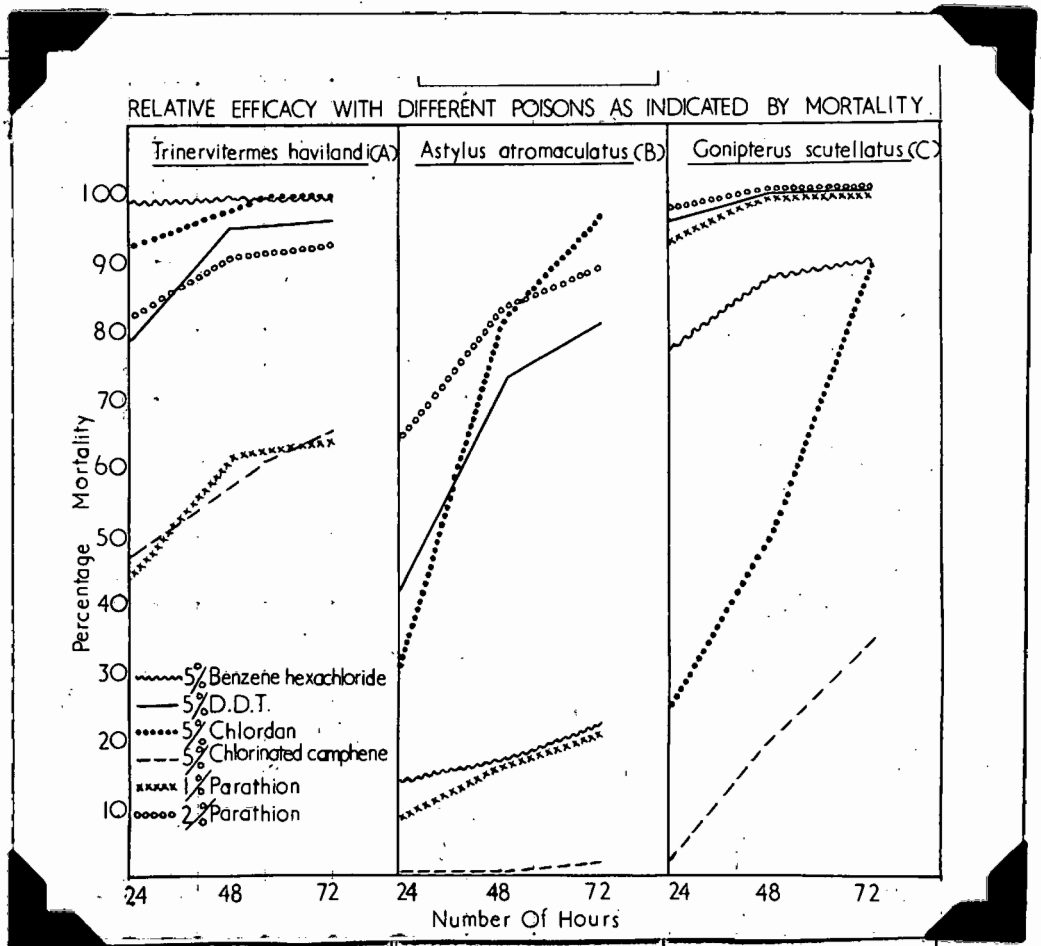
Contact Action Of Insecticides.



Control knock-down:- 0.0 per cent.

GRAPH I.

CONTACT ACTION OF INSECTICIDES.



Av. Cont. Mort.

4.4%

3.4%

2.5%

Control Mortality Range = 0.0 to 5.0%

GRAPH 2.

Graph 2 B shows that, as with Trinervitermes havilandi, the efficacy of the materials, as indicated by the final mortalities obtained, is not necessarily correlated with their value as knock-down agents. D.D.T., which exhibits the most rapid toxicity in the initial stages (Graph I B), drops to third place when the final mortality is considered. Chlordane, which is relatively slow in action as judged by the knock-down produced, is responsible for causing the highest final mortality. 2 Per cent parathion occupies second place as regards both rapidity of action and final mortality produced. B.H.C., 1 per cent parathion and toxaphene are relatively ineffective as contact agents against Astylus atromaculatus.

It is of interest to note that with Astylus atromaculatus and Trinervitermes havilandi, a certain percentage of the insects affected by contact with B.H.C. during the period of exposure to this material, show recovery after their removal from the treated surfaces. No such recovery was, however, recorded with the other insecticides tested.

C. GONIPTERUS SCUTELLATUS, Gyll.

The results presented in Graph I C clearly demonstrate the superiority of D.D.T. over all the other chemicals tested as a knock-down agent. 2 Per cent parathion is a poor second, followed by B.H.C.. Chlordane, toxaphene and 1 per cent parathion have no apparent effect on Gonipterus scutellatus during the first six hours of the experiment.

The final mortality figures show, however, (Graph 2 C), that D.D.T. and 1 and 2 per cent parathion produce complete mortality at the 72 hour period in spite of the fact that the two parathion preparations are markedly slower in action as indicated by their rate of knock-down. Second place is occupied by B.H.C. and chlordane, although the former is the better knock-down agent than the latter insecticide. Toxaphene

exhibits low toxicity to Gonipterus scutellatus.

INFLUENCE OF MOISTURE ON CONTACT ACTION OF POISONS.

During the course of the investigations on the contact action of the insecticides under consideration, it was observed that a higher mortality figure was obtained with 1 per cent parathion dust with Trinervitermes havilandi soldiers which were confined to dusted filter paper which had been accidentally moistened, than on dry filter paper. The difference in mortality was so marked that it was considered worth while following up this rather casual observation with more detailed studies on this point.

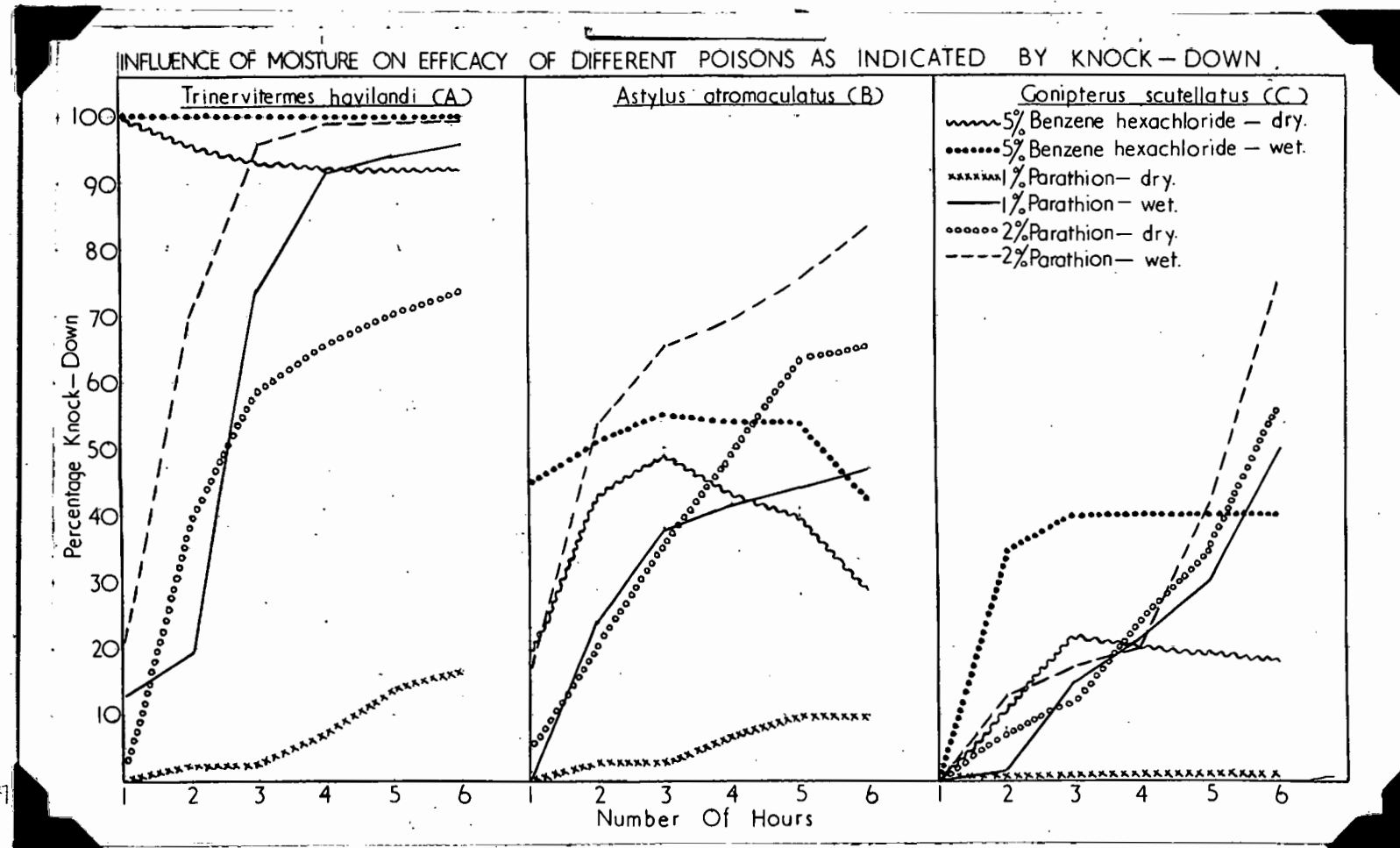
The dusting procedure and method of experimentation was the same as that described on page 91 with the exception that the various poisons were applied to both dry filter paper and paper moistened with 0.6 ml. of distilled water. D.D.T., B.H.C., chlordane, toxaphene and parathion were included in the tests. The results obtained are presented in Graphs 3 and 4.

No increased toxicity was obtained with D.D.T., chlordane or toxaphene on the moistened surfaces, hence results with these materials are not shown in the graphs. Only those obtained with B.H.C. and parathion are expressed graphically.

It is clearly evident from a study of Graphs 3 and 4, that the efficacy of these two insecticides is improved to a remarkable extent by their application to wet paper, not only with Trinervitermes havilandi, but also with Astylus stro-maculatus and Gonipterus scutellatus.

No adequate and convincing reason can, at this stage, be advanced by the writer to explain these rather surprising results, but it is possible that certain of the impurities of B.H.C. and parathion may be soluble in water to the extent of making them more readily available to the insects in toxic form when they are applied to wet surfaces. Whatever the reason

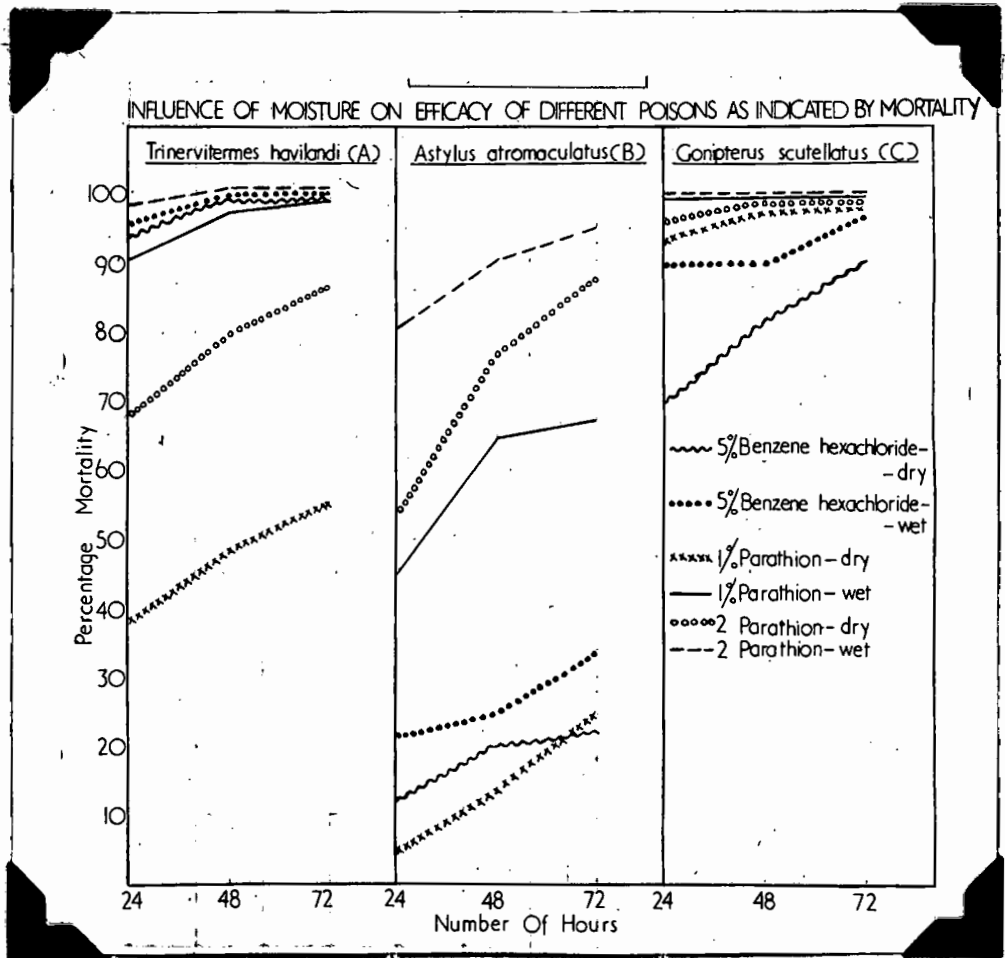
Influence Of Moisture On Contact Action Of Parathion And B.H.C.



Control knock-down:- 0.0 per cent.

GRAPH 3.

CONTACT ACTION AS AFFECTED BY MOISTURE



Av. Cont. Mort.

3.5 %.

2.3 %.

3.1 %.

Control Mortality Range = 0.0 to 5.0 %

GRAPH 4.

may be, however, it is felt that the results are of value not only from their obvious practical application in the use of these insecticides, but also in emphasizing the care that should be observed in maintaining uniformity in test conditions when evaluating the relative efficacy of different materials in laboratory experiments.

STOMACH TESTS. (Method 3, page 91).

A. GONIPTERUS SCUTELLATUS; Gyl.

The results obtained on the relative toxicity of D.D.T., B.H.C., chlordane, toxaphene and parathion as stomach poisons against Gonipterus scutellatus are shown in Table 23.

TABLE 23.

Relative Efficacy of Different Poisons as Indicated by Mortality.

Insecticides.	Percentage Mortality after 96 Hours.
5% D.D.T.	72.2
5% B.H.C.	53.5
5% Chlordane.	36.6
5% Toxaphene.	14.2
2% Parathion.	96.5
Control.	3.7

It has been stated previously (page 100), that the contact toxicity of the various chemicals to Gonipterus scutellatus, as judged by the final mortality obtained is D.D.T. and parathion first with 100.0 per cent mortality followed by B.H.C. and chlordane with 90.0 per cent and toxaphene last with 35.6 per cent mortality.

It is apparent, therefore, in comparing these figures with those given in Table 23, that parathion is similar

in its order of toxicity both as a contact and as a stomach agent, whereas D.D.T., although occupying second place as a stomach insecticide, is more effective as a contact poison. B.H.C. and chlordane produce the same final mortality by contact action but the first-named material is the better stomach poison of the two. Toxaphene is relatively ineffective as a stomach or as a contact insecticide when used against Gonipterus scutellatus.

DISCUSSION OF RESULTS OBTAINED ON THE FUMIGATION, CONTACT AND STOMACH ACTIONS OF THE POISONS.

From the results obtained, it appears that chlordane is superior to the other materials as a fumigant against all three test insects followed in order of efficacy by B.H.C. and parathion. D.D.T. and toxaphene exhibit very poor fumigation properties. It is clearly shown that chlordane, B.H.C. and parathion, when used in an enclosed space such as a desiccator, have the greatest concentration of toxic vapours at the top of the container.

The results obtained on the contact actions of the poisons indicate the danger in trying to adopt any single insecticide as an over-all panacea and tend to emphasize the specific actions of the poisons to the different test insects.

When the value of the insecticides is judged by their performance as knock-down agents, B.H.C. is outstanding against Trinervitermes havilandi, while D.D.T. shows the most rapid knock-down action with Astylus atromaculatus and Gonipterus scutellatus. If the final percentage mortality produced is used as a basis for evaluating the efficacy of the poisons, however, then B.H.C. and chlordane are the most effective against Trinervitermes havilandi while good results against termites are also obtained with D.D.T. and parathion. Chlordane causes the highest mortality with Astylus atromaculatus and 2 per cent parathion is also highly efficacious. Against Gonipterus

scutellatus, best results are obtained with parathion and D.D.T., with B.H.C. and chlordane also causing high kills. It is evident, therefore, that the efficacy of the insecticides as indicated by the final mortalities obtained with them is not necessarily correlated with their value as knock-down agents.

The results obtained on the relative toxicity of the chlorinated hydrocarbon insecticides and parathion as stomach poisons with Gonipterus scutellatus, show parathion to be superior to the other chemicals tested in this respect.

SECTION 5.AGRICULTURAL APPLICATION OF NEW ORGANIC INSECTICIDES.

The question is often asked "Are poisonous chemicals necessary in the production of fruit and produce?". The writer's opinion on this question is that, in general, it is absolutely essential to use economic poisons to protect most crops during their growing season. It is true that it has long been the cherished hope among entomologists that the natural balance between harmful insects and their parasites and predators may be tipped sufficiently to give practical control of the pests, and a vast amount of energy has been spent in the search for beneficial insects and on their artificial propagation prior to liberation in large numbers. Undoubtedly some outstanding successes have resulted from this work, but when measured against the total number of serious pests, it is quickly obvious that progress has been made painfully slowly. It is likely that this research will be extended and given more generous support, but the time is certainly not ripe to consider it as a general substitute for chemical control.

Similar considerations apply to other auxiliary measures such as the development of resistant plant varieties. Much is being done with general cultural practices, but the results achieved do not measure up to the problem.

A word of caution should be sounded, however, regarding the application of insecticides. The materials used for control should be carefully selected for the pest involved. In this connection Cox (1950), states that limiting the kinds of insecticides which may be used would enhance the possibility of insects of economic importance becoming partially or totally resistant to those insecticides used. There are many instances in which materials at first afforded excellent control of a particular pest, but later failed to control it. The recognized

effective insecticides should be alternated and kept useful for as long as possible. Without an opportunity to use alternate pesticides, the resistance of pests builds up more rapidly and new materials would have to be discovered faster. Another point to be remembered is that there is still a place for older insecticides such as the arsenicals and fluorine compounds, where the newer ones cause biological upset or other complications. A wide selection of insecticides is desirable to fill a wide range of specific needs.

EXPERIMENTAL PROCEDURE.

The laboratory experiments described in this section of the thesis have been carried out under the same controlled conditions as those outlined in the two previous sections. In certain instances, however, field tests have been included in the experimental programme and the methods of experimentation used will be dealt with when these experiments are described.

Special attention has been paid to the newer organic insecticides D.D.T., B.H.C., chlordane, toxaphene, parathion, " hexaethyl tetraphosphate " and tetraethyl pyrophosphate in these studies, although in many experiments older insecticidal materials such as oryolite, lead arsenate, nicotine and pyrethrum have been included to serve as a basis for comparison for the new materials.

The experimental technique in handling the insects prior, during and subsequent to treatment must of necessity vary according to their individual habits, but certain general rules in experimental procedure for the laboratory tests can be laid down for most of the insects and the mite studied.

I. Prior, during and subsequent to the application of the insecticides, the test insects were kept under constant

temperature and humidity conditions (75 degrees F. and 70 to 75 per cent R.H.).

2. The dusting powders were applied by means of the apparatus described in Section 2.
3. With the exception of the wattle bagworm (Acanthopsyche junodi, Heyl.), the red spider mite (Tetranychus bimaculatus, Harvey.) and the cochineal insect (Dactylopius opuntiae Ckl.), where it was found to be impracticable, the percentage knock-down, due to the action of the insecticides, was recorded every hour for the first six hours of the experiments. Except in the case of the cochineal, mortality records were made at 24 hourly intervals until all the test animals were dead or had apparently recovered. The technique followed with Dactylopius opuntiae, Ckl. will be described later in the text.
4. As far as possible, only insects feeding normally for 24 hours prior to the commencement of the experiments, were included in the tests.
5. The mortality figures presented in the tables have all been corrected for normal mortality by means of Abbot's formula.

RED SPIDER (Tetranychus bimaculatus, Harvey.).

This mite is extremely abundant at certain times in most parts of South Africa. It is common on Cape gooseberry, plum, peach, beans, violets, cotton, tomato, sweetpeas, holly-hock and many other plants are often found to be heavily infested.

The adult female varies greatly in colour, being sometimes greenish or yellowish but most often brick red. The adult male is paler in colour.

The female lays 50 to 100 eggs after which

she dies. The eggs hatch in from four to five days in summer and the young six-legged nymphs appear. The mites have sucking mouthparts and puncture the surface of the leaves to suck the sap. The presence of mites soon becomes evident by the white, bleached appearance of the leaves which later turn brown and fall off.

Considerable work on the control of Tetranychus bimaculatus with new synthetic insecticides has been done in recent years by Boyce et al. 1939, Kearns et al. 1945, Hey, 1946, Haring 1946, Ludvik and Decker 1947, Roark 1948, Hockett 1948, Hough 1948, and Petty 1948. Insecticides such as elemental sulphur and those containing dinitro compounds (dinitro-ortho-cyclohexyl phenol and its amine salt), and Azobenzene have given promising results although somewhat variable. In laboratory and field tests, the writer has found D.D.T., B.H.C., chlordane and toxaphene to be relatively ineffective against this pest and in fact, there is definite evidence that the use of D.D.T. is often followed by heavy outbreaks of this mite.

Extensive experiments are at present being carried out by the writer on the control of Tetranychus bimaculatus with the phosphorus compounds " hexaethyl tetraphosphate ", tetraethyl pyrophosphate and parathion. Work is also in progress with certain of the systemic insecticides including bis(bis dimethylamino phosphonous) anhydride. These tests have not yet reached finality, but sufficient data are available to indicate that sprays containing " hexaethyl tetraphosphate " and tetraethyl pyrophosphate diluted to concentrations of 1 to 1200 and 1 to 2000 respectively with water, are highly effective. Parathion too, formulated as a 1 per cent dusting powder or as a wettable powder and used at a concentration of 0.03 per cent, has given excellent control. Highly promising results are also being obtained with bis(bis dimethylamino phosphonous) anhydride. This material used at a concentration of 0.2 and 0.4 per cent has given effective control for a period of ten days.

III.

"Hexaethyl tetraphosphate " and tetraethyl pyrophosphate have little, if any ovicidal action, and since their toxicity disappears rather rapidly through hydrolysis after application, there is no residual effect. Parathion, on the other hand, has shown evidence of possessing some ovicidal properties and in addition has definite residual action which exerts a toxic effect on the nymphs which do emerge from the eggs.

ELEGANT GRASSHOPPER (*Zonocerus elegans*, Thunb.).

The Elegant grasshopper, also known as the " Stinksprinkaan ", often does a great deal of damage to lands, gardens and orchards by its attack on a variety of plants. The favourite plant for young hoppers is the common milkweed (*Asclepias fruticosa*), although both nymphs and adults will eat almost any plant product.

The adults are brightly coloured green, yellow and pink insects. They are never strong fliers, and in the majority the wings are rudimentary or undeveloped. They do not form definite swarms, but tend to congregate in small groups at nightfall. The female lays her eggs in the ground during Autumn and these hatch the following Spring. The newly emerged hoppers are black with yellow stripes and markings on their bodies, and they cluster closely together on plants a few days after hatching.

From the control point of view, the best times to apply poisons are when the insects congregate at nightfall or when they are clustered in their young stages.

The insecticides tested were 5 per cent and 10 per cent B.H.C., 10 per cent D.D.T., 5 per cent chlordan and 2 per cent parathion. They were used as dusts and were applied at the rate of 0.16 mg. and 0.22 mg. per sq. cm. which is the equivalent of 15 and 20 pounds per acre in field application.

Three groups of 30 test insects were used for each insecticide and there were five replications of each experiment. The total number of test insects for each insecticide was, therefore, 450.

RESULTS .

The results obtained with the different dusts are given in Table 24.

TABLE 24.

Insecticides.	Age of insects	Dosage. Lb. per acre.	Percentage final mortality.	Time required for final mortality.
5% B.H.C.	Half grown hoppers.	15	26.6	48 Hours.
10% B.H.C.			100.0	24 "
10% D.D.T.			16.6	48 "
5% Chlordane.			100.0	48 "
2% Parathion.			100.0	24 "
5% B.H.C.	Half grown hoppers.	15	33.3	48 "
10% B.H.C.			100.0	48 "
10% D.D.T.			13.3	48 "
5% Chlordane.			100.0	48 "
2% Parathion.			100.0	24 "
5% B.H.C.	Three quarter grown hoppers	15	26.6	48 "
10% B.H.C.			80.0	48 "
10% D.D.T.			10.0	48 "
5% Chlordane.			96.6	48 "
2% Parathion.			100.0	48 "
5% B.H.C.	Three quarter grown hoppers.	20	16.6	48 "
10% B.H.C.			100.0	24 "
10% D.D.T.			13.3	48 "
5% Chlordane.			100.0	48 "
2% Parathion.			100.0	24 "
5% B.H.C.	Adults.	20	40.0	48 "
10% B.H.C.			96.6	48 "
10% D.D.T.			-	-
5% Chlordane.			96.6	48 "
2% Parathion.			100.0	24 "
5% B.H.C.	Adults.	20	33.3	48 "
10% B.H.C.			100.0	48 "
10% D.D.T.			-	-
5% Chlordane.			96.6	48 "
2% Parathion.			100.0	24 "

Control mortality = 0.0 per cent.

CONCLUSIONS.

- a. Taking into consideration rapidity of action and final mortality, parathion at 2 per cent concentration is superior to 5 and 10 per cent B.H.C., 10 per cent D.D.T. and 5 per cent chlordane.

spots. They assist in the damage but the greatest injury is caused by the shiny, mahogany coloured nymphs which puncture the plant tissue and feed on the plant juices.

Up to the present the bugs have proved to be highly resistant to all the insecticides used and in view of the fact that none has effectively controlled them, laboratory experiments were undertaken to determine the relative efficacy of D.D.T., B.H.C. and pyrethrum dusts. The powders were used at a concentration of 5 per cent, the diluent in every case being a mixture of china clay and gypsum. They were applied at the rate of 0.11 mg. and 0.22mg. per sq. cm., which is the equivalent of 10 and 20 pounds per acre respectively in field applications. The only spraying tests were done with a D.D.T. emulsion consisting of 25 parts D.D.T., 68 parts medium solvent naphtha and 7 parts Triton X-100 as the emulsifier. This was diluted with water to a concentration of 0.2 per cent D.D.T. The bugs were bred on stock plants, hence these were used as the food plant throughout all the experiments.

The experimental procedure was as follows:-

- a. Foliage and bugs were dusted, and the bugs were confined to the dusted foliage for 24 hours.
- b. Foliage only was dusted, and untreated bugs were confined to the treated foliage for 24 hours.
- c. Bugs only were dusted, and were exposed to the insecticide for 15 minutes. Thereafter they were confined to untreated foliage for 24 hours

adult

Three groups of 40/Bagrada bugs were used for each insecticide in each experiment which was replicated five times. The total number of test insects used for each insecticide was, therefore, 600.

RESULTS.

The results obtained with the dusts are presented in Table 25.

TABLE 25.

Insecticides.	Dosage. Lb. per acre.	Treatment.	Percentage final mortality.	Time required for final mortality.
5% B.H.C.	10	Foliage and bugs dusted.	100.0	48 Hours.
		Foliage dust- ed.	75.0	48 "
		Bugs dusted.	40.0	96 "
5% B.H.C.	20	Foliage and bugs dusted.	100.0	48 "
		Foliage dust- ed.	100.0	48 "
		Bugs dusted.	50.0	96 "
5% D.D.T.	10	Foliage and bugs dusted.	90.0	96 "
		Foliage dust- ed.	62.1	96 "
		Bugs dusted	31.8	144 "
	20	Foliage and bugs dusted.	90.0	72 "
		Foliage dust- ed.	83.4	96 "
		Bugs dusted.	41.6	96 "
5% Pyrethrum.	10	Foliage and bugs dusted.	0.0	-
		Foliage dust- ed.	0.0	-
		Bugs dusted.	0.0	-
5% Pyrethrum.	20	Foliage and bugs dusted.	0.0	-
		Foliage dust- ed.	0.0	-
		Bugs dusted.	0.0	-

Average control mortality = 2.5 per cent.

Control mortality range = 0.0 to 5.0 per cent.

Three groups of 100 adult aphids were used for each insecticide in each experiment which was replicated five times. The total number of test insects was, therefore, 1500 for each insecticide.

RESULTS.

The results of these tests are given in Table 26.

TABLE 26.

Insecticides.	Dosage. Lb. per acre.	Percentage final mort- ality.	Time required for final mortality.
5% B.H.C. 5% D.D.T. 4% Nicotine. 2% Parathion.	15	83.4 66.7 100.0 98.8	72 Hours. 72 " 24 " 48 "
5% B.H.C. 5% D.D.T. 4% Nicotine. 2% Parathion.	15	94.6 87.5 100.0 100.0	72 " 96 " 24 " 48 "
5% B.H.C. 5% D.D.T. 4% Nicotine. 2% Parathion.	15	93.7 84.3 100.0 99.4	48 " 72 " 24 " 48 "
5% B.H.C. 5% D.D.T. 4% Nicotine. 2% Parathion.	20	100.0 87.5 100.0 100.0	48 " 72 " 24 " 48 "
5% B.H.C. 5% D.D.T. 4% Nicotine. 2% Parathion.	20	96.7 90.4 100.0 100.0	48 " 72 " 24 " 48 "

Average control mortality = 5.1 per cent.

Control mortality range = 2.5 to 7.5 per cent.

CONCLUSIONS.

- Nicotine, B.H.C. and D.D.T. are all highly toxic to the aphids at the concentrations and rates of application used.

- b. Taking rapidity of action and final mortality into consideration, 4 per cent nicotine dust is superior to 2 per cent parathion, 5 per cent B.H.C. and 5 per cent D.D.T.
- c. 2 Per cent Parathion is more effective than 5 per cent B.H.C. and 5 per cent D.D.T.
- d. B.H.C. causes a quicker rate of mortality and a higher ^{final} rate of mortality than does 5 per cent D.D.T.
- e. The results suggest that 4 per cent nicotine, 2 per cent parathion, 5 per cent B.H.C. and 5 per cent D.D.T. dusts should be effective in reducing infestations of Aphis craccivora when applied at the rate of 15 to 20 pounds per acre. The insecticides are named in order of effectiveness.

WATTLE JASSID (*Bythoscopus cedaranus*, Naudé.) and WATTLE CAPSID (*Lygidolon laevigatum*, Reut.).

" Froghopper " damage in wattles is caused principally by the large green jassid, *Bythoscopus cedaranus*, Naudé, and a capsid bug, *Lygidolon laevigatum*, Reut. The trouble usually affects only young trees up to two years old. The saliva injected by the insects, while feeding on the foliage poisons the cells, causing dead spots to appear on the leaflets followed by leaf-shedding. When a terminal leaf bud is poisoned in this way, several leaders grow out instead of a single branch, resulting in undesirable crooking of the timber and a severe set-back to growth. In certain areas where wattles are grown, jassid and capsid attacks are considered to be a more serious threat to the trees than bagworm damage.

A certain proprietary pyrethrum powder diluted with talc to contain 0.1 per cent of pyrethrins was found

to be fairly satisfactory against these pests . (Ripley and Petty, 1940). It was felt, however, that the degree of control obtained with this insecticide could be improved upon, and laboratory tests were, therefore, undertaken in order to determine the toxicity of D.D.T. to these insects. Unfortunately the pyrethrum dust previously used was unobtainable, and so pyrethrum powder obtained from locally grown flowers was substituted. In the majority of the experiments only the insects were dusted, at the rate of 0.16 mg. per sq. cm. or 15 pounds per acre. In a few experiments, however, in an endeavour to approximate field conditions more closely, both the insects and the wattle foliage on which they were fed were treated at the same rate of application, and the insects were confined to the dusted leaves for twelve hours.

Three groups of 50 insects were used for each insecticide in all the experiments and at least one concentration of each insecticide was replicated five times, making a total of 750 test animals.

The following insecticides were tested:-

- a. 0.5 per cent pyrethrum in talc.
- b. 1.0 " " " " "
- c. 2.0 " " " " "
- d. 3.0 " " " " "
- e. 5.0 " " " " "
- f. 2.0 per cent D.D.T. in talc.
- g. 3.0 " " " " "
- h. 5.0 " " " " "

The first series of experiments was carried out with jassid and capsid adults, and the results are given in Table 27.

TABLE 37.

Experiment No.	Jassid Adults.								Capsid adults.				
	Percentage					Mortality.			Percentage		Mortality		
	0.5% Pyreth- -rum.	1.0% Pyreth- -rum.	2.0% Pyreth- -rum.	3.0% Pyreth- -rum.	5.0% Pyreth- -rum.	2.0% D.D.T.	3.0% D.D.T.	5.0% D.D.T.	0.5% Pyreth- -rum.	1.0% Pyreth- -rum.	2.0% Pyreth- -rum.	5.0% Pyreth- -rum.	5.0% D.D.T.
I	70.6	91.8	90.8	-	100.0	48.0	-	-	18.6	71.2	82.3	100.0	-
2	72.4	92.1	91.7	-	100.0	43.6	-	47.6	25.0	81.4	89.5	100.0	50.0
3	-	-	100.0	100.0	100.0	39.1	49.1	50.0	-	-	100.0	100.0	63.2
4	-	-	98.5	100.0	100.0	42.1	52.2	55.6	-	-	98.4	100.0	47.4
5	-	-	93.4	-	100.0	45.6	-	57.2	-	-	83.3	100.0	56.2
6	-	-	-	-	100.0	-	-	67.8	-	-	-	100.0	65.4

Average control mortality :- 4.5 per cent. Control mortality range :- 1.5 to 7.5 per cent.

CONCLUSIONS.

- a. From the data presented in Table 27, it would appear that the adult capsids are more resistant to pyrethrum dusts than are the jassids, but that both are equally susceptible to D.D.T.
- b. It is evident that the pyrethrum dusts, even at the lowest concentrations used, are considerably more toxic than the powders containing D.D.T.

Work done by the writer in previous years showed that both jassid and capsid nymphs are more susceptible to pyrethrum dusts than are the adult insects, a dosage of 0.16 mg. per sq. cm. killing 70 per cent of adult jassids, a somewhat lower percentage of adult capsids, and 90.0 to 100.0 per cent of jassid and capsid nymphs. Since dusting for the control of these pests should be done when most of the insects are in the nymphal stage in order to ensure satisfactory control and protection of the wattle trees, experiments were carried out to ascertain the relative susceptibility of adults and nymphs, of both jassids and capsids, to D.D.T. dusts. Only the insects were treated, and the number of test animals and replications were the same as in the previous experiment.

RESULTS.

The results are presented in Table 28.

TABLE 28.....

TABLE 28.

Experiment No.	JASSIDS.						CAPSIDS.					
	Adults.			Nymphs.			Adults.			Nymphs.		
	Percentage Mortality			Percentage Mortality			Percentage Mortality			Percentage Mortality		
	5% D.D.T.	3% D.D.T.	2% D.D.T.	5% D.D.T.	3% D.D.T.	2% D.D.T.	5% D.D.T.	3% D.D.T.	2% D.D.T.	5% D.D.T.	3% D.D.T.	2% D.D.T.
I	60.8	-	55.8	63.6	-	51.4	68.0	48.5	-	80.0	61.2	-
2	72.4	-	-	64.0	-	-	81.5	-	-	90.7	-	85.0
3	66.6	58.4	48.6	71.9	56.2	58.6	64.5	-	42.5	82.6	-	87.5
4	62.6	73.4	-	70.2	74.5	-	69.0	71.5	-	96.0	92.4	-
5	71.4	-	-	74.8	-	-	64.0	-	-	83.4	-	-

Average control mortality :- 5.5 per cent. Control mortality range :- 2.5 to 6.2 per cent.

CONCLUSIONS.

- a. The figures given in Table 28 confirm the conclusions drawn from the previous experiment, namely, that adult jassids and capsids are approximately equally susceptible to D.D.T. dusts.
- b. Jassid nymphs are no more easily killed than are the adults. The capsid nymphs, on the other hand, are strikingly less resistant to D.D.T. than are the adult insects.

In the experiments just described, only the insects were dusted and it follows, therefore, that under field conditions, where both insects and foliage receive the insecticidal deposits, a higher percentage kill might well be expected. In order to obtain more definite information on this point, tests were carried out in which insects only and insects and foliage were dusted.

Three groups each of 50 jassid adults, jassid nymphs, capsid adults and capsid nymphs were used in each experiment which was replicated five times.

The results of these tests are summarised in Table 29.

TABLE 29.

Insecticide.	Dosage. Lb. per acre.	Treatment.	Percentage Mortality.			
			Jassid adults.	Jassid nymphs.	Capsid adults.	Capsid nymphs.
5% D.D.T.	15	Insects dusted.	65.6	67.4	69.4	88.6
5% D.D.T.	15	Insects and fol- iage dus- ted.	86.2	88.7	86.7	100.0

Average control mortality = 5.0 per cent.

Control mortality range = 2.5 to 7.5 per cent.

CONCLUSIONS.

- a. As would be expected, a considerably higher mortality figure is obtained when the insects and foliage are dusted than when the jassids and capsids alone are treated.
- b. The results indicate that whereas 5 per cent D.D.T. dust is not as toxic to wattle jassids and capsids as pyrethrum powder, it could, nevertheless, probably be used under field conditions with a fair measure of success in controlling these insects. Field experiments are required, however, before any definite recommendations can be made regarding the use of D.D.T. on a commercial scale.

COCHINEAL (*Dactylopius opuntiae*, Ckl.).

The cochineal, *Dactylopius opuntiae*, Ckl., is causing serious damage to spineless cactus, with the exception of the round, bluish-green, thick leaved varieties, throughout South Africa. It was first imported to the Union from Australia in 1937 to aid in the destruction of the common pest pear *Opuntia megacantha*. The insect was reared at Uitenhage and was distributed from 1940 to 1944 in areas where prickley pear had become a menace. The insects spread rapidly and proved to be highly effective in destroying the prickley pear, but unfortunately they were found to thrive and increase rapidly on spineless cactus varieties cultivated for fodder.

Laboratory and small scale field tests were undertaken by the writer with a view to finding an effective insecticide for the control of *Dactylopius opuntiae* on spineless cactus plantations (Petty, 1946). The insecticides tested included various oil sprays, pentachlorophenol and different D.D.T. formulations. Certain of the oil sprays and pentachlorophenol proved to be efficacious in killing the insects but

caused such severe damage to the plants that they were discarded. D.D.T. wettable powder killed the larvae, but was relatively ineffective against the mature insects. Several D.D.T. emulsion concentrates were tested, and as a result of these tests, a concentrate containing 25 per cent D.D.T., 10 per cent Triton X-100 and 65 per cent medium solvent naphtha, diluted to contain 2 per cent of D.D.T., was found to be the most effective of the formulations used.

Subsequent large scale field experiments carried out with D.D.T. wettable powder and the emulsion concentrate, fully confirmed the results obtained in the preliminary tests.

Owing to the expense of the material, however, the use of the D.D.T. emulsion is only practical before the cochineal infestation has become extensive. In view of this fact and with the discovery of newer insecticides, further investigations were carried out by the writer in the hope of finding a more economical method of controlling this insect.

LABORATORY EXPERIMENTS.

The insecticides tested were:-

- a. B.H.C. wettable powder diluted to contain 0.005% Gamma isomer
- b. " " " " " " 0.02% " "
- c. Parathion wettable powder diluted to contain 0.03% Parathion.
- d. " " " " " " 0.015% Parathion
- e. " " " " " " 0.0075% "
- f. D.D.T. wettable powder diluted to contain 0.1% D.D.T.
- g. " emulsion concentrate diluted to contain 1.0% D.D.T.

METHODS.

Leaf pads infested with cochineal were collected in the field. From each leaf, eight squares $2\frac{1}{2} \times 2\frac{1}{2}$ inches were cut, each square having 15 cochineal colonies of approximately the same size, on one surface. There were approximately

eight adult insects in each of the 15 colonies. The cochineal on the other side of the leaf squares were removed. Seven of the squares were sprayed with the insecticides under investigation and the eighth was sprayed with water and retained as a control. There were eight replications for each experiment. The number of adult test insects was, therefore, in the region of 960 for each insecticide, but the number of immature crawlers was considerably in excess of this figure.

The leaf squares were suspended on thin wire and both sides were sprayed at 10 pounds pressure per sq. inch with a Prima sprayer, the nozzle being held at a distance of one foot from the surface to be treated. Each side of the leaf was exposed to the spray for five seconds.

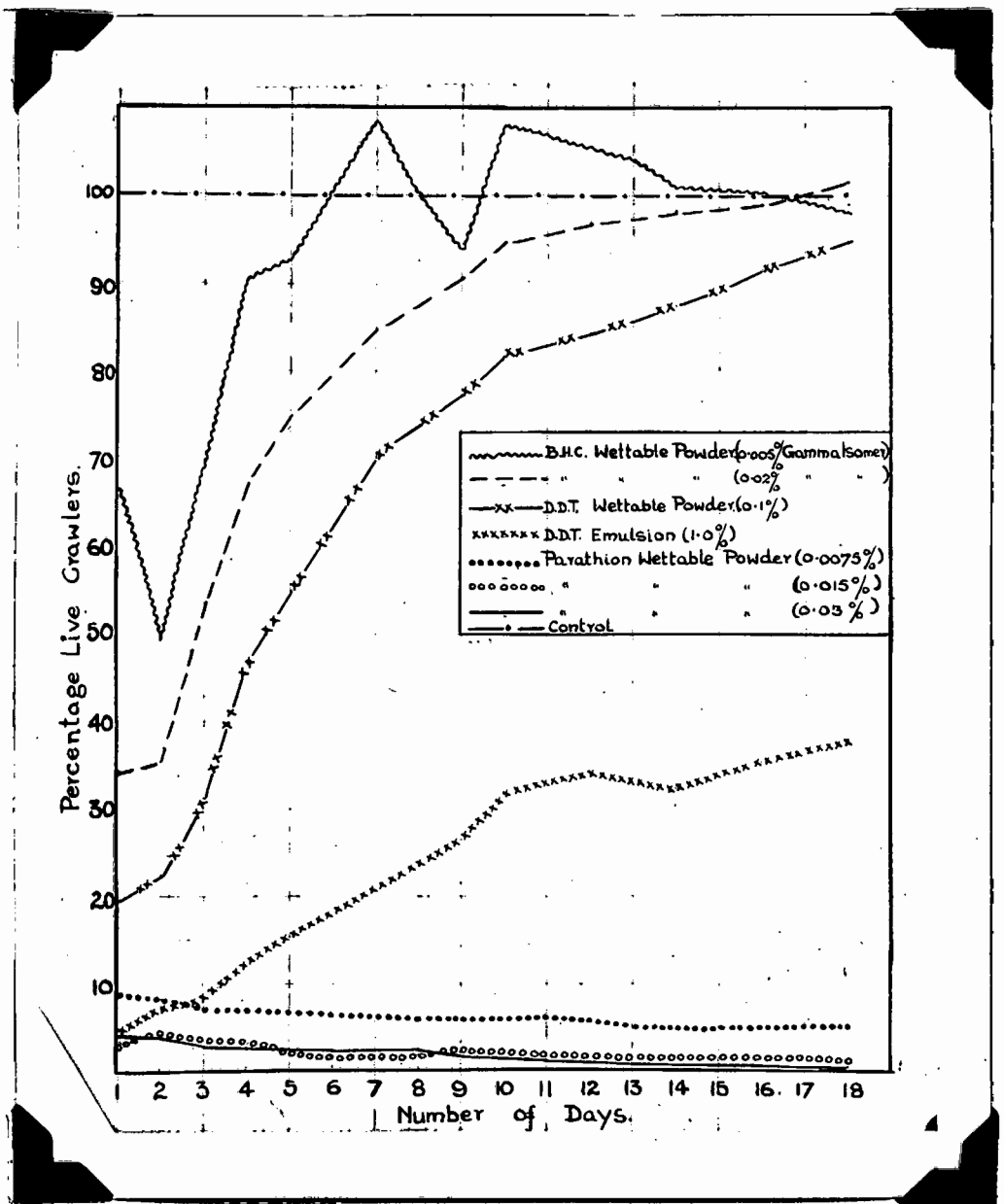
The sprayed squares were immediately transferred to the constant temperature and humidity chamber and placed on separate sheets of white paper. The squares were surrounded by a band of Oetico to prevent any crawlers leaving the leaves from escaping. At 24 hourly intervals, all live crawlers were removed from treated and control leaf squares, and also from the papers, and the numbers were recorded. After 18 days, the cochineal colonies were microscopically examined to determine the percentage mortality of mature insects.

RESULTS.

The data are presented in the form of a graph and two tables. Graph 5 represents the relative efficacy of the seven insecticidal formulations when applied in the manner previously described.

In order to minimize the error in comparing results obtained at various times from different experiments, they are all expressed relative to the untreated controls which are arbitrarily placed at 100. The graph shows the percentage of live crawlers on the variously treated leaves as they varied from day to day, always relative to those found on the untreated

LABORATORY TESTS WITH COCHINEAL.



GRAPH 5.

leaves. The figures on which the graph is based represent the averages obtained from the eight replications.

CONCLUSIONS.

- a. At the concentrations and rates of application used, B.H.C. is less effective than the other insecticides tested. As would be expected, the higher concentration is superior to the lower one, reducing the number of live crawlers to below that on the untreated leaves for a period of 16 days as compared with only 6 days with the 0.005 per cent concentration.
- b. 0.1 Per cent D.D.T. wettable powder is superior to 0.02 per cent Gamma B.H.C., and causes a reduction in the crawler population for at least 18 days. 1.0 per cent D.D.T. emulsion is markedly more effective than the D.D.T. wettable powder, there being only 38 per cent live crawlers at the end of 18 days with this treatment as compared with 94 per cent with the water suspension over the same period.
- c. Parathion is outstanding among the other insecticides tested. There appears to be no significant difference between the 0.03 and 0.015 per cent concentrations, while the 0.0075 per cent concentration is only slightly less effective. With the two higher concentrations, no live crawlers could be found after the tenth day.

The percentage mortality of mature cochineal insects as revealed by microscopic examination 18 days after the application of the insecticides is given in Table 30.

TABLE 30.....

TABLE 30.

Time after spray- ing.	Percentage Mortality Of Mature Cochineal Insects.							
	Wettable			Powders.			Emul- sion.	Con- trol.
	B.H.C. 0.005%	B.H.C. 0.02%	D.D.T. 0.1%	Para- thion. 0.03%	Para- thion. 0.015%	Para- thion. .0075%	D.D.T. 1.0%	Water.
18 Days.	18.7	23.7	32.4	100.0	95.7	90.6	85.4	5.6

Additional evidence regarding the efficacy of the different insecticidal formulations is given in Table 31, where the average number of live crawlers found on the variously treated leaf squares, over a period of 18 days is given.

TABLE 31.

Dur- ation of expt.	Number Of Crawlers On Leaf Squares Over 18 Day Period.							
	Wettable			Powders.			Emul- sion.	Con- trol.
	B.H.C. 0.005%	B.H.C. 0.02%	D.D.T. 0.1%	Para- thion. 0.03%	Para- thion. 0.015%	Para- thion. .0075%	D.D.T. 1.0%	Water.
18 Days.	2243	1556	1398	26	31	150	669	2296

GENERAL CONCLUSIONS ON LABORATORY STUDIES.

- a. The evidence suggests that neither D.D.T. or B.H.C., formulated as wettable powders, at the concentrations and rate of application used, is satisfactory for the control of cochineal. Both insecticides kill the nymphs but are relatively ineffective against the mature insects, presumably because they do not penetrate the

No rainfall or cloudy weather was recorded during the duration of the experiment, hence further tests under varying weather conditions will be necessary before the practical value of parathion suspension sprays can be fully determined.

It must be emphasized that the sprayed plants were surrounded by heavily infested, untreated spineless cactus, hence the chance of the treated leaf pads becoming reinfested was much greater than under practical control conditions where all infested areas would be sprayed.

RESULTS.

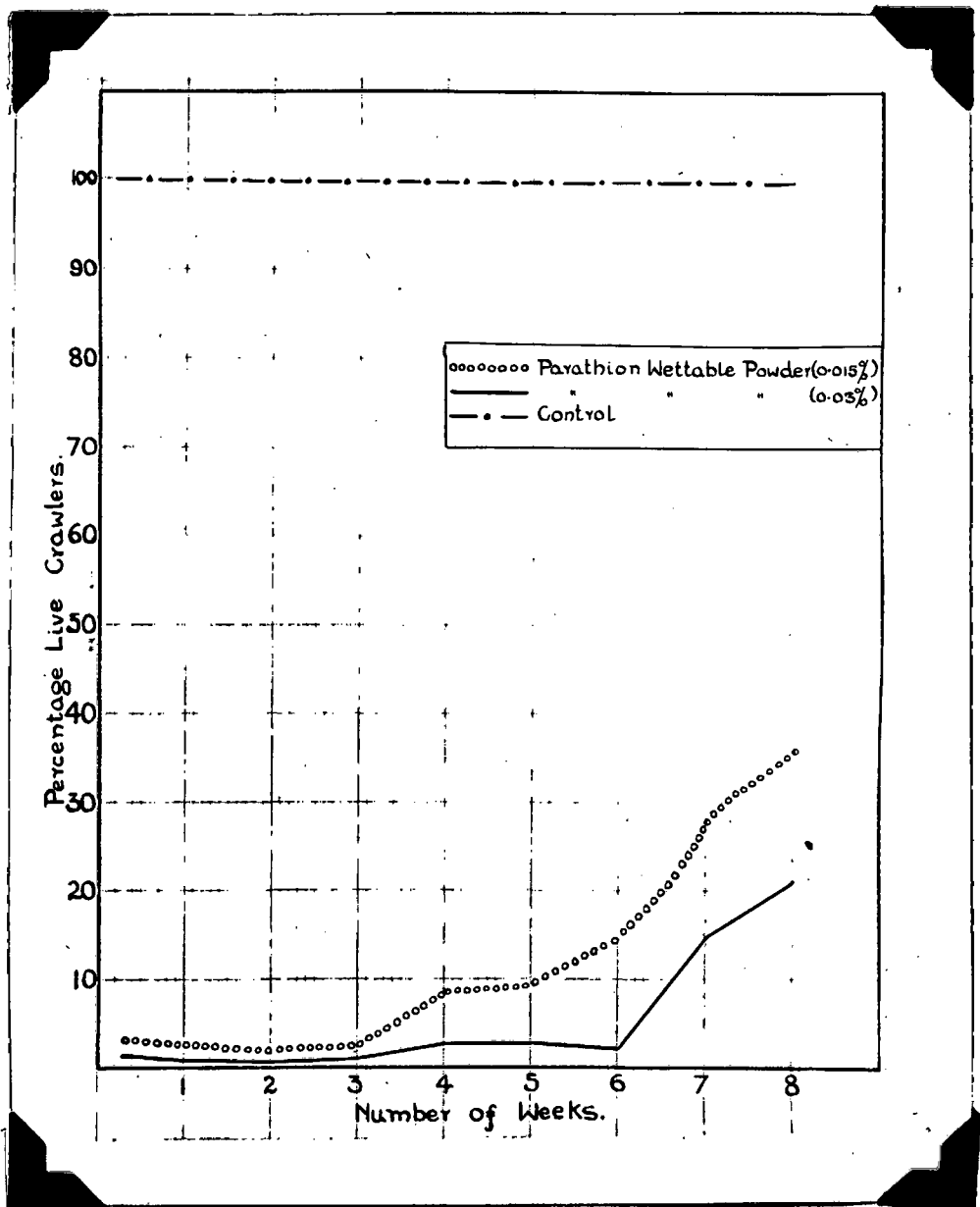
The relative efficacy of the two parathion sprays under the practical conditions encountered during the course of this experiment, are presented in Graph 6. As in the case of the laboratory tests, the graph shows the percentage of live crawlers on the sprayed leaves relative to those on the untreated controls, which are arbitrarily placed at 100. The figures on which the graph is based represent the average number of crawlers in three replications for each experiment.

Conclusions.

A study of Graph 6 indicates that:-

- a. Concentrations of 0.015 and 0.03 per cent parathion wettable powder are both highly toxic to Dactylopius opuntiae.
- b. For the first three weeks there is little difference in the relative efficacy of the two concentrations used, as represented by the number of live crawlers, although the 0.03 per cent concentration is superior to the weaker one. This is in agreement with the laboratory experiments (Graph 5), although there the difference is less marked. After the three week period, however, 0.03 per cent parathion shows marked superiority over the 0.015

FIELD TESTS WITH COCHINEAL.



GRAPH 6.

per cent concentration.

- c. For satisfactory cochineal control, the parathion spray should be applied as soon as an appreciable number of larvae appear on the leaf pads of infested plants. A second application of the 0.015 per cent concentration should be made approximately four weeks later while, in the case of the 0.03 per cent spray, a second application is not required before six or seven weeks.

The number of applications will depend largely on the pressure used for spraying and on how well the insect has become established. After considering the results obtained in field experiments with D.D.T. (Pettey, 1948), which is inferior to parathion for cochineal control, it is thought doubtful whether more than two or three treatments will be necessary in the course of a season, even when heavy infestations are encountered.

The percentage mortality of mature cochineal insects found on the treated leaf pads 18 days after the application of the sprays, is given in Table 32.

TABLE 32.

Time after spraying.	Percentage Mortality Of Mature Cochineal.	
	0.03% Parathion wettable powder.	0.015% Parathion wettable powder.
18 Days.	95.7	84.6

Average control mortality = 4.9 per cent.

Control mortality range = 3.6 to 8.4 per cent.

As was previously mentioned, leaf squares were cut from plants in the field two days after spraying and thereafter at weekly intervals. Daily records were made of the

numbers of live crawlers on treated and untreated leaf samples for each weekly collection over a period of 18 days. In order to give a clearer picture of the relative efficacy of the two parathion sprays, the average number of crawlers found per leaf square from treated and untreated plants for each collection over the 18 day period, are given in Table 33.

TABLE 33.

Time of collection after spraying.	Average Number Of Live Crawlers Per Leaf Square Over 18 Day Period.		
	0.03% Parathion wetable powder.	0.015% Parathion wetable powder.	Control.
2 Days	2	8	2473
1 Week.	1	22	2083
2 Weeks.	2	20	1823
3 Weeks.	4	56	2658
4 Weeks.	66	148	2099
5 Weeks.	119	431	3616
6 Weeks.	146	500	4209
7 Weeks.	267	697	3174
8 Weeks.	315	713	3671
Totals.	922	2,595	25,806

In conclusion, it would appear safe to state that parathion wettable powder, applied at low concentrations, offers greater promise for the control of Dactylopius opuntiae in spineless cactus plantations than any other insecticide thus-far tested.

THE AMERICAN BOLLWORM (*Heliothis armigera*, Fabr.).

The American bollworm, *Heliothis armigera*, Fabr., is a pest of great economic importance in South Africa and in other parts of the world. It is commonly found attacking not only cotton but also lucerne, maize, tomatoes, peas and citrus. It causes a good deal of damage to ordinary garden plants and is a serious pest in buds of carnations. It is known under a variety of names, such as tassel worm or ear worm of maize, tomato fruit worm etc.

A great deal of preliminary research work on the relative toxicity of the newer insecticides, D.D.T., B.H.C., chlordane, toxaphene and parathion to the American bollworm has been done in recent years in different parts of the world, and promising results have been obtained with some of the materials. (Stevenson et al., 1944; Ivy et al., 1945; Ivy, 1947; Parencia et al., 1946; Floyd, 1947; Petty, 1948; Butler and Carruth, 1949; U.S.D.A. report, 1950).

The insecticides tested in the experiments now to be described were 2 per cent parathion, 5 per cent B.H.C., 5 per cent chlordane, 5 per cent D.D.T. and natural cryolite applied as dusts at the rate of 0.22 mg. per sq. cm., which is equivalent to a field application of 20 pounds per acre.

Both the caterpillars and their food plant, in this case, fresh maize cobs, were dusted, and the larvae were confined in cages with the treated food for 24 hours. Thereafter they were transferred to clean cages and fed on untreated maize cobs.

Three groups of half grown larvae, 30 to each group, were used for each insecticide in each experiment which was replicated five times. The total number of test insects for each insecticide was, therefore, 450.

RESULTS.

The results obtained are summarized in Table

TABLE 34.

Insecticides.	Dosage. Lb. per acre.	Percentage final mortality.	Time required for final mortality.
5% B.H.C.	20	71.7	48 Hours.
5% D.D.T.	20	99.6	48 "
5% Chlordane.	20	84.4	48 "
2% Parathion.	20	92.4	48 "
Natural cryo- lite.	20	91.7	96 "

Average control mortality = 2.4 per cent.

Control mortality range = 0.0 to 6.6 per cent.

CONCLUSIONS.

- a. D.D.T. is more effective than parathion, natural cryolite chlordanes and B.H.C. at the concentration and rate of application used.
- b. 2 per cent parathion and natural cryolite cause similar final mortalities, but cryolite is slower in action than parathion.
- c. 5 Per cent chlordanes is less toxic to Heliothis armigera than either cryolite or 2 per cent parathion, while B.H.C. proved to be the least effective of the insecticides tested.
- d. The results suggest that control of the American bollworm should be obtained by the application of 5 per cent D.D.T., 2 per cent parathion, natural cryolite or chlordanes dusts when applied at the rate of 20 pounds per acre. At the rate of application used, 5 per cent B.H.C. was too weak a concentration for effective control.

THE PINE BROWN TAIL MOTH (*Euproctis terminalis*, Walk.).

Euproctis terminalis, Walk., popularly known as the pine brown tail moth, is indigenous to South Africa and is one of the most serious pests of conifers in the Union. It is responsible for defoliating hundreds of acres of pines, and has a widespread distribution. The defoliation of the trees causes a severe set-back to growth and results in loss of increment and vigour.

Extensive experiments on the control of *Euproctis terminalis* by chemical means were started as early as 1931 and an account of this work was given by Tooke in 1938. It was found that calcium and lead arsenates were, at that time, the most promising insecticides for the control of this pest. In recent years, however, the search for new insecticides has resulted in the release of several new compounds into the field of chemical control of insects, and as it was felt that these might prove more effective than the insecticides previously used, laboratory tests were undertaken with those which were available.

The insecticides tested were 5 per cent D.D.T., 5 per cent B.H.C., 5 per cent chlordane, 5 per cent toxaphene and lead arsenate applied as dusts at the rate of 0.16 mg. per sq. cm., which is the equivalent of 15 pounds per acre in field application.

Both the insects and the pine needles on which they were fed were dusted. The larvae were isolated in glass specimen tubes plugged with cotton wool, and were fed for 24 hours on pine needles dusted with the insecticides under investigation. Thereafter they were transferred to clean tubes containing fresh, untreated food.

Three groups of 40 fourth instar larvae were used for each insecticide in each experiment which was replicated five times. The total number of test insects used for each

insecticide was , therefore, 600.

RESULTS.

The results obtained with the different insecticides are presented in Table 35.

TABLE 35.

Insecticides.	Dosage. Lb. per acre.	Percentage final mortality.	Time required for final mortality.
5% B.H.C.	15	51.4	120 Hours.
5% D.D.T.	15	80.2	120 "
5% Chlordane.	15	43.3	120 "
5% Toxaphene.	15	89.6	120 "
Lead arsenate.	15	81.3	168 "

Average control mortality = 5.0 per cent.

Control mortality range = 0.0 to 7.5 per cent.

CONCLUSIONS.

- a. D.D.T., toxaphene and lead arsenate are more effective than B.H.C. and chlordane at the concentration and rate of application used in the tests.
- b. 5 Per cent toxaphene is slightly more toxic than either 5 per cent D.D.T. or lead arsenate. The latter two insecticides produce similar final mortalities, but D.D.T. is more rapid in action than lead arsenate.
- c. 5 Per cent B.H.C. is more effective than 5 per cent chlordane.
- d. The results suggest that, of the insecticides tested,

toxaphebe, D.D.T. and lead arsenate will afford more effective control against Euproctis terminalis than either B.H.C. or chlordane.

ARMY WORM (*Laphygma exempta*, Walk.).

The army or mystery worm is one of the most serious pests of grain, pastures and forage crops in South Africa. Dusting with natural cryolite was found to be an effective method of controlling this pest (Hattingh, 1941). With the discovery of such new insecticides as D.D.T. and B.H.C., however, it was considered that better control might be achieved with these materials, and laboratory experiments were carried out to determine their toxicity relative to that of cryolite.

The insecticides tested included 5 and 10 per cent D.D.T., 5 per cent B.H.C. and natural cryolite applied as dusts at the rate of 0.16 mg. per sq. cm. which is equivalent to a field application of 15 pounds per acre.

Third to sixth instar worms were used in order to determine the relative susceptibility of the different instars to the poisons. Both the caterpillars and their food plant were dusted and 30 larvae were confined in each cage with the dusted forage for 24 hours, three cages being used for each insecticide with five replications of each experiment. 450 test insects were used, therefore, for each insecticide. After the period of exposure to the poisons, the worms were transferred to clean cages with untreated food.

RESULTS.

The results obtained are presented in Table 36.

TABLE 36.

Insecticides.	Dosage. Lb. per acre.	Percentage Final Mortality.			
		3rd. instar worms.	4th. instar worms	5th. instar worms	6th. instar worms.
5% D.D.T.	15	98.9	97.5	65.5	35.2
10% D.D.T.	15	100.0	-	64.2	48.2
5% B.H.C.	15	72.4	60.0	45.3	37.4
Natural cryolite.	15	100.0	94.0	88.9	91.3

Average control mortality = 3.2 per cent.

Control mortality range = 0.0 to 6.6 per cent.

CONCLUSIONS.

- a. Up to the fourth instar, D.D.T. is just as effective as cryolite as regards the final mortality produced but it is more rapid in action.
- b. For the later instars, cryolite is definitely superior to D.D.T., both as regards rapidity of action and final mortality.
- c. 10 per cent D.D.T dust is not sufficiently more toxic than the 5 per cent concentration to warrant its use.
- d. B.H.C. is inferior to D.D.T. and cryolite at the rate of application and concentration used.
- e. The results indicate that good control of the army worm, Laphygma eximpta may be obtained with natural cryolite and 5 per cent D.D.T. dusts up to the fourth instar. For older larvae, however, cryolite is the more toxic insecticide. B.H.C. at 5 per cent concentration is inferior to both D.D.T and cryolite for all stages of

development.

Unpublished results of field experiments undertaken by van de Linde, of the Division of Entomology, Pretoria, confirmed the fact that D.D.T. dusts afford an effective control measure only up to the fourth instar.

In all the laboratory experiments, cryolite appeared to be more repellent than the other insecticides tested. This was especially the case with the last two instars, where the forage treated with D.D.T. was much more readily eaten than that treated with cryolite. It is difficult, however, to differentiate between sickness and repellence in such experiments, and it is possible that non-feeding may have been due to the former factor. This appears to be borne out by the fact that the fifth and sixth instar caterpillars, which were affected to a lesser extent by the D.D.T. dusts than the earlier instars, ate the foliage much more readily than the younger worms.

THE WATTLE BAGWORM (*Acanthopsyche junodi*, Heyl.).

The wattle bagworm is a native insect which normally lives upon indigenous thorn trees, but soon took to the black wattle, *Acacia molissima*, and to a lesser extent to the green wattle, *Acacia decurrens*, when they were cultivated on an extensive scale, where it has increased to an alarming extent and become a pest of great economic importance. The larvae of this insect, when abundant, defoliate the trees during the early summer months. This defoliation decreases the vigour of the wattle and consequently the yield of bark and timber.

The menace of the bagworm has been recognized for a number of years, and much research on the control of this pest with insecticidal dusts has been published. (Ripley and Petty, 1932 and 1934; Ripley, Petty et al., 1936 and 1939; Petty, 1946 and 1948).

Up to the present the application of natural cryolite by means of aircraft has proved to be the most satisfactory method of controlling this pest. The great disadvantage of this insecticide is, however, its high repellence to the insects, resulting in great reduction in feeding on the treated foliage with the result that a heavy enough application has to be made to obtain a good kill in spite of the reduced feeding. (Ripley, Petty et al., 1936 and 1939). Another difficulty encountered with a purely stomach insecticide such as cryolite, is rain falling within 24 hours of dusting which considerably reduces the efficacy of treatment. It was felt that insecticides such as the chlorinated hydrocarbons which have a combined stomach and contact effect, might offer greater promise than cryolite, and laboratory experiments were, therefore, undertaken to obtain information on this point

In all the tests, with the exception of those designed to determine the fumigating effect of B.H.C., the insecticides were applied to both wattle foliage and bagworms. The larvae were isolated in glass specimen tubes which were plugged with cotton wool, and were fed for 24 hours on pieces of leaf of standard size which were treated with the various chemicals under investigation. After 24 hours, the insects were transferred to clean tubes containing undusted leaves.

The first experiments included only D.D.T. and natural cryolite. Both materials were applied as dusts at the rate of 0.11 mg. per sq. cm. or 10 pounds per acre. The cryolite was undiluted while D.D.T. was used at 5, 10 and 20 per cent concentrations.

Three groups of 30 bagworms were fed on each compound in each experiment. There were five replications, making the total number of test insects for each insecticide

450
600.

RESULTS.

The results of these experiments are given in

Table 37.

TABLE 37.

Insecticides.	Dosage. Lb. per acre.	Instar worms.	Percentage final mortality.
Natural cryolite.	10	2nd.	60.6
5% D.D.T.	10	2nd.	25.7
10% D.D.T.	10	2nd.	31.1
20% D.D.T.	10	2nd.	36.3
10% D.D.T. + 90% Natural cryolite.	10	2nd.	63.1

Average control mortality = 3.4 per cent.

Control mortality range = 0.0 to 5.7 per cent.

CONCLUSIONS.

- a. From the figures given in Table 37, it is evident that D.D.T. at the concentrations used is markedly inferior to natural cryolite.
- b. The addition of as much as 10 per cent D.D.T. to cryolite resulted in no significantly higher toxicity.

The second series of experiments included not only cryolite and D.D.T., but also B.H.C. formulated as a 5 per cent dust. The rate of application and number of bagworms used was the same as that in the previous experiment.

RESULTS.

The results are summarized in Table 38.

TABLE 38.....

TABLE 38.

Insecticides.	Dosage. Lb. per acre.	Instar worms.	Percentage final mortality.
Natural cryolite.	10	2nd.	64.6
5% D.D.T.	10	2nd.	28.8
5% B.H.C.	10	2nd.	89.9

Average control mortality = 2.1 per cent.

Control mortality range = 0.0 to 7.5 per cent.

CONCLUSIONS.

- a. The results not only confirm those presented in Table 37, with regard to the superiority of cryolite over D.D.T., but in addition demonstrate the superiority of B.H.C. over cryolite.

When supplies of chlordan and toxaphene became available, these materials were included in the experimental programme in laboratory tests with the wattle bagworm.

The insecticides tested were 5 per cent B.H.C. 5 per cent toxaphene, 5 per cent chlordan and natural cryolite. No further tests were done with D.D.T. owing to the poor results obtained with it in the previous experiments. The poisons were applied as dusts at the rate of 0.05 mg., 0.07 mg., 0.09 mg. and 0.11mg. per sq. cm. which is equivalent to 5, 7, 9 and 10 pounds per acre respectively. In certain experiments, as indicated in the following table, both the foliage and the larvae were dusted while in others only the leaves were treated.

Three groups of 40 bagworms were used in every experiment for each insecticide. Since each experiment

was replicated at least five times, the minimum number of insects used for each insecticide was 600.

RESULTS.

The results are presented in Table 39 (page 147).

CONCLUSIONS.

- a. B.H.C., chlordane, and toxaphene are markedly more effective than cryolite against first and second instar bagworms when applied to leaves only or when both leaves and worms are dusted.
- b. B.H.C. appears to be slightly more effective than chlordane and toxaphene against the first two instars.
- c. The superiority of B.H.C. over cryolite is not nearly so marked when used against third and fourth instar worms. For third and early fourth instars, B.H.C. is no better than cryolite when only the leaves are dusted. When leaves and worms are dusted, however, B.H.C. does cause a higher mortality than cryolite. The superiority becomes less evident as the larvae become older, until it disappears altogether with late fourth and early fifth instar worms.
- d. There is some evidence that toxaphene is more toxic than B.H.C. or cryolite against third and fourth instar larvae. This conclusion has subsequently been definitely confirmed by field experiments (Ripley, 1949).
- e. Chlordane is less effective than cryolite for the older bagworms.

TABLE 39.

Expt.	Instar worms.	Dosage (lb. per acre)	PERCENTAGE		FINAL		MORTALITY.			
			CRYOLITE		5 Per cent B.H.C.		5 per cent CHLORDANE		5 Per cent TOXAPHENE	
			Leaves dusted.	Leaves and worms dusted.	Leaves dusted.	Leaves and worms dusted.	Leaves dusted.	Leaves and worms dusted.	Leaves dusted.	Leaves and worms dusted.
I	Ist. and 2nd.	7	83.3	83.3	-	100.0	-	96.6	-	100.0
2	2 nd.	7	63.3	66.6	96.6	100.0	96.6	91.7	83.3	96.6
3	2nd.	5	53.3	-	100.0	-	86.6	-	83.3	-
4	3rd.	7	43.3	-	40.0	-	26.6	33.3	50.0	56.6
5	3rd. and 4th.	10	73.3	-	60.0	-	33.3	26.6	-	-
6	3rd. and 4th.	10.	43.8	40.0	40.0	53.7	-	-	60.0	57.8
7	3rd. and 4th.	9	46.6	-	56.6	63.4	-	-	66.7	66.7
8	Mainly 4th.	10	70.0	-	-	73.3	31.4	36.2	-	-
9	Mainly 4th.	10	-	-	-	66.3	-	-	-	-
10	Late 4th. and 5th.	10	30.0	34.8	20.0	33.3	-	-	-	-
II	Late 4th. and 5th.	10	30.0	31.6	26.9	33.3	-	-	-	47.1

Average control mortality :- 3.1 per cent.

Control mortality range :- 0.0 to 6.6 per cent.

- f. It has been shown in a previous publication (Ripley and Petty, 1934), that the deposit of natural cryolite required to give a lethal dose to third and fourth instar worms is nearly twice that for the first and second instars, and very much more for instars beyond the third and fourth. It is evident from the results given in Table 39, therefore, that, as with cryolite, dusting with B.H.C., chlordane and to a lesser extent with toxaphene, should, if possible, be completed before a high percentage of the larvae have entered the third instar.

TOXICITY OF OIL SOLUTIONS CONTAINING B.H.C. TO WATTLE BAGWORM.

Weather conditions play an important part in determining the degree of success obtained by the aerial application of insecticidal dusts for bagworm control. When heavy showers, light prolonged rain or strong wind follows immediately after dusting or before the bagworms have fed appreciably, the treatment will usually have to be repeated to ensure a satisfactory kill, thus doubling the cost of application. It should be pointed out that frequently 25 per cent of the larvae may be undergoing ecdysis on the day of dusting, so that many will not begin to feed until some time during the next two days. This factor increases the danger of insecticide loss due to unfavourable weather conditions before the larvae can ingest lethal quantities of the poisons. Although good results have been obtained with dusts on a commercial scale (Naudé, Ripley and Petty, 1939), it was considered, that in view of the weather hazard, other formulations should be investigated with a view to obtaining better adhesion to the foliage which would allow greater latitude as regards unfavourable weather conditions subsequent to the application of the poisons. Water suspensions were considered but discarded owing to the high evaporation factor which is encountered in the application of water borne insecticides

from aircraft. Oil solutions were selected as being the most promising formulations from the adhesive point of view, especially as it had been ascertained that a low rate of application, three or four gallons per acre, would cause no serious damage to wattle foliage. Laboratory experiments were, therefore, undertaken with 3 per cent B.H.C. in diesel oil to determine its toxicity relative to that of cryolite.

Spraying was done with the apparatus described on page 36, and the solution was applied to give deposits of 0.0220 mg., 0.0110 mg. and 0.005 mg. B.H.C. per sq. cm., which is equivalent to field dosages of 2 pounds, 1 pound and $\frac{1}{2}$ pound of B.H.C. per acre respectively. The deposit of 0.0110 mg. per sq. cm. corresponds to an application of 20 pounds per acre of a 5 per cent B.H.C. dust, the dosage recommended for commercial dusting. Cryolite was applied at the rate of 10 and 20 pounds per acre.

Both the bagworms and the wattle leaves on which they were fed were treated with the poisons, and as in previous experiments, the worms were isolated in glass specimen tubes with the sprayed or dusted foliage for 24 hours. There were five replications, and three groups of 40 fourth instar larvae were used for each treatment in each replication. The results obtained are, therefore, based on a total of 600 worms for each treatment.

RESULTS.

The results are presented in Table 40.

TABLE 40.

Insecticides.	Dosage. Lb. per acre.	Instar worms.	Percentage final mortality.
B.H.C. Solutions.	0.022 mg. per sq. cm. (2lb. per acre).	4th.	99.8
" "	0.011 mg. per sq. cm. (1 lb. per acre)	4th.	77.6
" "	.0055 mg. per sq. cm. ($\frac{1}{2}$ lb. per acre).	4th.	32.6
Natural cryolite	10	4th.	33.3
" "	20	4th.	74.7

Average control mortality = 3.4 per cent.

Control mortality range = 0.0 to 7.5 per cent.

CONCLUSIONS.

- a. B.H.C. applied as a spray solution to give a deposit equivalent to 2 pounds of actual B.H.C. per acre is more toxic than the lower spray applications and is also superior to cryolite at 10 and 20 pounds per acre.
- b. The spray solution giving 1 pound of B.H.C. per acre, (which is equivalent to a 20 pound application per acre with a 5 per cent B.H.C. dust), causes no significantly higher final mortality to fourth instar worms than 20 pounds of natural cryolite per acre. This tends to confirm previous results given in Table 38, where it is shown that a 5 per cent B.H.C. dust applied at the same rate as natural cryolite, is no more toxic to late fourth instar larvae than is cryolite.
- c. A spray solution applied to give $\frac{1}{2}$ pound of B.H.C. per

acre (equivalent to a 10 pound per acre application with a 5 per cent B.H.C. dust), is markedly inferior to the 1 pound per acre application but is no better against fourth instar larvae than natural cryolite applied at 10 pounds per acre.

- d. The results indicate that B.H.C. applied as an oil solution is at least as toxic as B.H.C. dusts and natural cryolite when used against fourth instar bagworms.

PENETRATION OF OIL SPRAYS THROUGH WATTLE CANOPY.

Adhesiveness and toxicity are not the only factors to be considered in the practical application of insecticides to forest trees. It is essential to obtain a good coverage of the foliage in the case of stomach poisons, and of both foliage and insects with a material such as B.H.C. which combines both stomach and contact action. No difficulty has been experienced in this respect as far as dusts are concerned, but there was no information available regarding the extent to which oil sprays would penetrate the canopy of wattle trees which is often of an extremely dense nature. In order to be able to answer this question, the writer, in collaboration with other officers of the Division of Entomology, undertook a large scale field experiment in the wattle areas in the Eastern Transvaal. Furnace oil was applied by means of an Anson aircraft at the rate of approximately 3 gallons per acre to trees 20 to 25 ft. in height which had a canopy of average density. The degree of penetration of the spray through the foliage, which was on the average 15 ft. in depth, was determined by exposing glass plates, which were later chemically analysed by the Division of Chemical Services, Pretoria, and specially prepared papers, on which the droplets of oil were clearly visible, at

different levels in the trees throughout the sprayed area. The results obtained show clearly that not more than 10 per cent of the oil solution will penetrate even half way through the average tree canopy. Since this is quite inadequate, the application of dusts by aircraft will have to be relied on until a more efficient method of applying oil sprays, such as the possible use of helicopters which is at present being investigated, is developed.

FUMIGATION ACTION OF B.H.C. ON WATTLE BAGWORM.

It has already been shown that certain chlorinated hydrocarbon insecticides act as contact and stomach poisons and in addition have a fumigant effect on insects. The question therefore arose whether or not the marked superiority of B.H.C. over cryolite in laboratory tests with first and second instar bagworms is not due, in part, to its fumigant action. It was felt that if fumigation was a factor in causing mortality, it would operate to a far greater extent in closed tubes, such as those used in the laboratory experiments, than under field conditions and that the results would, therefore, not be a true reflection of the relative efficacy of cryolite and B.H.C. Experiments were, therefore, undertaken to elucidate this point. The experimental procedure was as follows:-

In each test, 80 leaves were dusted with 5 per cent B.H.C. powder at the rate of 10 pounds per acre, and they were then placed separately in specimen tubes. In half of the tubes third instar bagworms were confined, one to a tube, so that they could come in contact with and feed on the treated foliage. In the other 40 tubes, the worms were separated from the dusted foliage by means of coarse wire mesh and were fed on untreated leaves. The tubes were plugged with cotton wool as was done in the experiments previously described. The larvae coming in contact with the dusted leaves were subjected to the

combined contact, stomach and fumigating action of B.H.C., whereas those separated from the treated foliage had only the fumigating effect. After 24 hours, the insects were all transferred to clean tubes and fed on fresh foliage.

Each experiment was done in triplicate and there were four replications, making the total number of test insects 480.

RESULTS.

The results are presented in Table 41.

TABLE 41.

Insecticide.	Dosage. Lb. per acre.	Treatment.	Percentage final mortality.
5% B.H.C.	10	Worms fed on dusted foliage.	52.1
5% B.H.C.	10	Worms separated from dusted foliage.	4.6

Average control mortality = 3.2 per cent.

Control mortality range = 0.0 to 7.5 per cent.

CONCLUSIONS.

- a. The results indicate that with the technique used in laboratory experiments with wattle bagworm, no appreciable mortality can be attributed to the fumigating effect of B.H.C. and the mortality is due, therefore, to the combined stomach and contact action of the insecticide.

THE ASTYLUS BEETLE (*Astylus atromaculatus*, Bl.).

The *Astylus* beetle is a small black and yellow spotted insect about $\frac{3}{8}$ to $\frac{1}{2}$ inch in length and belongs to the family Melyridae. It appears to have been introduced from South America during the Anglo-Boer war and has become established as a pest of farm lands and gardens in this country. It is attracted to flowers and often forms clusters on maize and bean plants and on many garden flowers, feeding on parts of the flower and on pollen. It has also become a troublesome pest on young maize cobs, destroying the grain as it is formed. As a leaf feeder it is not a troublesome pest. The larvae are hairy grubs which live in the soil and feed on the roots of plants.

Spraying and dusting with the older conventional insecticides, both stomach and contact, were found to be ineffective and tests were undertaken with some of the newer organic insecticides in the hope that they might afford a better measure of control against this pest.

The insecticides used were 2 per cent para-thion, 5 per cent B.H.C., 5 per cent D.D.T. and 5 per cent chlordane. The materials were applied as dusts at the rate of 0.16 mg. per sq. cm. or 15 pounds per acre. Both the beetles and their food plant were dusted and the insects were confined in cages with the dusted flower heads for 24 hours. At the end of this period they were transferred to clean cages and given untreated food.

Three groups of 50 *Astylus* beetles were used for each insecticide in each experiment which was replicated five times. The total number of insects used for each insecticide was, therefore, 750.

RESULTS.

Table 42 summarises the percentage mortalities obtained with the different poisons.

TABLE 42.....

TABLE 42.

Insecticides.	Dosage. Lb. per acre.	Percentage final mort- ality.	Time required for final mortality.
5% B.H.C.	15	61.3	72 Hours.
5% D.D.T.	15	91.8	48 "
5% Chlordane.	15	100.0	48 "
2% Parathion.	15	100.0	24 "

Average control mortality = 2.3 per cent.

Control mortality range = 0.0 to 5.0 per cent.

CONCLUSIONS.

- a. Although 2 per cent parathion and 5 per cent chlordane produce the same final mortalities, parathion is superior to chlordane in that its rate of action is more rapid.
- b. 5 per cent D.D.T. is somewhat less toxic to Astylus atromaculatus than either parathion or chlordane, but it is considerably more effective than B.H.C.
- c. The results suggest that 2 per cent parathion, 5 per cent chlordane and 5 per cent D.D.T. dusts should prove effective in controlling these insects when applied at the rate of 15 pounds per acre, while 5 per cent B.H.C. would not afford adequate control at this rate of application.

C.M.R. BEETLES (*Decapotoma lunata*, Pall.).

These yellow and black banded Meloid beetles are sometimes known as blister beetles owing to an oily secretion in their bodies, cantharidin, which blisters the flesh.

There are many different species in South Africa, ranging in size from $\frac{1}{2}$ to $1\frac{1}{4}$ inches in length. The toxicity tests described here were, however, done with only one species, Decapodoma lunata, Pall., which is one of the commonest species occurring in this country.

The life-history of these beetles is complicated. The immature stages of certain species are passed as parasites inside the egg-cases of locusts and allied insects.

The adult beetles are commonly seen in gardens and orchards where they sometimes appear in large numbers feeding on the leaves and flowers of peas, beans, the leaves of potatoes and the blossoms of many plants, including fruit trees.

The insecticides tested for the control of these insects were 5 per cent and 10 per cent B.H.C., 5 and 10 per cent D.D.T., 5 per cent chlordane and 2 per cent parathion. They were applied as dusts at the rate of 0.22 mg. per sq. cm. or 20 pounds per acre. Both the beetles and the flower heads were treated and the insects were confined in cages with the dusted flowers for 24 hours.

Three groups of 30 beetles were used for each insecticide in each experiment which was replicated five times. The total number of insects used for each insecticide was, therefore, 450.

RESULTS.

A summary of the results obtained is given in Table 43.

TABLE 43.

Insecticides.	Dosage. Lb. per acre.	Percentage final mortality.	Time required for final mortality.
5% B.H.C.	20	72.1	48 Hours.
10% B.H.C.	20	100.0	24 "
5% D.D.T.	20	99.3	48 "
10% D.D.T.	20	100.0	24 "
5% Chlordane.	20	100.0	24 "
2% Parathion.	20	100.0	24 "

Average control mortality = 3.3 per cent.

Control mortality range = 0.0 to 6.6 per cent.

CONCLUSIONS.

- a. 2 per cent parathion, 10 per cent B.H.C., 10 per cent D.D.T. and 5 per cent chlordane all cause complete mortality in 24 hours, but the rate of knock-down was considerably faster with parathion than with the other insecticides.
- b. 5 per cent chlordane produced a faster knock-down than did 5 per cent D.D.T., but was no more rapid in action than 10 per cent D.D.T. 5 per cent B.H.C. was the least effective of the poisons tested.
- c. The results suggest that the control of Decapotoma lunata should be obtained by the application of 2 per cent Parathion, 5 per cent chlordane, 5 per cent D.D.T. and 10 per cent B.H.C. at the maximum rate of 20 pounds per acre B.H.C. at 5 per cent concentration appears to be too

weak for effective control, whereas 10 per cent D.D.T is an unnecessarily high concentration for the control of these insects.

FRUIT-EATING BEETLES (*Pachnoda impressa*, Gold.).

These fruit-eating beetles belong to the family Scarabaeidae which is well represented in South Africa. The most destructive species are *Pachnoda rufa*, DeG., *Pachnoda sinuata*, F., *Pachnoda cineta*, DeG. and *Pachnoda impressa*, Gold. Beetles belonging to the latter species were used as test insect in the experiments now to be described, although information on the toxicity of the various poisons to *Pachnoda cineta* and *Pachnoda sinuata* was also obtained.

These Cetoniid beetles cause serious damage to ripe and ripening fruit and when present in large numbers, they are capable of destroying a high proportion of the fruit crop.

The insecticides tested were 5 and 10 per cent^t B.H.C., 5 and 10 per cent D.D.T., 5 per cent chlordane, 2 per cent parathion and natural cryolite. These dusts were applied at the rate of 0.22 mg. per sq. cm. or 20 pounds per acre. Both the beetles and the fruit on which they were fed were dusted, and the insects were confined in cages with the dusted fruit for 24 hours. Thereafter, they were transferred to clean cages and fed on untreated fruit.

Three groups of 30 beetles were used for each insecticide in each experiment which was replicated five times. The total number of beetles used for each insecticide was, therefore, 450.

RESULTS.

The mortality figures obtained with the

various insecticides are presented in Table 44.

TABLE 44.

Insecticides.	Dosage. Lb. per acre.	Percentage final mortality.	Time required for final mortality.
5% B.H.C.	20	38.7	120 Hours.
10% B.H.C.	20	56.6	120 "
5% D.D.T.	20	22.7	120 "
10% D.D.T.	20	22.5	120 "
5% Chlordane.	20	11.7	144 "
2% Parathion.	20	100.0	24 "
Natural cryolite.	20	9.8	144 "

Average control mortality = 1.1 per cent.

Control mortality range = 0.0 to 3.3 per cent.

CONCLUSIONS.

- a. Neither D.D.T., chlordane or natural cryolite can be considered for the control of fruit-eating beetles at the concentrations and rate of application used in these tests.
- b. 2 per cent parathion is highly toxic to these insects and is far superior to 10 per cent B.H.C., which is the only other insecticide among those tested which could be considered for use against this pest.
- c. The results suggest that 2 per cent parathion applied at the rate of 20 pounds per acre should provide effective control. 10 Per cent B.H.C. dust applied at the

rate of 20 pounds or more per acre, should afford some measure of control, but there is the danger of taste contamination to ripe and ripening fruit with this insecticide.

In the course of the experiments on Pachnoda impressa, preliminary observations were made on the relative susceptibility of Pachnoda sinuata and Pachnoda cincta to the various poisons. The results obtained indicate that these two species exhibit the same degree susceptibility as Pachnoda impressa to the insecticides.

GROUND WEEVILS (*Protostrophus amplicollis*, Fhs.).

Protostrophus amplicollis and several other species of ground weevils appear most commonly as pests of new lands which have recently been cultivated, and less frequently as pests on older lands. Under natural conditions, the full-grown weevils live on grass and other veld plants while those in the immature stage, which hatch from the eggs laid in the soil, feed on the roots of these plants. Damage appears to be done mainly by hibernating weevils. According to observations, the eggs are generally laid in the beginning of December and the new weevils appear late in February or March.

Records show that maize, cotton, potatoes, tobacco, ground-nuts and even newly planted deciduous fruit trees may be attacked. When the natural food plants are destroyed, as with ploughing, they will feed on almost any crop.

The insecticides tested were 5 per cent B.H.C., 5 per cent D.D.T., 5 per cent chlordane, 2 per cent parathion and natural cryolite. The poisons were used as dusts and were applied at the rate of 0.16 mg. per sq.cm. or 15 pounds per acre.

Three groups of 30 beetles were used for

each insecticide in each experiment which was replicated five times. The results obtained, therefore, are based on a total of 450 insects for each insecticide.

RESULTS.

The results of the experiments are presented in Table 45.

TABLE 45.

Insecticides.	Dosage. Lb. per acre.	Percentage final mortality.	Time required for final mortality.
5% B.H.C.	15	99.5	48 Hours.
5% D.D.T.	15	95.2	72 "
5% Chlordane.	15	97.2	72 "
2% Parathion.	15	99.8	24 "
Natural cryolite.	15	48.9	120 "

Average control mortality = 1.1 per cent.

Control mortality range = 0.0 to 6.6 per cent.

CONCLUSIONS.

- a. Parathion, B.H.C., chlordane and D.D.T. are highly toxic to the adult beetles. Natural cryolite is considerably less effective than the other insecticides tested.
- b. 2 Per cent parathion is more rapid in action than either B.H.C., chlordane or D.D.T. when used at 5 per cent concentration.
- c. B.H.C. is superior to both chlordane and D.D.T. as regards rapidity of action. Chlordane does not appear

to be significantly more toxic than D.D.T.

- d. The results suggest that parathion used at a concentration of 2 per cent, and B.H.C., chlordane and D.D.T. at 5 per cent concentration should be effective in controlling Protophila amplicollis when applied at the rate of 15 pounds per acre. Cryolite is considerably less effective than these four insecticides, and if used, should be applied at 20 pounds per acre or over.

THE EUCALYPTUS SNOUT-BEETLE (*Gonipterus scutellatus*, Cyll.).

The Eucalyptus snout-beetle is a small dark brown beetle not more than a quarter of an inch in length. It was introduced from Australia in about 1914, and for a time the ravages of this insect menaced the entire eucalyptus-growing industry. The damage is done mainly by the greenish-yellow slug-like larvae which hatch from the eggs laid in a small capsule of dark brown matter and stuck to the leaves. In cases of severe outbreaks, entire eucalyptus plantations may be practically defoliated.

Various expedients were tried by the Division of Entomology to control this pest, such as winter cultivation and burning of coppice, but these measures were ineffective. In 1926 experiments on the control of *Gonipterus scutellatus* by the application of arsenical dusts from aircraft were undertaken and although promising results were obtained, this method of control proved to be too costly for general use.

In 1926, F.G.C. Tooke of the Division Of Entomology, visited Australia and discovered a Nymphid egg parasite which was introduced into the Union during the same year. The introduction of this parasite has resulted in economic control of the Eucalyptus snout-beetle over at least 75 per cent of the

infested area.

Although the use of insecticides could never be considered for the general control of this insect on account of the very high measure of success obtained by means of biological control, it was, nevertheless deemed advisable to obtain data on the relative toxicity of certain of the newer insecticides from the purely scientific point of view and in the event of their possible use in certain very restricted localities where the parasite has not become established.

The insecticides tested were 5 per cent D.D.T. 5 per cent B.H.C. and natural cryolite applied as dusts at the rate of 0.16 mg. per sq. cm. or 15 pounds per acre. Both the insects and the eucalyptus foliage on which they were fed were dusted. The beetles were confined in cages with the treated leaves for 24 hours and were then transferred to clean cages with undusted food.

Three groups of 30 beetles and three groups of 30 half-grown larvae were used for each insecticide in each experiment which was replicated five times. The total number of beetles and of larvae used for each insecticide was, therefore 450.

RESULTS.

The results of the experiments are given in Table 46.

TABLE 46.

Insecticides.	Dosage. Lb. per acre.	Percentage final mortality.		Time required for final mortality.	
		Adults.	Larvae.	Adults.	Larvae.
5% B.H.C.	15	19.1	7.8	120 Hours	120 Hours
5% D.D.T.	15	91.2	39.1	96 "	96 "
Natural cryolite.	15	24.9	15.1	144 "	144 "

Average control mortality = 3.1 per cent. (Adults).
2.3 " " (Larvae).

Control mortality range for adults and larvae = 0.0 to 6.6 per cent

CONCLUSIONS.

- a. 5 per cent D.D.T. dust is far superior to B.H.C. used at 5 per cent concentration or to natural cryolite for the control of both adult beetles or half-grown larvae.
- b. Natural cryolite appears to be slightly more toxic to both adults and larvae than 5 per cent B.H.C., but both poisons are relatively ineffective.
- c. The adult snout-beetles are more susceptible to all three poisons than are the half-grown larvae.

RECENT DEVELOPMENTS IN AGRICULTURAL INSECTICIDES.

Ever since the insecticidal properties of D.D.T. were recognized and reported, a wide variety of chlorinated compounds such as the methoxy analogue and the fluorine

analogues of D.D.T., Rhothane (dichloro diphenyl dichloroethane), chlordane, toxaphene and many others have been proposed as substitutes for or improvements on this chemical, with the result that references to new chlorinated hydrocarbon insecticides abound in recent entomological literature. One of the latest suggested improvements for D.D.T. is the addition to it of piperonyl cyclonene in cases where certain insects have developed resistance to D.D.T. Perry (1950), states that resistance to D.D.T. depends on the rate at which it is converted into a quite innocuous chemical in the bodies of insects. He considers that the conversion of D.D.T. into the innocuous form can be blocked by piperonyl cyclonene, and that a mixture of this chemical and D.D.T. will account for the most resistant race of insects yet developed.

Two of the newest of the chlorinated organic compounds recognized as insecticides are 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexa-hydronaphthalene and its oxygenated derivative 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4,5,8-dimethanonaphthalene, known as Aldrin (Compound II8) and Dieldrin (Compound 497), respectively.

Aldrin is a nearly odourless, white crystalline solid, with a melting point of 100 to 103 degrees C. It is very highly soluble in most organic solvents, but is insoluble in water. It is stable in the presence of organic and inorganic alkalies and metallic chlorides. Aldrin is formulated as a wettable powder, an emulsifiable concentrate, as an oil solution and as low percentage dusts.

Dieldrin resembles Aldrin in most of its physical properties, although it is somewhat less soluble in organic solvents. Its melting point is 173 degrees C. It is stable in strong alkalies, but decomposes in the presence of strong acids. It is formulated for agricultural use in the same way as Aldrin.

Both these compounds have shown promise against a wide variety of pests including certain soil insects (Rawlins et al., 1949; Shread, 1949; Wolcott, 1949), house-flies, cockroaches and grasshoppers (Kearns et al., 1949), bollweevil (Lyle, 1949), thrips (Weinman, 1949) and many other insect species.

The important difference between these two materials is that of much higher vapour pressure of Aldrin with accompanying higher rate of volatility, and a very marked residual property commensurate with a much lower vapour pressure in the case of Dieldrin.

Both Aldrin and Dieldrin should be handled with extreme care and inhalation of the materials must be avoided.

Of the phosphorus compounds, the use of a new systemic insecticide, bis(bis-dimethylamino phosphonous) anhydride is described by Ripper et al., 1950. Alternative names for this material are tetrakis dimethylamino phosphonous anhydride and octa-methylpyrophosphoramide.

This material is described as a selective insecticide, that is, one which kills the pests but does not harm their natural enemies, and is absorbed by the plant and translocated in the sap so that parts of the plant other than those treated become toxic to certain sucking insects

The compound is normally a dark brown liquid having a slight odour. When highly purified it is a pale straw colour, having a melting point of 14 to 20 degrees C. It is miscible in all proportions with water and most organic solvents, but is only slightly soluble in refined mineral oils and incompletely miscible with vegetable and crude mineral oils.

Bis(bis dimethylamino phosphonous) anhydride has a very weak direct contact effect against aphids, and against

other insects the contact effect is negligible. There is no contact action by residual film and no fumigation effect either of the chemical itself or from sprayed plants. The systemic action is most marked against aphids but certain other sucking insects and spider mites can also be destroyed. In all cases prolonged toxicity from two to five weeks after spraying has been recorded. It is not effective against all sucking insects. This has been clearly demonstrated by the writer in tests where this chemical has failed to control Begrada hilaris, Burm.

Exhaustive toxicological studies have revealed that its toxicity to mammals is similar to that of para-thion, but slightly less. Ripper et al.(1950), have shown that no toxic residue can be detected at harvest if crops have been sprayed up to six weeks before hand.

Another systemic insecticide which is also being investigated is p-nitrophenyl diethyl phosphate. This material is, however, not selective in action and has a shorter effective duration in the plant than bis(bis dimethylamino phosphonous) anhydride.

Another recent discovery among the phosphorus compounds is ethyl-p-nitrophenol thionobenzene phosphonate commonly known as EPN, and is mainly for mite control. The only available information found on this material is published by the Graselli Chemical Division, U.S.A., 1950. Their published report states that field trials carried out by entomologists of the Bureau of Entomology have indicated that EPN will control Tetranychus bimaculatus, Harvey. Paratetranychus pilosus, Canã F., and Bryobia praetiosa, Koch., and that it has residual toxicity up to four to six weeks. It is also reported to be promising against thrips, fruit fly and codling moth and is safer to use than parathion.

Two other new acaricides which are giving promising results and are now on the market are bis(p-chlorophenoxy) methane (Neotran) and Arathane, the active ingredient of

which is dinitro capryl phenyl crotonate. Reliable experimental data on the efficacy of these materials is somewhat fragmentary, but what information there is suggests that they are fairly effective against the European red mite (Paratetranychus pilosus, C and F.), the two spotted spider mite (Tetranychus bimaculatus, Harvey.) and the Pacific mite (Tetranychus pacificus, McG.). Results of preliminary investigations were reported by Underhill, (1947) and Lathrop (1949).

Many other promising new compounds with possible insecticidal properties are being investigated by research workers all over the world, but as this work is still largely in the experimental stage, the writer hesitates to comment on them until more reliable data are available.

SUMMARY.

I. The need for organized large scale control operations against insect enemies is appreciably greater and more urgent today than in the past, owing to increased world populations necessitating greater food production and, therefore, more efficient methods of food protection. In addition, depleted soil fertility with the consequent reduction in crop yields makes it imperative to save the crops from destruction by insects. A major problem intimately connected with greater food production is the control of serious pests of livestock. Apart from the purely agricultural aspect of pest control, there is too, the question of protecting the ever increasing world populations from the ravages of those diseases transmitted by insects and Arachnids.

Confronted with this situation, there is every reason for the entomologist to use every available weapon to control these insect enemies. Chemical control by the use of insecticides is one of the most direct, effective and spectacular methods and is the one with which this thesis is mainly concerned. It is pointed out, however, that other supplementary control measures should not be lost sight of.

2. A description is given of the properties of the newer organic insecticides tested, namely, the chlorinated hydrocarbons, B.H.C, D.D.T., toxaphene and chlordane, the chlorinated phenol, pentachlorophenol, and the phosphorus compounds parathion, " hexaethyl tetraphosphate ", and tetraethyl pyrophosphate. It is emphasized, however, that the history of these materials as insecticides is comparatively new and further investigations are necessary in order to obtain a better knowledge of their potential usefulness and possible hazards, particularly in respect of their use against pests attacking agricultural crops. These insecticides must be intelligently applied, since

their promiscuous and improper use may lead to other serious problems. There is especial danger in destroying beneficial forms of life by the indiscriminate use of poisons such as the chlorinated hydrocarbons and there is, in addition, the danger of plant injury from their use, either directly or through soil contamination and their effect on soil micro-organisms. These and other points arising out of the use of the newer insecticides are discussed in the light of information accumulating as a result of recent researches in the field of chemical control of insects.

3. A section of this thesis is devoted to descriptions of three types of original laboratory apparatus and their application in the biological assay of insecticides.

a. An apparatus for the application of insecticidal dusts whereby they can be quickly and accurately applied, and with which any desired weight of material can be deposited per unit area. The apparatus is designed for the evaluation of the toxicity of contact and stomach poisons and it can also be used for the determination of the effective duration of insecticides with residual action. A formula is given whereby pounds per acre may be calculated from laboratory applications of insecticides.

b. An apparatus for quick and accurate application of contact sprays. It may be used for insecticides with rapid knock-down action or for those having persistent residual toxicity. Figures are given which serve to indicate the accuracy that can be obtained, and what correlation exists between deposits obtained in relation to the volume of liquid sprayed.

c. An apparatus for testing the adhesiveness of insecticidal dusts and with which the relative adhesive values of insecticides on different types of foliage may be determined. Tables are given which illustrate the degree of accuracy which may be expected with the use of this apparatus.

4. The third section of the thesis is devoted to the residual toxicity of certain chlorinated hydrocarbon insecticides and pentachlorophenol. The insecticidal materials, D.D.T., B.H.C, chlordane and pentachlorophenol were formulated as smokes and as oil solutions. A description is given of the technique and methods of experimentation evolved for the accurate biological assay of the different formulations and of the use of the termite, Trinervitermes havilandi, Hgrn. as a test insect.

The results obtained from the experiments designed to determine the persistent toxicity of D.D.T, B.H.C. and chlordane formulated as oil solutions and applied to different surfaces commonly used in household construction, indicate that the period of effective residual duration varies according to the nature of the treated surface and that B.H.C. and chlordane can not compare with D.D.T. with regard to effective duration of residual toxicity on any of the surfaces used. Surfaces painted with flat, enamel and oil paints, an oil varnish and an oil stain are unsatisfactory when the sprays are applied as long as a month after the surfaces are painted. The solutions are, however, more effective on old than on fresh paint, although even on wood painted two years prior to the application of the sprays, the residual effect disappears rapidly. Considerably better results are obtained on absorbent materials such as filter paper or on unpainted wood, glass and distempered surfaces. In the case of distemper, however, the insecticides should not be used when the distemper is freshly applied.

Experiments designed to determine whether sprays containing pure D.D.T. have longer residual action than those made up with the impure material, show the reverse to be true.

When applied as a surface or residual treatment, B.H.C. smokes do not possess the lasting property exhibited by those of D.D.T. and pentachlorophenol. As with oil solutions, the persistence of D.D.T. smoke residues is of markedly shorter duration on oil and enamel paints than on unpainted

wood or distemper. Results are presented indicating that, in the case of indoor dispersion of insecticides by means of smoke generators, vertical surfaces do not retain the toxic deposits as well as horizontal surfaces.

5. Data are presented on the comparison of the fumigation, contact and stomach actions of B.H.C., D.D.T., chlordane, toxaphene and parathion, using Trinervitermes havilandi, Hgrn., Astylus atromaculatus, Bl. and Gonipterus scutellatus, Gyl. as test insects.

It is demonstrated that chlordane is superior to the other insecticides as a fumigant against all three test insects followed in order of efficacy by B.H.C. and parathion. D.D.T. and toxaphene exhibit very poor fumigating properties.

The results obtained on the contact actions of the poisons indicate the danger in trying to adopt any single insecticide as an over-all panacea and emphasize the specific actions of the poisons to the different test insects.

When the value of the insecticides is judged by their performance as knock-down agents, B.H.C. is outstanding against Trinervitermes havilandi while D.D.T. shows the most rapid knock-down action with Astylus atromaculatus and Gonipterus scutellatus.

If the final mortality produced is used as a basis for evaluating the efficacy of the poisons, however, then B.H.C. and chlordane are the most effective against Trinervitermes havilandi, while good results are also obtained with D.D.T. and parathion. Chlordane causes the highest mortality with Astylus atromaculatus and parathion is also highly efficacious. Against Gonipterus scutellatus best results were obtained with parathion and D.D.T. with B.H.C. and chlordane also causing high kills.

It is evident that the efficacy of an insecticide as indicated by the final mortality obtained is not necessarily correlated with its value as a knock-down agent.

Tests on the influence of moisture on the contact action of the poisons under consideration demonstrate that B.H.C. and parathion are considerably more toxic on wet than on dry surfaces. Similar experiments with D.D.T., chlordane and toxaphene indicate that moisture in no way increases their efficacy as contact poisons.

The results obtained on the relative toxicity of the chlorinated hydrocarbon insecticides and parathion as stomach poisons with Gonipterus scutellatus, show parathion to be superior to the other chemicals in this respect.

6. The final section of the thesis deals with the relative toxicities of B.H.C., D.D.T., chlordane, toxaphene, parathion, "hexaethyl tetraphosphate" and tetraethyl pyrophosphate as compared with certain of the older insecticides, against sixteen common agricultural pests.

The phosphorus compounds, parathion, "hexaethyl tetraphosphate", and tetraethyl pyrophosphate have proved to be highly toxic to the red spider mite, Tetranychus bimaculatus, Harvey. Parathion is more effective than B.H.C. or chlordane for the control of the Elegant grasshopper, Zonocerus elegans, Thunb., although the indications are that the latter two compounds may also be used with a high measure of success. D.D.T. is relatively ineffective against this pest.

B.H.C. is more toxic to the Bagrada bug, Bagrada hilaris, Burm. than D.D.T. but satisfactory control may be obtained with both insecticides. Pyrethrum dust is, however, ineffective against this pest. The aphid, Aphis craccivora, Koch has shown itself to be more susceptible to nicotine dust than to parathion, B.H.C. or D.D.T., although all these materials are highly toxic to this species of aphid.

Laboratory experiments with D.D.T. and pyrethrum dusts indicate that whereas the latter insecticide is the

more toxic of the two to the wattle jassid, Bythoscopus cedaranus, Naudé, and the wattle capsid, Lygidolon laevigatum, Reut., D.D.T. can, nevertheless, probably be used under field conditions with a fair measure of success.

Field and laboratory tests show clearly that parathion formulated as a wettable powder is outstanding for the control of the cochineal, Daetylopus opuntiae, Skl., on spineless cactus and it is considerably more efficacious than B.H.C. or D.D.T. Against the American bollworm, Heliothis armigera, Fabr., and the pine brown tail moth, Euproctis terminalis, Walk., D.D.T. has exhibited high toxicity, whereas B.H.C. has given disappointing results. Good results are also obtained with parathion, cryolite and chlordane with the former insect, while toxaphene and lead arsenate produce high mortalities with the latter.

D.D.T. is equally as effective as natural cryolite for the control of the army worm, Laphygma exempta, Walk., for the first two instars, but cryolite is more effective for the last two stages. B.H.C. is inferior to D.D.T. and cryolite for all stages of development.

D.D.T. is ineffective against the wattle bagworm, Acanthopsyche junodi, Heyl., whereas laboratory tests show B.H.C., toxaphene and chlordane to be more toxic than natural cryolite, the insecticide at present used for the control of this pest, when used against first and second instar larvae.

Experiments in which B.H.C., chlordane, parathion and D.D.T. were tested against the Astylus beetle, Astylus atramaculatus, El. and the C.M.R. beetle, Decapotoma lunata, Fall., show parathion, chlordane and D.D.T. to be more effective than B.H.C., the first-named compound being the most toxic.

The fruit eating beetle, Pachnoda impressa, Gold., proved to be highly resistant to D.D.T. and chlordane and to a lesser extent to B.H.C. Parathion, on the other hand,

is highly toxic to this Cetoniid beetle.

Laboratory experiments indicate that good control of the ground weevil, Prostrophus amplicollis, Fhs., may be obtained with parathion, B.H.C., chlordane and D.D.T. Cryolite is considerably less efficacious than the other insecticides.

D.D.T. is shown to be superior to cryolite and B.H.C. in tests against the Eucalyptus snout-beetle, Gonipterus scutellatus, Cyl.

A short review is given of some of the more recent developments in the field of agricultural insecticides.

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