DDT FOR THE PROTECTION OF STORED POTATOES.

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SUMMARY.

At the strengths used, DDT, derris and pyrethrum-piperonyl butoxide as dusts and DDT-impregnated Chapman sacks and sugar-bags were all efficacious in protecting stored tubers when the initial infestation was less than 4 per cent. DDT dusts, ranging in concentration from 0.5 to 2 per cent., and containers treated in DDT emulsions ranging in concentration from 0.5 to 2.5 per cent. arrested infestations varying from 8 to 35 per cent. satisfactorily. The higher levels of DDT were more efficacious, however, when the initial infestation exceeded 20 per cent.

Results with pieces of DDT-impregnated burlap and DDT-treated paper strips placed among the tubers were not conclusive.

A 2 per cent. DDT dust applied at the rate of ½ lb. per bag, and a dipping strength of 2 per cent. DDT emulsion for impregnating containers, were considered the most efficacious for general application in the field.

Second-hand lightweight hessian sugar-bags provide a satisfactory alternative to the standard Chapman sacks for storing tubers. Multiple-layered paper bags are not suitable for storing tubers under Queensland conditions.

Quantities of DDT are transferred to tubers when DDT-impregnated containers are handled. DDT residues on tubers, whether acquired from the container or from dust application, persist during storage but are reduced to within safe limits during handling from store and preparation for the table.

I. INTRODUCTION.

Potatoes from the spring-planted crop in South Queensland are harvested in early summer and provide tubers for table use and seed for planting the autumn crop. Also, tubers produced during the winter months in more northern parts of the State are harvested when temperatures are rising. A considerable proportion of these tubers may be stored for a long period under conditions suited to the rapid development of the potato tuber moth, *Gnorimoschema operculella* (Zell.). The incidence of the pest in the tubers from these crops at harvest and during storage is therefore of major importance.

Field control of the tuber moth in Queensland is designed chiefly to provide maximum yields of sound tubers of marketable size (May 1952). At harvest, some infested tubers are often inadvertently included with sound tubers during bagging operations in the field. Also, in bulk stores, where levels of moth populations may be high during summer, infestation from outside the bags is an added problem. The need to destroy these nuclei of infestation from the field and to prevent reinfestation during storage has always been appreciated in Queensland.

The problem of protecting stored tubers from *Gnorimoschema* attack is not confined to this State. Derris, applied as a dust to bagged tubers, was generally recommended in Australia prior to 1940, but its unavailability in later years induced a search for alternative materials. Many inert dusts, including magnesite, pyridine, ferric oxide and kaolin, were tested with varying

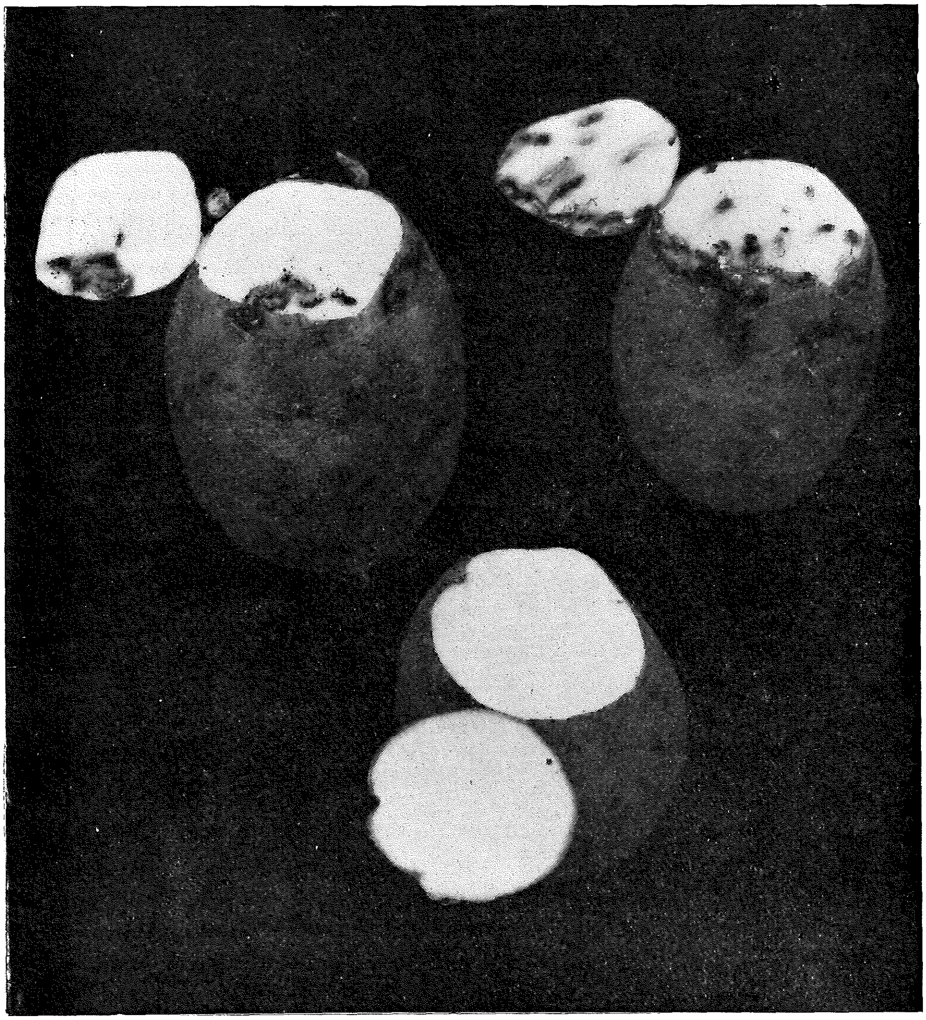

Fig. 1.
Larval Damage to Tubers. Lower tuber not infested.

success (Helson 1942; Lloyd 1943). These materials were merely protectants and for success required humidities below 80 per cent. and a very low initial incidence of infestation (Helson 1942).

Lloyd (1947) advocated dusting tubers with derris soon after fumigation with carbon bisulphide. Fumigation is not practicable under the system of handling adopted in Queensland, and application of an effective insecticide during bagging operations in the field is a more suitable method of control. Walker and Anderson (1944) reported good tuber moth control in seed potatoes with 2 per cent. DDT dust.

Following tests in North Queensland with DDT, derris and magnesite, and in South Queensland with derris, magnesite and other inert dusts (Brimblecombe and Cannon 1949), it was concluded that either DDT or derris could be advocated for protecting stored table potatoes. Helson (1949) had also shown that the addition of ferric oxide did not impair the protection afforded by DDT dust and left tubers a desirable colour.

The dependence of inert dusts on humidity and a low initial infestation for the successful protection of stored potatoes, and the limited availability of derris dust, meant these materials were unsatisfactory for general recommendation in Queensland. The application of a brown-pigmented 2 per cent. DDT dust, at the rate of 8 oz. per bag, as the tubers were bagged for market was considered a more practical method of control.

Though the efficacy of DDT dust, when properly applied, had been demonstrated, further testing at various levels of initial infestation and reinfestation was necessary, while the status of residues on DDT-dusted table potatoes at the end of storage warranted investigation.

In contrast to direct application of insecticidal dust, impregnating the container with DDT had been employed by Hayhurst (1945) and Parkin (1948) to protect stored grain from insect attack. In America, Hofmaster and Anderson (1948) had prevented tuber infestation by storing clean tubers in DDT-impregnated bags, while confetti and paper streamers treated with 5 per cent. DDT significantly reduced tuber infestation but did not give complete control. These workers found that moths emerging in DDT-treated containers moved freely among the tubers and were attracted to the light filtering through the sacking. These moths died within 24 hours of emergence. This American work and somewhat similar tests by Lloyd (1951) in New South Wales were conducted under laboratory conditions.

These methods of applying DDT to protect stored tubers might, it was thought, overcome some of the supposed problems associated with direct DDT dust application and warranted study under field and commercial conditions.

Experiments were carried out therefore in the Gatton district, Lockyer Valley, for three consecutive seasons, commencing in the summer of 1949-50, to investigate the relevant aspects of *Gnorimoschema* control in stored tubers. This involved studying the effects of levels of DDT applied as direct dusts or impregnated in the storage containers, of which three types were used, and of placing strips of DDT-impregnated burlap or brown paper among the tubers. Alternative dusts of possible control value were compared with the current standard. The persistence of the DDT residues in containers and on tubers during storage was also investigated.

II. TUBER PROTECTION.

(1) Materials.

(a) Potatoes.

The variety Sebago was used throughout this work. All tubers were first and second grades as bagged on the farm for marketing. Percentages of tuber moth infestations in the bulk samples varied with source, depending on control measures used during the growth of the crop, but all were within the limits of commercial supply. Normally, tubers are treated with insecticide during bagging operations. The potatoes for these experiments were removed from the field and sampled for tuber moth infestation before insecticides were applied. In some instances, a short time elapsed before this sampling could be undertaken.

Before commencing each experiment, damaged and misshapen tubers were discarded. Where uninfected tubers were required, those showing evidence of larval tunnelling were also discarded. Some, however, usually escaped the sorters, as it was impracticable to identify a proportion of those carrying only eggs and newly emerged larvae.

(b) Containers.

The three types used were:—

(1) The Chapman sack or Australian standard cornsack—41 in. x 23 in. hemmed, $2\frac{1}{4}$ lb., 8 porter, 9 shot, plain dry sewn.

(2) 70 lb. sugar-bag—manufactured by Colonial Sugar Refining Co. Ltd., Sydney, from 12 oz. hessian, 12 porter, 15 shot.

(3) Paper bag—a 5-layered, heavy-duty brown-paper bag.

Only the paper bags were new. The sugar-bags were once-used, while the Chapman sacks had been discarded for grain storage and were representative of bags normally used for potato marketing. With the exception of the experiment concerned with comparing storage containers, the Chapman sack was used throughout this work.

(c) Insecticides.

The following insecticides were used:—

DDT emulsion.—An emulsion concentrate containing 25 per cent. *p.p′* isomer, w/v: formulated with 70 per cent. *p.p′* isomer DDT.

DDT dispersible powder containing 40 per cent. *p.p′* isomer: formulated with DDT containing 80 per cent. *p.p′* isomer.

DDT dust containing 2 per cent. *p.p′* isomer in pyrophyllite.

Derris dust containing 0·75 per cent. rotenone.

Pyrethrum-piperonyl butoxide dusts.—

(*a*) Piperonyl butoxide 0·8 per cent., pyrethrins 0·05 per cent., in a carrier of exhausted pyrethrum powder 20 per cent. and talc 80 per cent.

(*b*) Piperonyl butoxide 1·6 per cent., pyrethrins 0·1 per cent., in a carrier of exhausted pyrethrum 20 per cent. and talc 80 per cent.

Kaolin.—A diluent, made from a Queensland clay.

The various treatments are detailed in the tables of results.

(2) Storage Conditions.

The insecticide screening experiment was conducted during 1951-52 in a well-ventilated basement of a concrete building; the other five were located in a 64 ft. x 20 ft. room constructed for storing potatoes below ground level.

During the 1949-50 series of experiments, temperatures near floor level during the months of December and January were 76 $\pm$ 4 deg. F.; in the same period, screen temperatures ranged between 63·7 deg. F. and 95·1 deg. F. Under these favourable conditions frequent inspections and sorting to remove rotten tubers were usually unnecessary, and thus comparisons of the effects of treatments on tubers were possible.

(3) Methods.

(a) Dust Application.

All dusts were applied at the rate of 8 oz. per bag for Chapman sacks and 4 oz. per bag for sugar-bags and paper bags. The dust required for treating each bag of tubers was divided into 1 oz. portions. One was placed in the bottom of a 4 gal. drum, which was then filled, and a further portion was poured over the tubers before these were tipped into the bag. This process was repeated until each bag was filled. Subsequent handling into store ensured a further spreading of dust among the tubers.

(b) DDT Impregnation.

Strengths of dips, prepared from both emulsion and dispersible powder, ranged from 0·5 per cent. to 5 per cent. Each jute container was treated separately and after immersion and thorough wetting was passed through a mangle at a fixed setting. Sacks were folded longitudinally, but sugar-bags readily passed through without folding. After thorough air-drying the containers were bundled according to type and treatment.

Paper bags were treated by pouring 1½–2 pints of dipping fluid into each bag and shaking to ensure complete wetting of the inner surface. After pouring out the surplus, the bag was held open with a light wooden frame until dry.

Burlap strips were made by cutting a Chapman sack impregnated with 2 per cent. DDT emulsion into eight equal portions. Four of these were placed amongst the tubers in each sack.

Brown-paper streamers ½ in. wide, were dipped in 5 per cent. DDT emulsion and dried, and 3 oz. of this treated paper was scattered amongst the tubers in each sack.

Randomised layouts were used with 4–6 replicates, depending on the number of treatments and the availability of suitable tubers. The plot unit was one sack or bag containing approximately 500 tubers in each Chapman sack and half this number in the other containers. The relevant details including layout are given in Tables 1 and 2.

All bags comprising an experiment were placed together on end in a single layer. Broad wooden slabs spaced beneath the bags and passages between replicates as well as between experiments ensured adequate ventilation. Once in position, bags were removed only for sampling purposes and then returned to the original positions. Bulk potatoes in another part of the store room and untreated plots within each experiment provided a continuous source of *Gnorimoschema* infestation throughout storage.

(c) Duration of Storage.

The period of storage depended on tuber decomposition and the purposes of the experiment. The method of handling varied also for each experiment, some bags being sampled for tuber infestation during storage (secondary inspections). A summary of relevant details is given in Table 1.

Table 1.

DETAILS OF STORAGE.

Experiment.	Commencement of Storage.	Duration (weeks).	No. of Secondary Inspections.
I	Dec. 12, 1951	13	2
II	Dec. 8, 1949	9	..
III (a)	Nov. 17, 1949	9	..
(b)	Nov. 18, 1949	9	..
(c)	Dec. 29, 1950	10	1
IV	Dec. 5, 1950	15	1
V	Jan. 4, 1951	9	1
VI	Jan. 5, 1951	6	..

(4) Assessing Results.

(a) Tuber Infestation.

Throughout these experiments, *Gnorimoschema* activity was determined as percentage of tubers infested. Many earlier workers (Helson 1942; Lloyd 1943; Hofmaster 1949; Lloyd 1951) had used moths, eggs laid and larval populations as criteria to determine efficacy of insecticide treatment. These workers had experimented with small containers in the laboratory but such detail could not be applied satisfactorily in these experiments. Without dissecting tubers, the old and fresh larval tunnelling could not be differentiated, nor could larval density per tuber be considered.

Moths, both dead and alive, and pupae were often encountered when bags were sampled for tuber infestation, but tuber breakdown, dust residue, dirt and other foreign material in the bags interfered with attempts at accurate determinations of moth populations. Percentage tuber infestation, however, was found quite adequate for the purposes of these studies.

Infestation per plot was determined by examining a number of samples each of 10 tubers taken at random from each bag. The number of samples taken differed with the experiment and was determined by the number of replicates (see Appendix I). The relevant information for each experiment is given in Table 2.

Table 2.

SAMPLING PROCEDURE.

Experiment.	Number of Replicates.	Number of Samples per Plot.	Total Tubers Examined per Treatment.
I	4	10	400
II	5	8	400
III (a) ..	6	8	480
(b) ..	6	8	480
(c) ..	4	12	480
IV	5	8	400
V	4	12	480
VI*	4	8	320

* Containers were half the capacity of those used in all other experiments.

The incidence of tuber moth was determined at the commencement, conclusion and in some instances (secondary inspections, see Table 1) during the period of storage. With the exception of Experiment II, samples were selected at random from each plot as the containers were being filled or after the tubers had been tipped from the container at the conclusion of each experiment. When Experiment II terminated, samples were taken from the upper, middle and lower portions of each sack as tubers were removed individually. From each portion, tubers were selected that were either in contact with the sack or from the centre.

At the final sampling in each experiment, tubers were washed to facilitate examination.

(b) Tuber Breakdown.

No mechanically damaged or obviously unsound potatoes were included when bags were filled at the commencement of each experiment. By recording the number of sound tubers at the commencement and the end of each experiment, the percentages of rotted tubers per bag were determined.

(5) Results.

(a) Experiment I—Screening of Insecticides.

At each secondary sampling, all unsound potatoes were discarded before re-bagging to improve storage. Results are given in Table 3, and representative tubers are shown in Fig. 2.

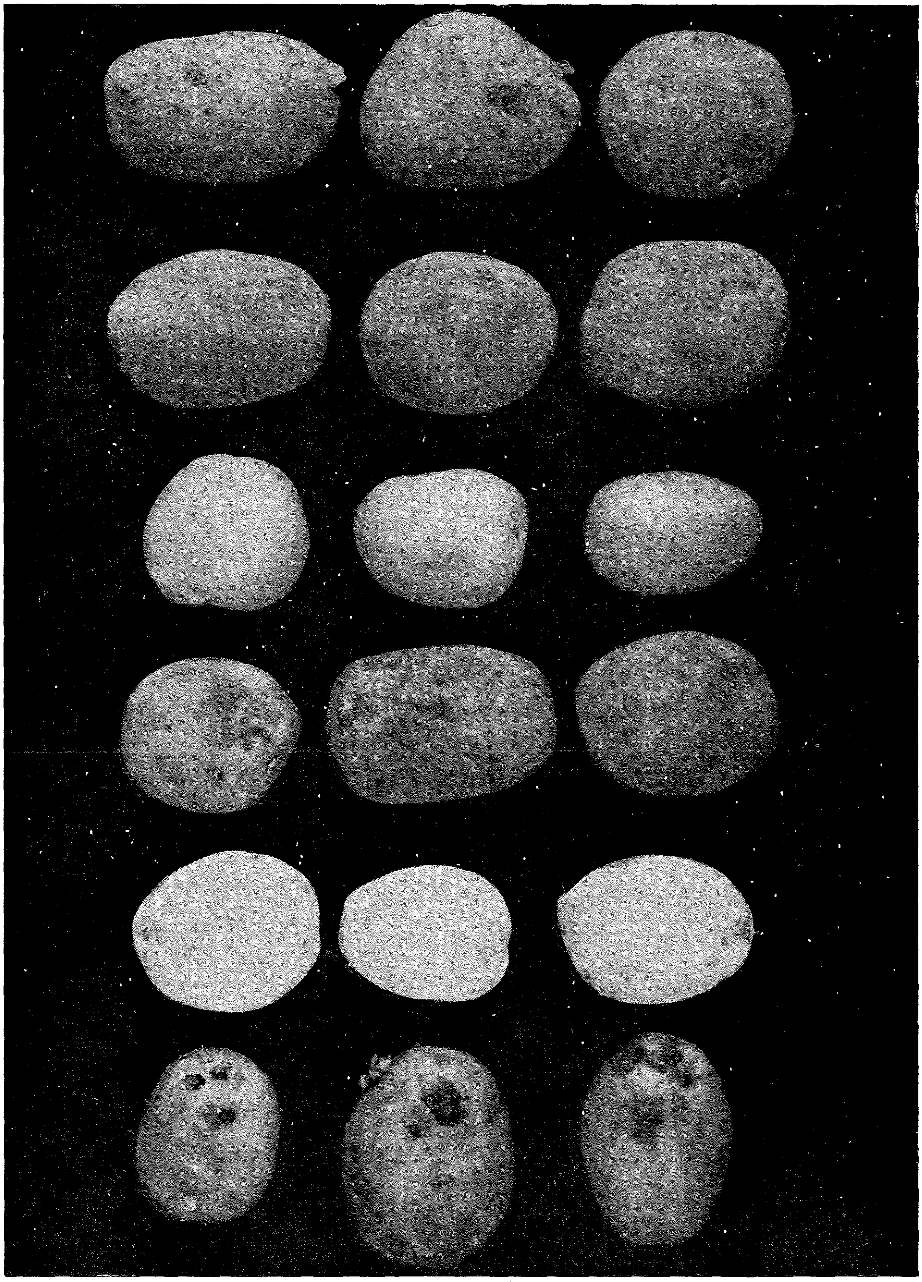

Fig. 2.

Comparisons Between Tubers After 13 Weeks' Storage (Experiment I). From top downwards:—pyrethrum-piperonyl butoxide dust (a); derris; derris (washed); DDT-treated sack; DDT dust (not pigmented); control. (Note infestation in control.)

Table 3.

EXPERIMENT I: TUBER MOTH INFESTATION AND BREAKDOWN.

Treatment.	Sampling Dates. Dec. 12, 1951.	Jan. 30, 1952.	Feb. 21, 1952.	Mar. 17, 1952.	Percentage Tuber Breakdown.
	Percentage Tubers Infested.				
1. DDT-treated sack (2·0% emulsion)	4·2	3·5	1·5	1·0	35·4
2. DDT 2·0% dust	2·0	2·5	0·8	0·0	41·6
3. Derris dust	2·0	3·0	1·5	1·2	29·7
4. Pyrethrum-piperonyl butoxide dust (a)	2·8	3·5	1·5	1·5	37·2
5. Pyrethrum-piperonyl butoxide dust (b)	2·0	4·5	2·5	0·2	44·7
6. Kaolin	3·8	5·8	4·5	6·0	32·6
7. Control	3·0	13·0	37·5	66·5	73·4
Differences necessary for significance 5%		2·4	1·9	1·4	
Differences necessary for significance 1%		3·3	2·6	1·9	

The insecticidal dusts were more efficacious than kaolin in preventing moth infestation. Tuber breakdown occurred in all treatments but was far more pronounced in the controls. Differences between treatments, however, were not significant.

(b) Experiment II—Preventing Infestation.

This experiment, using sound tubers, was run in two sections: in the first, four concentrations of dust were used, and in the second, the containers were impregnated with three levels of DDT emulsion.

Table 4.

EXPERIMENT II: PREVENTION OF INFESTATION.

Treatment.	Percentage Tubers Infested. Centre of Sack.	Away from Centre of Sack.	Mean Percentage Infestation.
1. DDT 2·0% dust	5·0	4·0	4·8
2. DDT 1·5% dust	3·0	3·0	3·0
3. DDT 1·0% dust	3 0	4·5	3·8
4. DDT 0·5% dust	7·0	7·5	7·2
5. DDT-treated sack (2·5% emulsion)	0·0	2·0	1·0
6. DDT-treated sack (1·0% emulsion)	1·5	2·0	1·8
7. DDT-treated sack (0·5% emulsion)	3·0	3·5	3·2
8. Control	36·2	34·5	35·4
Differences necessary for significance .. 5%			3·2
Differences necessary for significance .. 1%			4·2

The sections were combined for analysis as all potatoes were from the same source, and infestations in the controls were of the same order. Results are given in Table 4.

No relationship existed between infestation and position of tubers in the sack. The results of this experiment, however, indicate a range of DDT levels giving satisfactory protection.

(c) Experiment III—Arresting Infestation.

Concurrent with Experiment II, the same treatments were compared for arresting infestation already well established in the tubers at the commencement of storage (Experiments III (a) and (b)). The results are given in Tables 5 and 6.

Table 5.

EXPERIMENT III (a) : ARRESTING INFESTATION.

Treatment.	Percentage Tubers Infested. Commencement of Storage.	End of Storage.	Increase.
1. DDT 2·0% dust	27·1	38·5	11·5
2. DDT 1·5% dust	20·6	43·1	22·5
3. DDT 1·0% dust	22·1	42·1	20·0
4. DDT 0·5% dust	18·8	41·7	22·9
5. Control	22·7	90·8	68·1
Differences necessary for significance 5%	6·0	7·2	7·1
Differences necessary for significance 1%	8.2	9·8	9·6

Experiment III (c) covered both sack and dust treatments as in Experiment III (a) and III (b), with slight variations in DDT levels. The results are given in Table 7. Tuber infestation at the commencement of storage was lower than for the other two sections of this experiment, although this was somewhat compensated by a longer period of storage.

Table 6.

EXPERIMENT III (b) : ARRESTING INFESTATION.

Treatment.	Percentage Tubers Infested. Commencement of Storage.	End of Storage.	Increase.
1. DDT-treated sack (2·5% emulsion)	35·2	39·2	4·0
2. DDT-treated sack (1·0% emulsion)	24·0	42·9	19·0
3. DDT-treated sack (0·5% emulsion)	27·1	42·1	15·0
4. Control	41·2	94·4	53·1
Differences necessary for significance 5%	6·9	7·5	9·5
Differences necessary for significance 1%	9·6	10·3	13·2

Table 7.

EXPERIMENT III (c): ARRESTING INFESTATION.

Treatment.	Percentage Tubers Infested.		
	Commencement of Storage.	Secondary Inspection.	End of Storage.
	Dec. 29, 1950.	Feb. 16, 1951.	Mar. 12, 1951.
1. DDT 2·0% dust	12·2	8·0	10·9
2. DDT 1·5% dust	8·6	7·6	9·8
3. DDT 1·0% dust	13·6	18·3	11·7
4. DDT-treated sack (3·0% emulsion)	17·8	13·3	15·0
5. DDT-treated sack (2·0% emulsion)	10·6	9·0	11·1
6. DDT-treated sack (1·0% emulsion)	9·3	12·6	16·9
7. Control	13·3	29·1	45·7
Significant differences		1 to 6 $\ll$ 7 1, 2 $<$ 3	1 to 6 $\ll$ 7

($\ll$ = significantly less than, at 1% level; $<$ = significantly less than, at 5% level).

Tuber breakdown was of little consequence as all decomposing tubers were removed before the counts on Feb. 16 and Mar. 13. This had the effect of reducing the infestation recorded for certain treatments on these dates.

All DDT levels, irrespective of method of application, arrested appreciable infestation in the tubers (Tables 5, 6 and 7). The highest level of DDT, whether as dust or impregnated in the container, was more efficacious when more than one in five tubers was infested at the commencement of storage (Tables 5 and 6).

(d) Experiment IV—Commercial Trial.

Results from Experiments I, II and III suggested 2 per cent. DDT dust or sacks impregnated with 2 per cent. DDT emulsion as efficacious levels for commercial use. Accordingly, a commercial trial was undertaken.

After applying treatments in the field, the tubers were placed in a bulk potato store and handled in accordance with normal commercial practices.

Table 8.

EXPERIMENT IV: COMMERCIAL STORAGE.

Treatment.	Percentage Tubers Infested.		
	Commencement of Storage.	Storage for 9 Weeks.	Storage for 15 Weeks.
1. DDT 2·0% dust	10·6	21·8	9·6
2. DDT-treated sack (2·0% emulsion)	12·5	24·8	11·8
3. Control	12·0	85·6	83·5
Significant differences		1, 2 $\ll$ 3	1, 2 $\ll$ 3

($\ll$ = significantly less than, at 1% level).

The methods of assessing the results given in Table 8 are comparable with those that were obtained under experimental conditions. When examining for infestation after storage for nine weeks, all unsound tubers were discarded. Despite this, further infestation had developed when the experiment terminated, as under the system of sorting practised, some infested tubers were overlooked and returned to the bags. The influence of the DDT treatments, however, was obvious for the duration of storage: in the controls, few tubers were marketable at the end of the experiment.

(e) Experiment V—Alternative Methods of Applying DDT.

The impregnation of Chapman sacks with DDT and direct application of DDT dust to the tubers have several disadvantages, including lack of uniformity of application under farm conditions and residues on the tubers. Accordingly, an experiment including alternative methods of DDT application was designed. Details of treatments and results are given in Table 9.

Table 9.

EXPERIMENT V: ALTERNATIVE METHODS OF APPLYING DDT.

Treatment.	Percentage Tubers Infested.		
	Commencement of Storage.	Storage for 6 Weeks.	Storage for 9 Weeks.
1. DDT 2·0% dust	2·0	1·6	5·5
2. DDT-treated sack (2·0% emulsion)	2·9	9·8	11·2
3. DDT-treated burlap strips	1·3	7·7	7·0
4. DDT-treated paper streamers	1·7	3·3	3·3
5. Control	0·2	4·2	5·2
Significant differences	5 << 2 5 < 1	1, 4<< 2; 1<< 2 5 < 2	4 << 2 5 < 2

(<< = significantly less than, at 1% level; < = significanty less than, at 5% level).

Unfortunately, initial infestations were low. Breakdown due to Irish blight (*Phytophthora infestans* de Bary) was considerable in this experiment and necessitated severe culling during the secondary inspection. This prevented the expected increase in tuber moth incidence. Breakdown was greatest in the dusted tubers and least in sacks containing burlap strips: by the end of storage, the former treatment was in poor condition. Further work will be necessary to evaluate tuber protection by these alternative methods of application.

(f) Experiment VI—Alternative Storage Containers.

The shortage of Chapman sacks in some years, and certain other undesirable features associated with this type of container, suggested the need for alternative containers. Only two types are readily available in the trade—standard hessian sugar-bags and heavy-duty, multiple-layer paper bags.

Table 10.

EXPERIMENT VI: ALTERNATIVE STORAGE CONTAINERS.

Treatment.	Percentage Tubers Infested.		
	Commencement of Storage.	End of Storage.	Increase.
Chapman sack—			
1. DDT 2·0% dust on tubers	17·1	26·2	9·1
2. DDT-impregnated (2·0% emulsion)	15·9	19·4	3·5
Sugar-bag—			
3. DDT 2·0% dust on tubers	7·9	15·9	8·0
4. DDT-impregnated (2·0% emulsion)	4·8	6·9	2·1
Paper bag—			
5. DDT 2·0% dust on tubers	21·8	25·8	4·0
6. DDT-treated (2·0% emulsion)	13·4	25·8	12·4
7. Control	27·0	69·1	42·1
Significant differences	$4 \ll 1, 5, 7$ $3 \ll 5, 7$ $4 < 2, 6$ $2 < 7$	1 to $6 \ll 7$ $4 \ll 1, 5, 6$ $4 < 2$	

($\ll$ = significantly less than, at 1% level; $<$ = significantly less than, at 5% level).

Portions of the Chapman sacks were cut off so that holding capacity of all containers was similar. To ensure adequate ventilation in the paper bags, four evenly spaced holes of 1 in. diameter were punched in each side.

Results are set out in Table 10 in a form enabling comparisons of treatments within each container type, and in Table 11 to permit an evaluation of the containers and the application methods.

Table 11.

EXPERIMENT VI: ALTERNATIVE STORAGE CONTAINERS.

Treatment.	Mean Tuber Infestation.		
	Commencement of Storage.	End of Storage.	Increase
1. Chapman sack	16·5	22·7	6·2
2. Sugar-bag	6·3	11·0	4·7
3. Paper bag	17·4	25·8	8·4
DDT 2·0% dust	15·1	22·4	7·3
DDT-treated (2·0% emulsion)	10·8	16·5	5·7
Significant differences	$2 \ll 1, 3$	$2 \ll 3$ $2 < 1$	

$\ll$ = significantly less than, at 1% level; $<$ = significantly less than, at 5% level).

Despite a more open weave, the results obtained with sugar-bags were comparable with those from Chapman sacks. Paper bags were equally efficacious when the DDT was applied as a dust to tubers but were less so when it was applied to the container. Apparently, moths entered quite readily through the holes punched for ventilation and did not contact the DDT deposit before infesting tubers.

(6) Discussion.

At the strengths used, DDT, derris and pyrethrum-piperonyl butoxide as dusts and DDT-impregnated Chapman sacks and sugar-bags were all efficacious in protecting tubers when the initial infestations were less than 4 per cent. (Tables 3 and 4). Kaolin failed to arrest a comparable infestation.

All DDT treatments also satisfactorily arrested initial infestations from 8 to 35 per cent. (Tables 5, 6, 7, 8 and 11), although the higher levels of DDT were the more efficacious (Tables 5 and 6) when the initial infestation exceeded 20 per cent. These conclusions were biassed by the culling of damaged and rotting tubers at secondary inspections (Table 7).

Treating tubers with DDT dust at harvest is both practicable and effective under commercial conditions. The use of brown-pigmented dust largely overcomes the disadvantages of an unsightly white residue (Fig. 3). Breakdown, however, was more prevalent among dusted tubers, for in the presence of high humidity tubers retained moisture on their surfaces and this favoured the rapid spread of rot organisms.

The use of DDT-impregnated containers, though more expensive than dusting, is as effective as dusting and eliminates the unsightly dust residue. Tubers stored by this method remained drier and always opened in a more attractive condition than dusted tubers. In these experiments, however, shrinkage was evident following immersion of the containers in DDT emulsion. Passage through the mangle compressed the weave; this interfered with ventilation and, in turn, promoted the accumulation of moisture whenever rots developed.

Although Chapman sacks and sugar-bags proved equally suitable as storage containers, the latter, because of the more open weave, were seldom associated with breakdown. Paper bags, on the other hand, were impractical for lengthy storage. Moisture from decomposing tubers wet the paper and in extreme circumstances caused bag collapse.

Infestation from outside the containers was shown (Expt. II) to be of little significance. In this case, containers were tightly sewn after the tubers were added. The commercial practice of filling a bag so that the mouth is not closed entirely provides an easy means of moth entry, irrespective of the type of weave in the container.

The likelihood of appreciable levels of infestation in commercial potatoes at harvest in years that favour *Gnorimoschema* activity would require levels of DDT for field application commensurate with the more effective treatments in these experiments. Both 2 per cent. dust and containers impregnated with 2 per cent. emulsion proved adequate under commercial conditions (Expt. IV).

The storing of good-quality sound tubers under well-ventilated conditions, coupled with the periodic sorting out of decomposing tubers, should eliminate the drawbacks to either method of DDT application mentioned above.

III. DDT RESIDUES.

Experiments to determine DDT residues on containers and on tubers were carried out concurrently with those dealing with tuber protection.

Methods of sampling and the reasons for using DDT in emulsion form for impregnating containers are discussed in Appendix II.

(1) Methods and Assessing Results.

(a) Residues in Containers.

The method of treating containers and sampling for residues, devised from preliminary investigations (Appendix II), was standardised and was followed throughout these studies.

Residue determinations were made at the commencement and end of Experiments III (c), V and VI. The burlap strips used in Experiment V were sampled at the end of storage; the four unused strips provided the samples at the commencement of the experiment.

When preparing containers for Experiments III (c) and VI, four extra sampling sacks or bags were treated at each level of DDT emulsion for residue determinations at the commencement and the end of storage. Two additional sacks were impregnated with 2 per cent. DDT emulsion; the six sampling containers provided residue values for this treatment in Experiments III (c) and V.

At the end of storage, samples taken from the sampling containers as well as from the containers used to store the tubers provided a means of appreciating loss of residue due to handling. During storage, the sampling containers were left undisturbed in the storage shed.

(b) Residues on Tubers.

DDT residues on tubers at the end of storage were determined at the conclusion of Experiment I. Thirty tubers from the 2 per cent. DDT dust treatment and 40 from DDT-impregnated sacks provided samples for the analyses. Thirty tubers from the control sacks were included as blanks in the DDT determinations.

The persistence of the DDT deposit on tubers following various combinations of peeling and washing prior to cooking was investigated. A suitable quantity of commercially dusted tubers was obtained from storage. Samples of seven potatoes each with five replications were subjected to six different treatments of peeling and/or washing. All washing was carried out in still water, about two pints being used for each 1 lb. sample of tubers. Undusted tubers were similarly treated for comparison. Following treatments, the tubers were analysed for DDT residues. The various treatments are detailed in Table 12.

Table 12.

DDT RESIDUES AT COMMENCEMENT AND END OF STORAGE.
EXPERIMENTS III (c) AND V (CHAPMAN SACKS)—(g./sq. ft.).

Replicates.	1% DDT Emulsion.			2% DDT Emulsion.					3% DDT Emulsion.		
	Sample Bags.		Expt. III (c) End.	Sample Bags.		Expt. III (c) End.	Expt. V End.	Expt. V (Burlap) End.	Sample Bags.		Expt. III (c) End.
	Commencement.	End.		Commencement.	End.				Commencement.	End.	
A	1·06	·98	·40	1·20	·77	1·16	·63	·98	2·16	1·57	1·34
B	1·29	·39	·28	·92	·99	1·00	·94	1·25	1·96	1·84	1·70
C	·88	·39	·68	·97	·98	·93	·89	·99	1·83	1·66	1·68
D	1·06	·67	·49	·80	·94	·85	1·08	1·25	1·98	1·92	1·96
E	..	..	..	1·23	·99	..	..	..	..	..	..
F	..	..	..	·69	·99	..	..	..	..	..	..
Average ..	1·07 (1)	·61 (2)	·46 (3)	·97	·94	·98	·88	1·12	1·98 (1)	1·75 (2)	1·67 (3)
	1 >> 2, 3			No significant differences					1 > 3		

EXPERIMENT VI (2% DDT EMULSION).

Replicates.	Chapman Sacks (g./sq. ft.)			Sugar-bags (g./sq. ft.)			Paper Bags (mg./sq. ft.)		
	Sample Bags.		Expt. Bags End.	Sample Bags.		Expt. Bags End.	Sample Bags.		Expt. Bags End.
	Commencement.	End.		Commencement.	End.		Commencement.	End.	
A	·96	1·17	1·21	·86	·38	·41	134	128	83
B	1·02	1·21	·94	·45	·23	·72	137	89	108
C	*	1·52	1·03	·44	·39	·52	135	89	111
D	*	1·08	·98	·28	·49	·49	136	111	89
Average	·99	1·24	1·04	·51	·37	·54	136 (1)	104 (2)	98 (3)
	No significant differences			No significant differences			1 >> 2, 3		

(* = samples lost; >> = significantly greater than, at 1% level; > = significantly greater than, at 5% level.)

(2) Results.

(a) Residues on Containers.

The residue analyses of the sample discs from the extra sampling containers and those used in Experiments III (c), V and VI are set out in Table 12. The results are expressed as either grams or milligrams of *p.p.'* isomer per sq. ft.

Values of ·17, ·023 and nil were found in blank tests for Chapman sacks, sugar-bags, and paper bags respectively. No allowance has been made for these results in the values set out in Table 12.

Although sample bags remained undisturbed during storage periods, a significant reduction in DDT deposit had occurred at the final sampling for those treated with 1 per cent. DDT emulsion and for the paper bags used in Experiment VI.

A loss of residue also occurred in experimental bags treated with the lowest and highest DDT concentration in Experiment III (c) and for Chapman sacks and paper bags in Experiment VI. Among replicates, however, variability of residue was quite pronounced at the initial and final sampling, irrespective of container type and level of DDT concentration used.

Although differences in values between commencement and end of storage may be partly explained by deficiencies in the technique of sampling, it can be assumed that a portion of the DDT deposit in containers is dislodged during their handling.

(b) Residues on Tubers.

The mean values for residues on tubers from Experiment I at the end of storage are given in Table 13, and representative tubers are shown in Fig. 3.

Table 13.

DDT Residues on Tubers after 13 Weeks' Storage.

Treatment.	No. of Tubers Sampled.	Mean DDT Concentration (mg./100 g.).
DDT-treated sack (2·0% emulsion)	40	8·8
DDT 2·0% dust	30	9·2
Control	30	1·0

These tubers had been sampled for tuber moth infestation on three occasions prior to the taking of the samples for DDT determinations. This handling had resulted in a considerable transfer of DDT from the treated sack to the tubers, so much so that the analysis revealed a value comparable with that for the dusted tubers.

The results of the DDT determinations on tubers receiving various treatments of peeling and/or washing are given in Table 14.

Table 14.

DDT RESIDUE (p.p.m.) ON POTATOES PREPARED FOR COOKING.

Treatment.	Replicates.				
	A.	B.	C.	D.	E.
1. Peeled only	3·8	8·9	3·6	2·1	0·9
2. Washed, peeled and washed again in same water	2·9	2·0	3·3	1·8	0·9
3. As for 2, except washed again in clean water	Nil	1·5	1·5	Nil	0·9
4. Not peeled or washed	2·5	4·1	3·2	6·0	4·4
5. Washed but not peeled	0·8	Nil	0·8	Nil	0·8
6. Peeled, then washed in clean water ..	Nil	4·7	0·9	Nil	2·9
7. Undusted potatoes	Nil	Nil	Nil	Nil	Nil

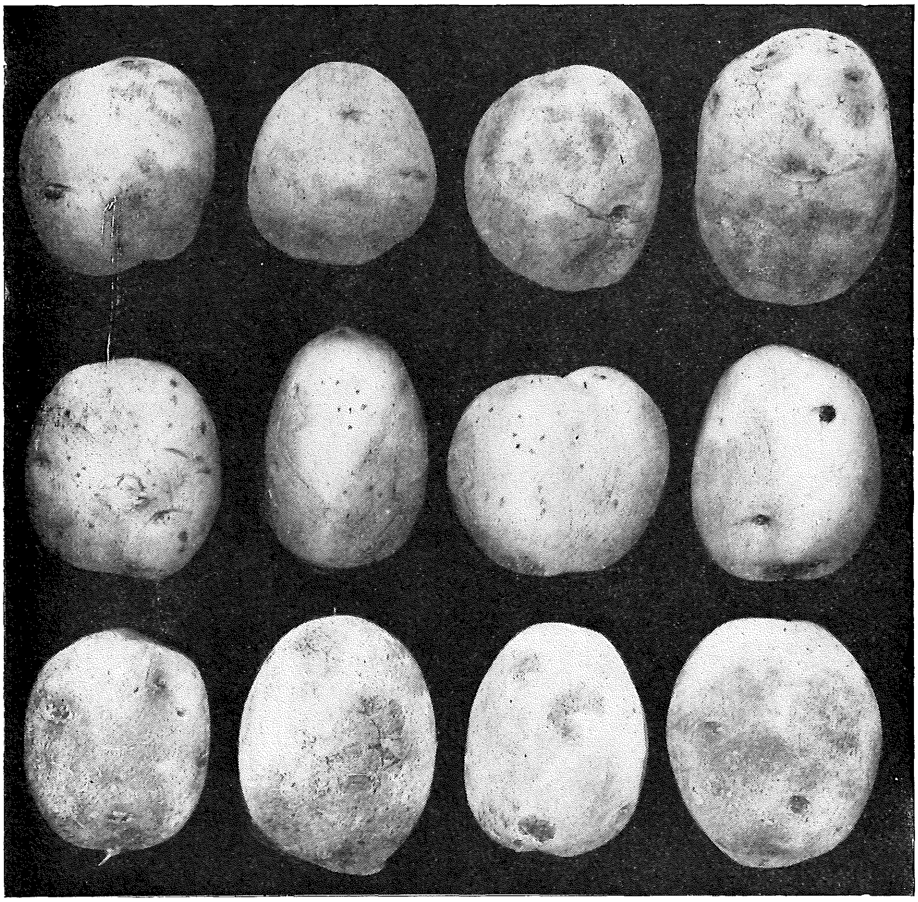

Fig. 3.

Residues on Tubers. From top downwards:—DDT brown-pigmented dust; washed; DDT non-pigmented dust.

Under the conditions of the experiment, washing alone reduced the residue to within the limits of DDT tolerance. When during peeling the cut surface of the tuber is contaminated with DDT, the deposit is more difficult to remove. Washing in clean water, whether before or after peeling, reduces the deposit to comparable levels.

(3) Discussion.

The mean DDT residues per square foot retained by both the Chapman sacks and sugar-bags (Appendix II) are roughly proportional to the emulsion concentrates used, though the more heavily woven Chapman sack retained a greater quantity of DDT per square foot than the sugar-bag. Hofmaster (1949) found that burlap dipped in a 5 per cent. DDT-xylene solution retained an average DDT deposit of 1·29 g. per sq. ft., a figure comparable with that obtained for sugar-bags treated with the same DDT concentration in these experiments.

Also, mean values for DDT residues per square foot for both Chapman sacks and sugar-bags treated with DDT emulsion do show some relationship in both the preliminary studies (Appendix II) and subsequent experiments (Table 12). Corresponding values for paper bags, however, are not comparable.

Despite these broad relationships between residues due to containers on the one hand and DDT concentrates on the other, many inconsistencies were obvious from the results (Table 12). Though the methods of treating containers and sampling for DDT residues were standardised throughout, scope for variation existed in both these processes.

The varying thickness of seam and variation in weave, by influencing the evenness of DDT deposit retained, would account for some variation among values for DDT deposit for related containers, more particularly for Chapman sacks. Also, unevenness of weave may have contributed to discrepancies between samples for chemical analysis. More consistent values were obtained for the more uniformly woven and thinner sugar-bags.

Though Chapman sacks and sugar-bags exhibited variations in residue among replicates within treatments, and also retained dissimilar quantities of DDT due to weight and closeness of weave, both containers proved suitable for DDT impregnation. Paper bags, apart from unsuitability as containers under moist conditions, did not lend themselves to uniform treatment with DDT emulsion, lost the DDT deposit more readily than the jute containers and could not withstand handling. This type of container can be ruled out of consideration for storing potato tubers.

Butterfield, Parkin and Gale (1949) found that DDT was transferred from the container to the foodstuff if the sacking contained a relatively high concentration of DDT or the sack was roughly handled, although the effect of handling was variable. In these studies, despite possible variation due to sampling and chemical methods adopted, loss of residue followed handling of containers (Table 12), but reductions were not consistent with degree of handling.

Appreciable quantities of the DDT lost from containers during handling were transferred to the tubers (Table 13). Hofmaster (1949) showed that potatoes in contact with burlap treated with 3 per cent. DDT retained an average DDT deposit of 3·05 p.p.m. Atkins and Greer (1953), investigating the storage of corn in jute bags treated with DDT, found 13·8 p.p.m. transferred from fabric impregnated with 1 per cent. DDT and 23·0 p.p.m. associated with 1·5 per cent. DDT. Thus storing tubers in treated containers, though overcoming the obvious deposit associated with DDT dust, does not reduce the hazard of DDT residue.

The ultimate fate of residues on tubers is of considerable importance to the consumer. It would be impossible to obtain a consistent figure for the DDT deposit persisting after tubers had undergone the handling associated with transport and sale to the consumer. Those used for the peeling and washing tests were taken direct from storage and did not receive the extra handling received by trade potatoes. Thus the residues would exceed greatly those obtaining in normal practice.

The DDT residue persisting after storage is superficial. Butterfield, Parkin and Gale (1949) had shown that fatty foodstuffs stored in DDT-treated containers absorbed DDT through the unbroken skin. In these experiments washing alone removed the greater proportion of the DDT and DDT recovered from peeled tubers had been transferred during peeling operations.

It is concluded that following normal washing and peeling prior to cooking, tubers lose most of the DDT still persisting after storage and handling.

IV. GENERAL CONCLUSIONS.

Effective field control of *Gnorimoschema,* rapid harvesting, the prompt culling of unsound tubers and the application of measures designed to prevent tuber moth activity in bagged tubers are essential to the successful storage of potatoes in Queensland. Under the system of grading, culling and bagging practised in the field, the inclusion of infested tubers can scarcely be avoided. This nucleus of infestation may be appreciable in seasons of major pest activity. The prompt application of measures that will arrest and destroy this initial infestation and prevent reinfestation is of prime importance whether tubers are stored as seed or for table use.

In these experiments, a 2 per cent. DDT dust applied directly on the tubers at the rate of $\frac{1}{2}$ lb. per bag, and placing tubers in either Chapman sacks or sugar-bags previously treated in a 2 per cent. DDT emulsion, were the most practical and efficacious means of protecting tubers. Both methods, also, proved entirely satisfactory under commercial conditions (Experiment IV) and were recommended for general use (May 1951). Their benefit is enhanced, however, if unsound tubers are graded out before bagging and tubers are stored under cool, well-ventilated conditions.

The use of inert dusts as protectants, or of non-toxic insecticides such as derris and pyrethum-piperonyl butoxide, cannot be advocated in preference to DDT for *Gnorimoschema* control. Their dependence on low humidity, low initial infestation, and the unlikelihood of reinfestation during storage for the successful protection of tubers detracts from their general adoption. Further, their use would not compensate for any of the bad features associated with the use of DDT.

When considered from the viewpoint of cost, ease of application, keeping quality of tubers in storage and appearance, each method of DDT application has its advantages. DDT dust, however, is preferable for protecting seed potatoes, especially when they are held in open trays or bulked on the shed floor.

Tubers treated with DDT dust or stored in DDT-impregnated containers may carry an appreciable DDT deposit at the termination of storage. The system of handling tubers from storage to the consumer, however, together with the several processes involved in their preparation for the table, reduces the DDT residue below the limit of tolerance for health standards.

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APPENDIX I.

Sampling Tubers.

In the following analyses the transformed variate, ϕ, defined by the relation

$$p=100 \sin^2 \phi,$$

where p is the percentage, has been used. The results are based on data from the 1949-50 series of experiments, viz. II, III(a) and III(b), excluding the control in the last experiment for the determination of inter-bag variability.

Mean Squares.				
Expt.	D.F.	Whole Plot Error.	D.F.	Sampling Error.
II ..	12	113·90	175	107·01
III (a) ..	20	120·81	210	108·58
III (b) ..	15	116·84	168	102·01
Average ..	47	117·78	553	106·09

It is assumed that the variability is made up of two parts, viz., an intra-bag component (variance σ_1^2) and an inter-bag component (variance σ_2^2). The sampling error mean square provides an estimate of σ_1^2. The whole plot error mean square provides an estimate of (1–f) $\sigma_1^2 + 8\ \sigma_2^2$, where f is the fraction of each bag sampled. The method adopted corresponds to a value of f$=\cdot 22$ approximately, and this value gives $4\cdot 38$ as an estimate of σ^2.

These estimates can be used to assess the accuracy of various methods of sampling. If 10n potatoes per bag are sampled and there are r replicates of each treatment, the estimated necessary difference for significance at the 5% level will be

$$\sqrt[3]{\left[\frac{1}{r}\left\{\frac{(1-f)}{n}\,\sigma_1^2 + \sigma_2^2\right\}\right]},$$

where f is the fraction sampled and depends on n. The values of this quantity for various values of r and 10n are tabulated below.

Replications.	Number Counted per Bag (10n).							
	20.	40.	60.	80.	100.	160.	240.	All.
4	11·1	7·9	6·6	5·8	5·2	4·3	3·6	3·1
5	9·9	7·1	5·9	5·2	4·7	3·8	3·2	2·8
6	9·0	6·5	5·4	4·7	4·3	3·5	3·0	2·6
8	7·8	5·6	4·6	4·1	3·7	3·0	2·6	2·2
10	7·0	5·0	4·1	3·6	3·3	2·7	2·3	2·0
12	6·4	4·6	3·8	3·3	3·0	2·5	2·1	1·8

Further discussion of sampling methods involves other than statistical considerations, e.g. the relative cost of different methods.

The above estimates are given in terms of the transformed variate. The equivalent percentages depend on the average percentage and are greatest in the neighbourhood of 50 per cent. The equivalent percentages corresponding to unit intervals of ϕ at 50 per cent. and 25 per cent. are given below.

Average Percentage.	Necessary Difference (ϕ).									
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
50 ..	1·8	3·5	5·2	7·0	8·7	10·4	12·1	13·8	15·5	17·1
25 ..	1·5	3·1	4·6	6·1	7·5	9·1	10·5	12·0	13·4	14·8

From the above a method of sampling was chosen commensurate with practicability. It was found more convenient to handle 4–6 replicates of each treatment and the sampling was regulated accordingly.

APPENDIX II.

Sampling Containers for Residue Analyses.

Preliminary studies were undertaken to investigate methods of treating and sampling containers for residue determinations thereby enabling an appreciation of bag-to-bag variation of residues. This work also provided a comparison between emulsion and dispersible powder DDT for treating containers.

Two series of containers, each comprising four Chapman sacks, sugar-bags and paper bags, were treated, one with emulsion and the other with dispersible powder. Concentrations used are given in Table 15.

When dry, five paired 1 in. diameter discs were punched from each container. The pattern of sampling was standardised throughout. To obtain the sample discs, the punch was given several sharp taps with a hammer, after which those strands not severed were cut with a knife. For paper bags, only the centre pair of discs from each punching was retained for analysis.

In addition, four untreated of each of the three types of containers provided blanks in the DDT determinations.

The results of DDT analyses, expressed as *p.p′* isomer DDT per sq. ft., are given in Table 15. Corrections have been made for the chlorine content (0·02 g./sq. ft.) of both Chapman sacks and sugar-bags.

Table 15.

DDT Residue Determinations.

Container.	Chapman Sacks. (g./sq. ft.).			Sugar-bags. (g./sq. ft.).			Paper Bags. (mg./sq. ft.).		
	DDT Emulsion.								
	2%	3%	5%	2%	3%	5%	2%	3%	5%
A	1·20	1·42	3·30	·70	·76	1·28	294	362	341
B	1·29	1·51	3·56	·68	·76	1·46	242	343	340
C	1·16	1·72	3·78	·55	·84	1·46	225	344	287
D	1·51	1·78	3·25	·55	·81	1·16	242	248	338
Means	1·29	1·61	3·49	·64	·79	1·34	251	324	326
	DDT Dispersible Powder.								
	2%	3%	5%	2%	3%	5%	2%	3%	5%
A	·92	2·42	1·82	·83	1·03	*	309	*	158
B	·93	2·54	1·53	·93	·93	·96	261	249	247
C	1·24	1·72	2·77	·58	1·07	1·47	261	257	308
D	·62	1·82	2·02	·78	1·18	1·23	158	155	154
Means	·93	2·13	2·04	·78	1·05	1·22	247	224	219

* = Samples lost.

Emulsions were retained by containers as fairly uniform dressings with no obvious residues. Unsightly white residues were obvious on containers treated with dispersible powder; the non-permanence of these deposits, particularly on paper bags, was evident during sampling and is reflected in the variations amongst replicates.

As a result of this preliminary work, emulsions only were used in all experiments and variance and fiducial limits for residues on containers are given in Table 16.

Table 16.

VARIANCE AND FIDUCIAL LIMITS FOR RESIDUES ON CONTAINERS.

Container.	D.F.	Variance per Container.	95% Range for Mean Based on		
			1 container.	4 containers.	9 containers.
Sugar-bags ..	9	·0102	± ·23 g.	± ·11 g.	± ·08 g.
Chapman Sacks ..	9	·0347	± ·42 g.	± ·21 g.	± ·14 g.
Average	18	·0224	± ·32 g.	± ·16 g.	± ·11 g.
Paper Bags ..	9	·1417	± ·85 mg.	± ·43 mg.	± ·28 mg.

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