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# INVESTIGATIONS IN THE CONTROL OF THE POTATO TUBER MOTH, *Gnorimoschema operculella* Zell. (LEPIDOPTERA: GELECHIIDAE), IN NORTH QUEENSLAND.

By R. C. CANNON, B.Sc.Agr., Entomologist, Science Branch.

## SUMMARY.

*Studies of the host relationships, seasonal history, and egg-laying habits of the potato tuber moth, experiments in its control in potatoes with DDT and BHC foliage sprays and dusts, and observations on cultural methods of control conducted at Home Hill in northern Queensland during 1946 and 1947 are described.*

*It has been concluded that the moth does not carry over from season to season in the Lower Burdekin district, and that this is due to the absence of summer-growing cultivated or native Solanaceae. From this it has been inferred that seasonal outbreaks result from introductions with "seed" stocks which, of necessity, are obtained annually from southern districts.*

*Haulm infestation was effectively controlled by the application of 0·1 per cent. DDT sprays at intervals of up to 3 weeks, and commencing 3 weeks after germination; 2·0 per cent. DDT dusts reduced infestation, but were inferior to sprays.*

*BHC spray had such a pronounced phytotoxic effect on the plant that its use was discontinued long before the termination of the experiment; when applied regularly, it reduced yields by about 1½ tons per acre. A 4·0 per cent. dust produced less severe injury and was not more effective than the DDT dust.*

*Tuber infestation was reduced to 7 per cent. or less by regular applications of 0·1 per cent. DDT foliage sprays, and comparable results were obtained with 2·0 per cent. DDT dust.*

*It is considered that the application of suitable insecticides to the foliage may serve as a useful adjunct to, rather than a substitute for, late hilling in the control of tuber infestation.*

## INTRODUCTION.

The potato tuber moth, *Gnorimoschema operculella* Zell., occurs in all Queensland potato-growing districts. The larvae attack both foliage and tubers, but the heaviest losses are usually those resulting from direct damage to the tubers. In severe outbreaks, mining in the haulms may be extensive and cause considerable reduction in yield, while in extreme cases and under very dry conditions plants may be completely destroyed.

Considerable attention has been devoted to the problem of tuber moth control. Since most insecticides had proved unsatisfactory, as the larvae are well protected during the period of feeding, control measures in the past have been directed more towards cultural methods designed to provide a mechanical barrier of soil to prevent larvae reaching the underground tubers. The special properties of DDT as a contact insecticide prompted the inauguration of trials with this material for the control of potato tuber moth in tobacco and potatoes. It proved highly effective against this insect in tobacco, almost completely eliminating leaf mining (Cannon and Caldwell, 1946), and, since the present investigations were commenced, has also been reported to be successful in reducing haulm damage in potatoes (Lloyd, 1946).

Of recent years there has been a rapid expansion of potato production on the Burdekin delta, in northern Queensland, and this has been accompanied by some serious outbreaks of tuber moth. In order to escape the high summer temperatures, the crop is grown during the winter with irrigation. Nowhere else in Australia are potatoes grown under comparable conditions, and modifications of established cultural practices have been evolved which are in many respects peculiar to the district. For this reason, it was considered desirable to investigate the problem of tuber moth control with particular reference to local conditions.

## SCOPE OF THE INVESTIGATIONS.

The life history of the insect has been studied by a number of workers and is fairly well known. However, it was considered that further information relating to its egg-laying habits, particularly insofar as they relate to tuber infestation in the field, would be desirable. Some attention was, therefore, given to this aspect of the problem. At the same time, an attempt has been made to clarify the seasonal history of the insect and its relation to cultivated and native hosts in the Lower Burdekin district.

The main purpose of the investigations concerned control of the pest in the field, with particular reference to the use of insecticides. An earlier trial had been carried out by Caldwell (1945) with late foliage sprays of DDT; the results indicated that these late sprays were inadequate to cope with a severe outbreak. The work reported here included two large-scale field experiments carried out in 1946 and 1947 with the object of investigating the usefulness of DDT and BHC as foliage sprays or dusts, and the ultimate formulation of a suitable commercial treatment schedule. Cultural practices designed to eliminate or reduce tuber infestation were also studied in the field, but no formal experiments were carried out.

## HOST RELATIONSHIPS AND SEASONAL HISTORY.

Before proceeding with a discussion of the problem, the climate of the area will be briefly described, since it has a distinct influence on cropping practices. In tropical northern Queensland, particularly along the coastal belt, there is not the same seasonal differentiation as in temperate regions. Mean temperatures are high, with a seasonal range of only about 15° to 20°F., and frosts are infrequent. On the Burdekin delta mean monthly temperatures range from 65° to 81°F. It is an area of essentially summer rainfall of a monsoonal nature, with a light winter rainfall. The district comes under the influence of the summer monsoons, but does not receive the high precipitations of the more northerly region. The mean rainfall for December is about 4 inches, and the peak is a little over 11 inches in January; thereafter there is a fairly regular decrease to a little over 2 inches in April, and the months May to November have under 2 inches, with an average of about 1 inch per month.

The potato tuber moth, though primarily a pest of potatoes, attacks a number of crops, such as tobacco, tomatoes, cape gooseberry, egg plant and peppers; in addition, many native plants of the family Solanaceae may serve as hosts. None of these is grown extensively during the summer months. Hence, as part of the general programme of investigation, a survey was undertaken to ascertain the nature and distribution of native Solanaceae which might serve as summer hosts of the tuber moth. However, the only native members of this family found at that time of the year were a few large and old specimens of *Physalis minima* and some large specimens of *Solanum torvum.* All plants of these species encountered in the course of the survey were examined for the presence of tuber moth larvae in leaves or stems; there was no sign of mining, and no larvae were obtained from the material. Following the monsoonal rains large numbers of *P. minima* plants appeared in old cultivations, and limited numbers of plants of *Datura* sp. were to be found in sandy deposits left by floods. Young plants of both species were all particularly healthy and showed no evidence of mining. These native species are essentially winter-growing annuals; they disappear during the summer, re-appearing after the rainy season. There are thus no native species persisting through the summer which might serve as hosts for tuber moth after the disposal of winter-grown susceptible crops.

Few insects appear to survive the period of two to three months during the warmest part of the year. It follows, therefore, that introductions from some outside source may be responsible for the initiation of seasonal outbreaks in autumn. In view of this conclusion, attention was next turned to the condition of "seed" supplies entering the district.

In 1945 a large consignment was heavily infested with tuber moth, and most farmers received a quota from this source, so that it was more or less uniformly distributed about the district. It is probably no coincidence that in this season the worst outbreak of tuber moth for many years occurred, when it was estimated that at least 30 per cent. of the crop was unmarketable on account of tuber infestation. Here, at least, was circumstantial evidence of "seed" in relation to tuber moth outbreaks, sufficient to warrant attention in subsequent seasons.

In 1946 most of the "seed" appeared to be free of tuber moth, but a consignment of the variety Bismarck, received about May, would not have been classed as heavily infested. Seven bags, taken at random, were obtained from this consignment for Departmental plantings, and were subjected to close scrutiny whilst being held pending planting. About the middle of May it was observed that moths were numerous, and one bag was emptied and picked over. From this sample 110 intact pupae were collected and 100 per cent. emergence resulted; apart from this, many pupae were damaged and about 100 or more pupating larvae were noted. Allowing for adults which had already emerged, it was estimated that each bag would harbour at least 300 individuals. Based on the relationship of temperature to rate of development in this species (Atherton, 1936; Attia and Mattar, 1939), it was calculated that, under local climatic conditions, two more generations would be produced by the end of August, making three generations within the life of a crop in the field. It is, therefore, evident that populations of considerable magnitude might easily arise from introductions with "seed," even though it might not be particularly heavily infested.

It was not possible to pay the same attention to other portions of this consignment, but many of them were traced. Generally speaking, the incidence of tuber moth in 1946 was light, severe outbreaks being to a large extent localized. However, it is significant that these outbreaks, often widely separated, all occurred in crops grown from this particular batch of Bismarck "seed," or in crops growing adjacent to plantings of the "seed."

In 1947 an effort was made to check the condition of "seed" supplies as they arrived, and samples of most consignments were examined; very few were entirely free of tuber moth, and some were heavily infested. Subsequently, the pest was active fairly early in the season and only a few crops, including those which had received foliage sprays of DDT, escaped early haulm damage. It is also rather significant that one farmer, who had treated a heavily infested batch of "seed" with DDT before planting, had no appreciable haulm damage in his crop. Towards the end of the season moths were very prevalent, though rather less numerous than in 1945.

The evidence so far accumulated, and presented herein, all points to "seed" as the main source from which fresh populations originate each season in the Lower Burdekin district. Consequently, it is considered that high moth populations might be avoided by strict attention to the condition of "seed" stocks secured for district plantings. It is admitted that the detection of eggs, or early larval activity, is extremely difficult, if not impossible, in farm practice. Hence, it becomes necessary to take additional precautions by having all "seed" destined for use in the district treated in the district of origin with a suitable insecticidal dust.

## EGG-LAYING HABITS IN RELATION TO CONTROL IN THE FIELD.

Most workers who have studied the life history of this insect on potatoes have stated that eggs are usually laid on the under-surfaces of leaves, or on the petioles and stems. No reference has been found to oviposition on the ground, or on exposed or covered tubers in the field. On the other hand, Atherton (1936), working on tobacco in northern Queensland, stated that eggs are usually deposited on the surface of the soil near the base of the plants, rather than on the plants themselves. This has an important bearing on control measures, for, if eggs are laid elsewhere than on the plant, complete control could not be achieved by foliage treatment alone.

In the laboratory, a small cage was set up containing fresh potato haulms protruding through a shallow tray of soil, and into this were introduced about 50 moths of both sexes, the females thus having a choice of oviposition sites. After a few days the haulms and soil were examined, and eggs were found on leaves, petioles and stems, usually in somewhat protected situations adjacent to leaf veins, or in grooves of the petioles and stems, but none was found on the loose soil when it was examined undisturbed nor after it was raked over.

In the field, large numbers of moths have been observed sheltering during the day under small clods, leaves and other debris, but in no case were eggs found in these situations. Late in the afternoon the moths leave these hiding places and a period of flight ensues, after which they settle on the foliage. Thereafter they remain quiescent and it is presumed that eggs are laid at that time. On examining plants taken from the field during flight periods, eggs have been found on the foliage, frequently partly obscured by hairs.

In order to discover whether egg-laying moths might be attracted to tubers in the field, a number of developing tubers near the surface were exposed during a period of peak moth activity, but before the haulms had commenced to die off. After several nights' exposure these tubers were removed and examined, but no eggs were found. Hence it has been concluded that exposed tubers are less attractive than green foliage.

Studies in the field further revealed that larvae will continue to feed in the leaves as long as they remain green and rarely desert their original mines until fully fed. Under these conditions, larvae which have been operating in the upper leaves frequently pupate on the foliage near the mine. Larvae in the lower leaves, particularly if they are actually touching the ground, usually leave the plant and enter the soil through a protective silken tunnel and pupate near the surface. As the leaves begin to die off, larvae forsake their mines and move downwards along the stem; older larvae may pupate, but the younger ones enter at leaf axils and re-commence feeding, often reaching the stems. In the later stages of plant senescence large numbers of larvae may be seen escaping from mines and moving downwards until they reach the ground, where they wander about and eventually burrow into the soil. Older larvae, no doubt, commence pupation, while many of the younger ones succeed in reaching tubers, where they can resume feeding.

These observations support the view, implied by other workers, that the moth will not oviposit on the soil provided there is healthy, green foliage available. They are in agreement with Graf's (1917) statement that "the larva does not prefer to feed on the tubers in the ground as long as the potato tops are green and succulent.'' It is inferred, however, that direct infestation of tubers may take place after the haulms cease to be sufficiently attractive. It is fairly evident that tuber infestation is largely the result of migration of larvae from the haulms after the onset of senescence. Hence, field control should be designed to reduce breeding on the foliage and to provide a mechanical barrier capable of preventing migrating larvae from gaining access to tubers in the ground.

## EXPERIMENTS WITH FOLIAGE SPRAYS AND DUSTS FOR TUBER MOTH CONTROL.

The object of these experiments was to investigate and compare the efficacy of DDT and BHC in controlling tuber infestation, when applied to the foliage of potato plants. The accumulated evidence from various sources, including the work on tobacco previously mentioned, had already indicated that DDT might reasonably be expected to control haulm infestation. The studies on egg-laying habits of the insect had not been undertaken when the first of these experiments was planned, and the extent to which haulm infestation might be related to tuber infestation was still in doubt. In the event of either of the insecticides proving effective, it was desired to secure sufficient data for the formulation of treatment schedules, and provision was made for investigating—

(1) a range of treatments over the growing period of the crop to determine the starting point for the application of control measures; and

(2) the maximum interval between applications commensurate with adequate economic control.

Both experiments were of essentially the same design; some modifications were introduced into the 1947 experiment in view of the results obtained from the 1946 experiment. They were conducted at Home Hill on different farms and were included among the later plantings so that they would encounter the higher moth populations which are characteristic of these late plantings.

### Design of the Experiments.

In both experiments the design involved split-plots, with main-plots comprising ranges and frequencies of application arranged factorially. These were subdivided into the requisite number of sub-plots to accommodate the types and forms of insecticide included for trial.

Potatoes were planted in rows 3 ft. 6 in. apart and the ''seed'' spaced 12 inches apart. Sub-plots were 6 rows wide and 32 ft. long, with buffer strips 5 ft. wide at the ends and separating the sub-plots. In order to reduce interference between treatments due to wind drift of insecticides, particularly the dusts, only the inner four rows of each plot were treated. As a further precaution against border effects, only the two inner rows were taken in computing data on infestation and yield. The plot units from which data were obtained were thus approximately 1/200 acre in area. The whole area of experiments exceeded 1 acre each.

In both experiments the main-plot treatments were identical; they comprised 3 ranges and 2 frequencies of application, as follows:—

**Ranges of Application.**

R1—First application made 3 weeks after germination.

R2—First application made at a stage corresponding to the initiation of flowering, estimated at 5 weeks after germination.

R3—First application made immediately after flowering, and about 2 weeks after R2.

**Frequencies of Application.**

F1—Applications made at 2-weekly intervals.

F2—Applications made at 3-weekly intervals.

Factorial arrangement of the two groups gave 6 combinations, which constituted the main-plots. There were 3 replications in the 1946 experiment, and 2 replications in 1947.

Sub-plot treatments differed as between the two experiments; details are given separately hereunder.

**Sub-Plot Treatments in Experiment No. 1 (1946).**

The plan provided for the inclusion of DDT and BHC as sprays and dusts. In view of the toxicity of BHC to tobacco, and the botanical relationship of the two crops, there was reason to expect that it might have a similar effect on potatoes. However, as no opportunity was afforded for carrying out a phytotoxicity test in advance of the main experiment, BHC was included, with provision for its replacement should undesirable symptoms appear. The original sub-plot treatments were:—

S1—DDT mayonnaise emulsion spray containing 0·1% p-p isomer of dichloro-diphenyl-trichloroethane.*

S2—BHC mayonnaise emulsion spray containing 0.2% gamma isomer of benzene hexachloride.†

D1—DDT-pyrophyllite dust containing 2.0% p-p isomer.‡

D2—BHC-pyrophyllite dust containing 0.4% p-p gamma isomer.‡

C—Control; untreated.

Within a week after the first application, a pronounced phytotoxic effect was observed following the BHC spray; the same effect, in a milder form, was

* Prepared from "Pespruf 20," a proprietary mayonnaise emulsion containing 20 per cent. of the p–p isomer of dichloro-diphenyl-trichloroethane.

† Prepared from "E.F. 488M," an experimental mayonnaise emulsion containing 1·95 per cent. of the gamma isomer of benzene hexachloride, supplied by Imperial Chemical Industries of Australia and New Zealand Ltd.

‡ Prepared from impregnated pyrophyllite dust containing 10 per cent. of the p–p isomer and 1·3 per cent. of the gamma isomer, respectively.

associated with the dust. Accordingly, the BHC spray was replaced by a 0.2% DDT spray in the R2 and R3 series. In the R1 series the second application was made with 0.2% DDT, but subsequent applications reverted to the original BHC spray, with the object of obtaining some data on its influence on yield.

**Sub-Plot Treatments in Experiment No. 2 (1947).**

In view of the phytotoxicity of BHC already mentioned, the only insecticide retained in this experiment was DDT, and it was restricted to one level each of spray and dust. In the meantime, consideration had been given to the inclusion of a fungicide to control target spot (*Alternaria solani*), which has been of considerable importance from time to time. In view of the suspected interference of copper compounds with the toxicity of DDT, as well as for other considerations, a copper fungicide was included in a factorial arrangement of 6 sub-plots, as follows:—

S1—DDT mayonnaise emulsion spray containing 0.1% p-p isomer of dichloro-diphenyl-trichloroethane.*

S2—DDT-pyrophyllite dust containing 2.0% p-p isomer.*

C1—Control; untreated.

D1—DDT spray as for S1, plus 0.17% copper as copper oxychloride.†

D2—DDT dust as for D1, plus 10.0% copper as copper oxychloride.‡

C2—Fungicide only; spray of 0.17% copper as copper oxychloride.†

## Field Notes on Experiment No. 1.

The area was fertilized and planted with the variety Brownell on June 17, 1946; the first plants appeared above ground on July 11, though germination was not complete until about July 24. The first hilling was carried out on August 4, following which the crop was irrigated at intervals of 4 to 9 days, receiving a total of about 16 inches of water. The crop made exceptionally good top growth and was harvested on October 10, 16 weeks after planting.

As already mentioned, tuber moth was not severe in 1946 and very few moths were encountered on the farm where the experiment was established. In the experiment proper no moths were observed until the last few weeks and even then only odd individuals were seen on the wing in the late afternoon. Haulm mines were almost entirely absent, even when the crop was mature, though a few may have been overlooked at this late stage.

The first insecticide application was made on August 10 and the schedule followed as planned, with variations of not more than a day in the intervals prescribed. Sprays were applied with a knapsack sprayer in sufficient quantity

* Prepared from the same materials used in Experiment No. 1.

† Prepared from "Cuprox," a proprietary dispersible powder containing 50 per cent. copper as copper oxychloride.

‡ Prepared from "Smutol," a proprietary fungicidal dust containing 50 per cent. as copper oxychloride.

to thoroughly wet the upper surface of the foliage, the average rate of application being 100 gallons per acre. Dusts were applied with a bellows type knapsack duster at a rate of 20 to 30 pounds per acre. There was a noticeable drifting of dusts across the plots, but it was considered that the small dust deposit reaching plots for which it was not intended could not have materially interfered with the designed treatments.

### Field Notes on Experiment No. 2.

The experimental area was not planted as a separate unit, but as part of the whole field of 20 acres of potatoes. A mechanical potato planter, which applied fertilizer at the same time, was used. The field was planted with the variety Brownell on May 15, 1947; germination commenced on June 10 and was more or less complete by June 17. The crop received the initial hilling on July 9, and was irrigated at regular weekly intervals thereafter, receiving a total of about 12 inches. It made fair top growth, but was by no means as vigorous as the 1946 crop. It was remarkably free from leaf-roll and target spot, for the control of which fungicides had been included in this experiment.

The incidence of tuber moth was much greater than in the previous season; the pest was widely distributed and haulm damage was observable within the first 3 weeks after germination. The crop, with the exception of the experimental section, was promptly sprayed with 0.1% DDT and copper oxychloride. This had the effect of reducing the over-all population in the field, but did not appear to materially influence the experimental strip. Moths were still present there in relatively large numbers, and haulm injury was evident, particularly in the control plots and the untreated border rows. Conditions in 1947, therefore, provided a more severe test of the treatments than they did in 1946.

The application of insecticides and the fungicide, using the same equipment as in 1946, was commenced on July 15, 4 weeks after germination. Rainy and windy conditions were encountered at times, and interfered with the regular schedule of treatments. The actual dates of application are shown hereunder :—

| Date of Application. | R1. | | R2. | | R3. | |
|---|---|---|---|---|---|---|
| | F1. | F2. | F1. | F2. | F1. | F2. |
| July 15 .. .. .. .. .. | x | x | | | | |
| July 29 .. .. .. .. .. | x | | x | x | | |
| August 6 .. .. .. .. .. | | x | | | | |
| August 12 .. .. .. .. | x | | x | | x | x |
| August 25 .. .. .. .. | x | x | x | x | x | |
| September 2 .. .. .. .. | | | | | | x |

The greatest departure from the schedule occurred with the second application of R2F2, in which the interval was 27 days, due to bad weather during the period August 18-23.

## PHYTOTOXIC EFFECTS OF BHC.

BHC, as spray and dust, was included only in Experiment No. 1 and within a week of the first application a marked effect on the foliage of BHC-sprayed plots was noticeable, it being possible to distinguish affected plots from a distance. There was a yellowing of the foliage, with thickening and curling of leaves, somewhat reminiscent of the symptoms associated with leaf-roll. Later, dark necrotic lesions developed, eventually destroying a large part of the total leaf surface. When the spray was withheld subsequent growth was quite normal, but the symptoms reappeared when spraying was resumed. In the case of the dust, symptoms were less severe, but otherwise similar to those produced by the spray. This reaction to BHC was not entirely unexpected in view of the experience with tobacco (Cannon and Caldwell, 1946), where the symptoms were not unlike those in potatoes.

Spray injury was so severe that it was evident that yields would be adversely affected if the application of the spray was continued. As the dust was so much less drastic in its action it was retained, but, for the second application, a 0·2 per cent. DDT spray was substituted for the BHC spray. Before the next application, however, it was decided to revert to the original BHC spray in the R1 series only, so as to secure some data relative to its effect on yield. In this series, therefore, except for the substitution of DDT in the second application, plots received BHC spray at the prescribed intervals. Table 1 sets out data on yield relative to BHC-sprayed plots and those not so treated.

**Table 1.**

MEAN YIELDS IN BHC-SPRAYED PLOTS AND GROUPS OF PLOTS OTHERWISE TREATED (EXPRESSED AS TONS PER ACRE OF NO.1 GRADE POTATOES).

| — | Control. | Mean of S1, D1, D2. | S2. |
|---|---|---|---|
| Mean Yield of Plots . . . . . . . . | 6·39 | 6·62 | 4·94 |
| Other Treatments less S2 . . . . . . | 1·45 | 1·68 | . . |
| S.E. of Difference . . . . . . . . | ±0·40 | ±0·36 | . . |

The above differences are significant at the 1 per cent. level. The application of BHC spray was responsible for yield depressions of the order of 1½ tons per acre.

Though foliage injury induced by the dust was less severe, there was undoubted evidence of toxicity, and this disposes of any suspicion that emulsifying agents in the spray, rather than the BHC itself, may have been responsible for the condition. The materials used were based on a commercial product consisting of a mixture of isomers, and containing only 13 per cent. of the gamma isomer. Since the mixture of isomers is involved, it is not clear whether all four isomers are equally toxic, and the point will remain in doubt until the pure gamma isomer is tested. In the meantime, BHC products at present available, containing a mixture of alpha, beta, gamma and delta isomers, are out of the question for use on potatoes.

## INFLUENCE OF DDT ON YIELD.

In neither experiment was there the slightest indication of foliage injury associated with the application of DDT, even where the concentration in the spray was increased to 0·2 per cent. in some series in Experiment No. 1. Appropriate yield data for the two experiments are given in Table 2. In Experiment No. 2 the yields are means of plots with and without the copper fungicide.

**Table 2.**

MEAN YIELDS IN DDT-TREATED AND CONTROL PLOTS IN EXPERIMENTS NOS. 1 AND 2 (EXPRESSED AS TONS PER ACRE).

| — | Experiment No. 1. | | Experiment No. 2. | |
|---|---|---|---|---|
| | Grade 1. | Grades 1 and 2. | Grade 1. | Grades 1 and 2. |
| 0·1% DDT Spray .. .. | 6·39 | 7·10 | 3·33 | 4·21 |
| 2·0% DDT Dust .. .. | 6·90 | 7·69 | 3·32 | 4·17 |
| Control .. .. .. | 6·39 | 6·77 | 3·20 | 4·11 |
| 0·2% DDT Spray .. .. | 6·64 | 7·45 | * | * |

* The means are based on yields of plots in R2 and R3 series only and are not subject to the same tests of significance as the other data.

The only significant difference is that between dusted and sprayed or control plots in Experiment No. 1, and that is just equal to the difference necessary for significance at the 5 per cent. level. The yields of treated plots were in all cases equal to, or better than, those of control plots, and it may be concluded that DDT did not significantly reduce yields.

## EFFECT OF FOLIAGE TREATMENT ON HAULM INFESTATION.

During the course of Experiment No. 1 moth populations were extremely low and no measurable haulm infestation was encountered during the growing period. It is possible that a few mines may have been commenced at a late stage and were overlooked. In the second experiment the pest was much more prevalent and haulm mines were in evidence within 3 weeks after germination. The extent of this was assessed on August 22, about a fortnight after flowering, and following the initial post-flowering insecticide application. Ten plants more or less in the centre of each plot, taking 5 consecutive plants in each of the two datum rows, were examined. Subject to certain limitations, due to the coalescence of some mines and the overlooking of others, the number of larval mines for each group of 10 plants was recorded, and used as a measure of infestation. In order to restrict all observations to the one day, two groups only of the plots were assessed in this manner, namely—

(*a*) all plots in the R1 series, for determination of the effects of the several insecticides; and

(*b*) sprayed plots only in all series, for evaluation of the effects of varying treatment schedules.

Table 3 sets out the sub-plot data from series R1, and Table 4 those relative to treatment schedules with the DDT sprays.

**Table 3.**

TUBER MOTH INFESTATION OF HAULMS IN SERIES R1 (EXPRESSED AS MEAN NUMBER OF MINES PER 10 PLANTS).

| Insecticide. | Without Copper. | With Copper. | Mean. |
|---|---|---|---|
| 0·1% DDT Spray .. .. .. .. | 16·8 | 12·0 | 14·4 |
| 2·0% DDT Dust .. .. .. .. | 165·5 | 162·2 | 163·9 |
| Control .. .. .. .. .. .. | 206·5 | 236·5 | 221·2 |
| Mean .. .. .. .. .. | 136·7 | 129·6 | 133·2 |
| Difference for significance at 5% level .. .. | .. | .. | 41·6 |

It is clear that DDT spray was highly effective in reducing haulm infestation to very small proportions. Although the dust did exercise some control over infestation, it did not reduce it to a level comparable with that of the spray. It is equally apparent that the inclusion of the copper fungicide had a negligible influence on the effectiveness of the DDT.

**Table 4.**

TUBER MOTH INFESTATION IN DDT-SPRAYED PLOTS IN ALL SERIES (EXPRESSED AS MEAN NUMBER OF MINES PER 10 PLANTS).

| Treatment Schedule. | Applied 2-Weekly. | Applied 3-Weekly. | Mean. |
|---|---|---|---|
| Commenced 2 weeks before flowering .. | 20·5 | 8·2 | 14·4 |
| Commenced immediately before flowering .. | 17·5 | 51·2 | 34·4 |
| Commenced immediately after flowering .. | 74·5 | 94·2 | 84·4 |
| Mean .. .. .. .. .. | 37·5 | 51·2 | 44·4 |
| Difference for significance at 5% level .. .. | .. | .. | 36·2 |

The only significant difference occurs between the three ranges of treatment, where R1 and R2 are both definitely superior to R3. This is understandable in the light of the outbreak to which the trial was subjected, as populations had reached a relatively high level before applications in the latter series were commenced. It is fairly certain that haulm infestation can be controlled with DDT, at least as a spray, provided treatment commences at the first sign of infestation, judged by the presence of mines in the lower leaves. The differences between 2-weekly and 3-weekly schedules are not significant, so that there is probably little to be gained by reducing the interval between treatments to less than three weeks.

## EFFECT OF FOLIAGE TREATMENT ON TUBER INFESTATION.

Immediately after harvesting, the tubers were examined for tuber moth larvae or evidence of their presence. Free and infested tubers from each plot were counted and weighed, taking into account grades 1 and 2, but discarding chats. Previous work at Ayr had demonstrated a close correlation between tuber infestation estimates based on numbers and weights, and, for the purposes of this report, infestation percentages have all been calculated on a weight basis, in terms of total yields of grades 1 and 2. For statistical analysis individual plot percentages have been transformed to degrees by the inverse sine transformation, and comparisons made in terms of the transformed variate.

In both experiments infestation of treated plots was significantly less than that of controls, though infestation of the latter was itself relatively low. This was to be expected in Experiment No. 1, where the general population level was low, but is not so easily explained in the case of Experiment No. 2. Both crops were grown under ordinary commercial conditions; they were subjected to the usual cultural practices followed in the district and applied at the discretion of the farmer concerned. The experiments were carried out on farms owned and farmed by the same man, who regularly applied rather drastic hilling with the object of reducing tuber infestation. It would appear that this measure, in itself, reduced infestation in both instances to a level of about 10 per cent., irrespective of foliage treatments, as shown by the results of controls.

The results are in distinct contrast to those based on haulm infestation in Experiment No. 2, where DDT-sprayed plots were, for all practical purposes, free of tuber moth, while the controls were heavily infested. As mentioned earlier, large numbers of larvae migrate to the ground during haulm senescence, and it has been concluded that these are primarily responsible for tuber infestation. However, the fact that in Experiment No. 2 about 6 per cent. of the tubers in plots virtually free from haulm infestation were affected would suggest that migrating larvae are not entirely responsible for the infestation of tubers. It might be argued that larvae could conceivably move across from untreated rows, but the presence of treated buffer rows adjacent to the datum rows would, it is considered, preclude this possibility. It seems more likely that gravid females reaching datum rows at or near maturity might, in the absence of green foliage, oviposit at the base of plants or on exposed tubers, though such behaviour has not actually been observed.

**Table 5.**

TUBER INFESTATION OF SUB-PLOTS (EXPRESSED AS SUB-PLOT MEANS IN TERMS OF PERCENTAGES AND DEGREES).

| — | Percentage Infested. | | Degrees. | |
|---|---|---|---|---|
| | Exp. No. 1. | Exp. No. 2. | Exp. No. 1. | Exp. No. 2. |
| 4·0% BHC Dust .. .. .. | 7·5 | .. | 15·3 | .. |
| 0·1% DDT Spray .. .. .. | 4·1 | 7·0 | 11·1 | 14·2 |
| 2·0% DDT Dust .. .. .. | 6·5 | 8·9 | 14·3 | 16·8 |
| 0·1% DDT Spray plus Copper .. | .. | 6·1 | .. | 13·8 |
| 2·0% DDT Dust plus Copper .. .. | .. | 6·7 | .. | 14·3 |
| Copper Spray .. .. .. .. | .. | 8·7 | .. | 16·9 |
| Control .. .. .. .. .. | 9·9 | 11·3 | 18·0 | 19·4 |
| Difference for Significance at 5% level | * | * | 2·6 | 3·3 |
| Mean Treated .. .. .. .. | 6·0 | 7·5 | 14·3 | 15·2 |
| Control .. .. .. .. .. | 9·9 | 11·3 | 18·0 | 19·4 |
| Difference for Significance at 1% level | * | * | 2·9 | 3·5 |
| Mean DDT Spray .. .. .. | * | 6·6 | * | 14·0 |
| Mean DDT Dust .. .. .. | * | 7·8 | * | 15·5 |
| DDT with Copper .. .. .. | * | 6·4 | * | 14·0 |
| DDT without Copper .. .. .. | * | 7·9 | * | 15·5 |
| Difference for Significance at 5% level | * | * | * | 2·4 |
| 0·2% DDT Spray .. .. .. | * | 5·0 | * | 12·6 |

* The infestation is based on plots in R2 and R3 series only, and the figures are not subject to the same tests of significance as the other data.

In Experiment No. 1, the 0.1% DDT spray was significantly better than the DDT or BHC dusts, but in Experiment No. 2 DDT sprays were only slightly better than the dusts, whether taken separately or grouped. This result is in close agreement with that obtained when using DDT sprays and dusts against the same insect in tobacco (Cannon and Caldwell, 1946). It was then suggested that the sprays may have possessed slightly superior residual properties. Another point to consider, however, is the possibility of providing equivalent control by increasing the concentration of DDT in the dust.

Since it has already been shown that BHC is toxic to the potato plant, and that copper oxychloride spray alone is distinctly inferior to DDT in reducing tuber infestation, the main plot data have been calculated from DDT-treated sub-plots only. Thus, in Experiment No. 1 only sub-plots S1 and D1 were used, and in Experiment No. 2 main-plot data are based on sub-plots S1, S2, D1 and D2 only.

**Table 6.**

TUBER INFESTATION OF MAIN-PLOTS (EXPRESSED AS SUB-PLOT MEANS IN TERMS OF PERCENTAGES AND DEGREES).

| Treatment Schedules. | Percentage Infested. | | Degrees. | |
|---|---|---|---|---|
| | Exp. No. 1. | Exp. No. 2. | Exp. No. 1. | Exp. No. 2. |
| R1F1 .. .. .. .. .. | 3·4 | 6·2 | 10·1 | 13·7 |
| R1F2 .. .. .. .. .. | 4·7 | 4·6 | 12·3 | 12·0 |
| R2F1 .. .. .. .. .. | 4·3 | 6·6 | 10·5 | 14·2 |
| R2F2 .. .. .. .. .. | 5·6 | 8·4 | 13·5 | 16·0 |
| R3F1 .. .. .. .. .. | 7·1 | 6·7 | 15·1 | 13·9 |
| R3F2 .. .. .. .. .. | 6·7 | 10·6 | 14·5 | 18·8 |
| Difference for Significance at 5% level | .. | .. | 5·4 | 4·1 |
| Commenced 2 weeks before flowering .. | 4·1 | 5·4 | 11·2 | 12·9 |
| Commenced just before flowering .. | 5·0 | 7·5 | 12·0 | 15·1 |
| Commenced after complete flowering .. | 6·9 | 8·6 | 14·8 | 16·4 |
| Difference for Significance at 5% level | .. | .. | 3·8 | 2·9 |
| 2-weekly applications .. .. .. | 5·0 | 6·5 | 11·9 | 14·0 |
| 3-weekly applications .. .. .. | 5·7 | 7·9 | 13·5 | 15·6 |
| Difference for Significance at 5% level | .. | .. | 3·1 | 2·4 |

In both experiments the R1 schedule, with applications commencing 2 weeks prior to flowering, was significantly better than R3, commencing after flowering, and the R2 schedule was intermediate, but not differing significantly from either of the others. A 3-weekly interval between applications was not significantly inferior to a 2-weekly interval, except in the R3 series in Experiment No. 2 where, as already mentioned, haulm infestation had reached considerable proportions before any insecticide was applied.

## OBSERVATIONS ON CULTURAL METHODS OF CONTROL.

When these insecticidal investigations were undertaken it was intended to carry out field trials with cultural methods of control, but, as circumstances did not permit the establishment of suitable experiments, studies were limited to examination of existing practices. Life history studies led to the conclusion that the critical stage for tuber infestation occurs during the period of haulm senescence, when the provision of an adequate soil barrier becomes imperative.

In the Lower Burdekin district it has been the usual practice to commence hilling somewhat earlier, for a number of reasons. Quite apart from the question of tuber moth control, relatively early hilling is a natural accompaniment of the construction of deep inter-row irrigation furrows. Under local conditions these furrows are necessary, though they might be less deep if the ground was suitably graded, but it is considered that they should be prepared with the minimum movement of earth towards the plants. With the vigorous top growth of crops it is also desirable that some soil should be thrown towards the plants to give support to the haulms, which would otherwise sprawl across the furrows and be damaged by late hilling.

Even with a row spacing of 39 to 45 inches, which is greater than that usually allowed elsewhere, it has been found that the hill is rather unstable and tends to weather down with the passage of time. In any case, in most varieties, with the possible exception of Bismarck, tuber-forming stolons tend to extend upwards and outwards, until they are relatively close to the soil surface, before tuber enlargement takes place, and early hilling tends to encourage the formation of tubers further from the main stem. These disadvantages have been partly overcome by repeating the operation, so that it has become one of progressive hilling. One of the disadvantages of this is that the final hill, required at the most critical stage, is even more unstable.

In practice, the method of progressive hilling has achieved some control of the pest; but, based on control plot data from the field experiments, it has not reduced tuber infestation below about 10 per cent. It has, therefore, been concluded that existing practices might, with advantage, be modified by reducing pre-flowering hilling and concentrating on more drastic hilling at the onset of haulm senescence. Such modifications were adopted by a few growers in 1947, and it is considered that their results fully justified the measures.

## GENERAL DISCUSSION OF RESULTS.

Field studies associated with these investigations have led to the interesting conclusion that tuber moth may not survive from season to season in the Lower Burdekin district. It is explained by the fact that cultivated and native Solanaceous plants in this region are almost entirely winter-growing annuals, which though present during the potato-growing season are virtually absent in the summer months. In some respects the problem of control is therefore simplified, since there is no established local population of any size to contend with at the beginning of each potato season. With the recent re-introduction of tobacco growing in the district, and its probable rapid expansion, the position is likely to be modified, since this crop is susceptible to attack and would be in the field during part, if not all, of the summer. However, control of this species in tobacco is essential and can be achieved very effectively by the use of DDT, and it is unlikely that any large population would be allowed to survive on this crop, except on stalks abandoned after harvesting.

Due to the presence in the district of *Myzus persicae* Sulz., a vector of the potato leaf-roll virus, it is generally accepted that the production of "seed" locally is out of the question, quite apart from any consideration of the difficulty of holding "seed" for as long as six months. Hence, it is inevitable that fresh stocks of "seed" must be drawn from southern districts each season. In order to avoid, or at least reduce, the risk of introducing nucleus populations of potato tuber moth, as probably no potato-growing district in Australia is completely free from the pest, it is considered that such "seed" should be treated with a suitable protective dust in the district of origin as soon as possible after harvesting.

Field studies, combined with the results of the two field experiments, have led to the conclusion that tuber infestation in the field is usually initiated by larvae migrating from senescent haulms. Hence, it has been inferred that destruction of larvae attacking the foliage will, to a very large extent, control tuber infestation. On the other hand, it is probable that egg-laying takes place on the ground or on exposed tubers after the haulms cease to be attractive to egg-laying moths. Complete control of the insect in potato crops does not entirely eliminate sources of late infestation, since it is possible that moths from neighbouring patches of susceptible weeds might reach the field and oviposit at the base of plants. Therefore, other methods of control, such as late hilling, need to be considered in conjunction with insecticidal methods.

The phytotoxicity of BHC spray to the potato plant was so pronounced, and the yield depression of $1\frac{1}{2}$ tons per acre so great, that this insecticide must for the present be abandoned for use on potatoes. In these experiments, where a comparison between 4 per cent. BHC dust and 2 per cent. DDT dust is afforded, the two dusts exhibited about equal toxicities to tuber moth. Therefore, should it eventually prove that the phytotoxicity of the crude product is not a property of the gamma isomer, and if products consisting of the pure gamma isomer are later produced commercially, consideration may have to be given to further trials with that insecticide.

In considering the effect of copper compounds on the toxicity of DDT to insects, reference to Tables 3 and 5 reveals that the inclusion of copper oxychloride had no appreciable effect on the toxicity of DDT. This is particularly interesting in view of the conclusion of Common (1947) that the addition of copper carbonate or copper oxychloride to DDT-pyrophyllite dusts reduced their toxicity to *Heliothis armigera* Hbn. The relative susceptibility of the two insects to DDT may, in part, explain the different experimental results. Though copper oxychloride spray alone did not reduce haulm infestation, it did reduce tuber infestation below that of controls. To an extent this is in agreement with the finding of Atherton (1936), that the application of cuprous oxide emulsion sprays reduced *G. operculella* infestation of tobacco seed-beds. Within a few weeks of harvesting it was observed that plots which had received sprays containing copper were slightly greener than the rest, though the difference was by no means clear-cut. This may, however, provide an explanation of the slight reduction in tuber infestation in that the foliage of such plots would be attractive to moths for a slightly longer period, thereby reducing oviposition on the ground, where hatching larvae would be less likely to come in contact with any insecticide residues.

In Experiment No. 2 there is a fairly close relationship between the control of haulm infestation and the control of tuber infestation by DDT applications. This is very much what would be expected in the light of the earlier conclusion that the bulk of tuber infestation results from the migration of larvae from the haulms. In this experiment the best results were obtained with applications commencing within three weeks of germination. It is considered that this was to a large extent related to the fact that infestation in the field commenced at about this time. Quite obviously, little benefit could be expected from commencing treatment much in advance of the appearance of the pest in the crop. It would seem then that the foliage treatment should be applied at the inception of an outbreak, and might safely be delayed until such time as this occurred. It has also been clear that the interval between successive applications may be extended to 3 weeks; but, since the experiments were not designed to investigate longer intervals, some doubt still exists as to whether the interval might not be further prolonged. There has been evidence, apart from these experiments, which would suggest that applications might be more widely spaced, even to the point of relying on a single application coincident with the first indication of an outbreak.

The evidence of both experiments indicates that complete control of tuber infestation cannot be achieved by foliage treatment alone, effective though it may be. This means that cultural measures, such as late hilling, still have a place in the programme of tuber moth control. Foliage treatment is, however, so effective that the same strict attention to cultural measures as heretofore is not necessary. Taking everything into consideration, there is reason to believe that infestation of tubers may be reduced to very small proportions by the use of a DDT foliage spray combined with late hilling. It is recommended that the insecticide be applied at the first indication of an outbreak, and the application repeated only when haulm infestation shows signs of increasing.

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