A STUDY OF THE TIPULIDAE (DIPTERA) OF AGRICULTURAL IMPORTANCE IN SOUTH EAST SCOTLAND

by

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GENERAL INTRODUCTION

Crane-flies are harmless but their larvae, popularly known as leatherjackets, are pests of economic importance to the farmer.

Leatherjackets are soil-living creatures. Chiswell (1956) has described 36 species of larvae living in British soils, but very few of them have economic importance as pests. As far as the reports of leatherjacket damage go the only important species is Tipula paludosa Meigen which causes considerable losses to cereals and pastures. Other species which are found as pests in association with T. paludosa are, in descending order of frequency of occurrence, Tipula oleracea Linnaeus, Nephrotoma quadrifaria Meigen, Nephrotoma flavesens Linnaeus, Nephrotoma flavipalpis Meigen, Tipula vernalis Meigen, Tipula czizeki De Jong and Nephrotoma analis Schummel. All of them belong to the order Diptera, sub-order Nematocera, family Tipulidae and sub-family Tipulinae. In grassland, Milne (1966) found the adults of T. paludosa and T. oleracea almost equally plentiful in light traps, but could not get the larvae in the grassland nor neighbouring swampy patches, banks of streams etc. T. paludosa has been found to be the dominant species in South-East Scotland and most of the field observations and all the experimental work of this study are based on this species.

Unlike T. oleracea, T. paludosa is univoltine (Milne, 1966); all larval stages of the life cycle normally occur in the top inch of pasture soil, though Brindle (1960) recorded them from a wide range of habitat. Adults are on the wing from July till September.

Soon after emergence from pupae, females mate and start laying eggs. Eggs hatch in about a fortnight and by December the larvae are already in the 3rd instar in which they over winter. By the end of April, they moult to final (4th) instar when they are most active. In the later part of June and early July pupation begins.

The greatest damage occurs in the first year after grassland is ploughed, especially to spring-sown crops but winter wheat may suffer if the leatherjacket population is high. Damage to crops following wheat may occur. When grasslands are ploughed, leatherjackets are in the sods till the grass rots when the larvae attack newly brairded plants. Patches of cereal crops are found eaten by the larvae due to their concentration in a limited area. Thus a low population in a field can cause patchy damage, whereas uniform distribution would not have done so, because plants would have produced compensatory growth by tillering. In spring, when crops are sown, larvae are in the top inch of the soil and they are in the late 3rd instar or 4th instar when considerable feeding occurs. Also mild climatic conditions favour their activity during the night (White, 1966). Root crops, other than potatoes, may also suffer from leatherjacket damage.

The importance of leatherjackets as an agricultural pest has been evaluated in England and Wales (Strickland, 1966). The importance is greatest in north and west England and Wales and less in south and east, associated with the incidence of rainfall. The average value of cereal losses may total £300,000 to £600,000 but total grassland losses are quite unknown. Losses in horticultural crops will be in the region of £500,000 (White, 1966).

Estimates of the total loss of crops due to leatherjackets per year in S.E. Scotland are not yet published; but here it is already established that the leatherjacket is a common pest of cereals, especially spring barley. West Lothian is the worst affected area in S.E. Scotland as this part is wetter and the soils tend to be heavier. A rough estimate has been made from the quantity of insecticides sold to the farmer for the control of leatherjackets. It has been shown that 31,500 acres of cereal fields were treated with BHC, DDT and aldrin in 1965 to control leatherjackets (Dunn, in litt). Among the cereals barley suffered the most (27,000 acres). So, if the total loss is evaluated in Scotland the figure is expected to be higher compared with England and Wales.

So, it is very important in this part of the country to consider some aspects of leatherjacket behaviour in field conditions, as there is no previous record on extensive studies on the subject. Although leatherjackets can occasionally cause loss to the farmers in this area, damage is usually not great, and a considerable amount of spraying is carried out where leatherjacket populations are not very high and where the plants could make compensatory growth and the eventual yield be little, if any, affected.

Continuous records of the activities of leatherjackets in cereal crops have not been made. Usually an estimate of the population is made and, if considered necessary, insecticidal treatment is applied. Thereafter estimates may be made of the probable loss in crop between treated and untreated area. This

does not give the true picture of what is happening in the field during the time of feeding of the larvae throughout spring and early summer. It is very important to notice the time when the cereals suffer most from the feeding, which gives the period of maximum activity of the larvae. Larvae not only cause extensive damage on the surface by cutting and shredding leaves and causing other mechanical injury to the plants, but also do a great deal of damage underground. A suitable method of investigation would make it possible to estimate all these types of damage in the field. The types of damage can then be compared with the recovery responses by the cereals, particularly in the production of new tillers.

Another important factor is the mode of feeding by the larvae. It is not possible to see the way they feed underground, but it could be possible to observe their behaviour on the surface at night when they come out for foraging. Milne (1966) has mentioned that about March/April, larvae of T. paludosa stop living in the mat and construct U-shaped tubes in the soil to which they return after each night's foraging. Apart from that nothing much is known about nocturnal activity. In an attempt to fill this gap in our knowledge, observations were made at night by time-lapse cinematography.

In this investigation control measures against the larvae could not be ignored. Chemical measures are taken in the field where quick results are obtained, but intensive sampling to determine the populations of larvae could reveal some of the other factors

like (1) climatic, (2) diseases, and (3) predators which could take some part in controlling leatherjackets in the field. Milne et al. (1965) and Meats (1966) have done extensive work on climatic factors. Some of the other factors are considered to explain the cause of the decline in the population of leatherjackets during the spring and early summer.

These studies could explain some of the unknown factors of the behaviour of leatherjackets as affecting their economic importance as an agricultural pest of S.E. Scotland.

SECTION 1. REVIEW OF LITERATURE

1.1. Biology and general information on crane-flies.

In this investigation, taxonomic studies are not very important, so only a short account of crane-flies, including their occurrence in Scotland, is given below.

Cuthbertson (1926, 1927, 1929) did considerable work on the less important crane-flies of the west of Scotland, including their parasites, swarming and mating behaviour. Rennie (1916, 1917, 1927) has dealt with the biology as well as the economic importance of T. paludosa Meigen as a pest in the north of Scotland. He also worked out the mating behaviour and found that they mate several times in a day with one or more flies and lay most of their eggs in the first day; mating and egg laying may follow on subsequent days. He also gave some useful information on the egg and larval stages. Oldham (1928) describes the egg and larval stages of T. paludosa; he also gives a key for the identification of adults of the oleracea group. An elaborate account on biology, morphology and taxonomy of crane-flies in general has been given by Alexander (1919, 1920). Audcent (1932) also deals with the taxonomy of some of the species. But the key provided by Coe (1950) on the British Tipulidae has been followed for the identification of adults. The reports of Chiswell (1956) and Brindle (1957, 1958, 1959, 1960) are of great importance for the identification of Tipulid larvae from the soil, especially Brindle's (1959) key for identifying larvae of the oleracea group.

The most extensive work on the biology of T. paludosa and T. oleracea has been done by Laughlin (1958, 1960, 1967). He described a rearing technique for leatherjackets and made a study on the growth of the larva of T. oleracea. Usually T. paludosa female emerges with eggs mature and ready to lay. Most flies emerge between dusk and mid-night. Coulson (1962) also has observed the emergence of T. paludosa after sunset and mating takes place immediately after emergence. The following account is based on observations for a number of years made by Laughlin (1967) on the growth of T. paludosa in the field. The eggs are black and ovoid, usually vary from 0.1 to 0·2 mg. according to age. The larva can grow up to 800 mg. or more. There are three moults at about 3, 50 and 160 mg. respectively and at full growth. The times of these moults are at the end of September to the first week of October, the first week of December and the late half of April respectively. Dunnet (1955) observes that larvaegrow very fast during the late spring and the increase in weight is about 250-300 per cent in three weeks.

1.2. The movement and food of larvae.

Rennie (1927) reports that larvae moved from one part of the rearing cage to others in search of food. Sometimes they crawled out when the food had been exhausted. He also reports the mass migration of larvae in the field. Selke (1937) has noticed the same. Larvae principally appeared on the surface in search of food. Darkness, moist-soil and humidity of the air at

ground level favoured but did not ensure their rising, and strong light and dry air checked but did not prevent it. In meadows, the depth at which the larvae live and the digging movements they make in search of food, depend on the position and the number of the plant roots. Maercks (1939) found that the young larvae preferred green leaves to roots. In feeding experiments, T. paludosa and T. oleracea developed quickly and mortality was less in white clover. Development was not completed in oats. Laughlin (1958) found that dried powdered grass was convenient to feed larvae in laboratory rearing.

1.3. Climatic factors and population fluctuations.

Climatic factors play a great part in year to year variation of the population of leatherjackets in a particular region. Rennie (1927) observed that in early stages, the larva was markedly susceptible to changes in the physical condition, particularly to dryness. When prevented from reaching the moist region of the soil they died off rapidly and the evidence obtained suggested strongly that a damp autumn favoured the survival of larger numbers of grubs. Frost at any rate had not the killing power popularly imagined. De Jong and Elize (1922) have also reported that the rate of mortality in Tipulid larvae is greater in dry weather in the first weeks of larval life. They resist frost and individual larvae thawed out of ice unharmed. He also observed that in spring larvae are quite near to the surface and migrate from one place to another at night over the surface. Flooding may prove fatal to them.

Considerable work has been done by Maercks (1939, 1941) on weather conditions and the occurrence of leatherjackets. He also found that eggs of T. paludosa are very sensitive to dryness and the mortality of those laid in moorland soil was least when the soil contained twice its dry weight of water. Dry weather in autumn kills eggs laid just below the surface of the ground. Larvae also required moisture for development, soil containing 3 times its dry weight of water being optimum. Tipulids are favoured by mild winters, cool summers and an average rainfall of at least 24 in. Considerable damage might be expected by larvae after abnormal rainfall in August and September and when winter is mild. He also (1941) observed the decreased number of larvae of T. paludosa after the hard winter of 1939-1940. Cameron (1945) reported heavy infestations of leatherjackets in West Lothian following two successive wet autumns.

Milne et al. (1965) carried out experiments to explain the population crashes of 1955 and 1959 in Northumberland. A field experiment in 1961, which included the simulations of the 1955 and 1959 rainfall conditions, led to the firm conclusion that the crashes of 1955 and 1959 were due mainly to excessive mortality from desiccation in the egg stage. Laughlin (1958) also showed by laboratory experiments that eggs die within 3 days in relative humidity of 90 per cent or below. Meats (1966) has reported from his extensive experiments that eggs survived 1½-4 days at 76 per cent relative humidity, 6-8 days at 92 per cent relative humidity and 12-20 days at 98 per cent relative humidity. Flooding of soil effects the hatching and survival of eggs. In

unsaturated air, larvae loose body weight, and around 75-86 per cent relative humidity they die. Soil flooding is also fatal to the larvae of T. paludosa.

1.4. Material and methods of leatherjacket sampling.

There are various ways of investigating the population of leatherjackets in the field, and each method has its own advantages and disadvantages. The time of the year is also important and different techniques may be advisable in different seasons. A review of different techniques follows to give the background to the application of suitable techniques in the present work.

1.41. St. Ives method

This is probably the earliest and most common technique for the estimation of leatherjacket populations. As a result of insecticidal properties studied by Dr. T.W. Evans, an emulsion has been devised (Dawson, 1932) at St. Ives Research Station, and Dawson gives the formulation at 16 parts by volume of orthodichlorobenzene, 4 parts of a 10 per cent solution of sodium oleate in water and 5 parts of Jey's fluid. For use this emulsion should be diluted 1 gallon in 400 gallons water and applied at 1 gallon per square yard of turf.

Dawson (1932) observes that leatherjackets are not killed by St. Ives fluid. Barnes (1941) also reports that leatherjackets come out of the soil after a few minutes from the application,

they are in no way damaged, they go down into the soil again within 10 minutes. Milne et al. (1958) compared the St. Ives method with a hot water process. They conclude that St. Ives fluid irritates leatherjackets, so they come to the surface. Arrival time depends on the climatic conditions (Dawson and Ferro, 1936). Of many causes, Milne et al. (1958) have observed that the temperature is a very important factor affecting the time of appearance of leatherjackets on the surface. Usually they come within 1-2 minutes after the application of the fluid. The counting should be finished in 10 minutes.

Efficiency of this method differs with different observers. Barnes (1941) obtained 80 per cent of the population. Most convincing experiments have been carried out by Milne et al. (1958) in which they got efficiency of up to 85·5 per cent. The efficiency varied at different times of the year; the result is steady up to May and then drops. Barnes (1941) got more or less steady results up to March or April, and Escritt (1947) confirmed the same. Mayor and Browne (1964) suggest a much lower figure by the St. Ives method.

Cohen (1953) revised the sampling at random of 10 square yards with St. Ives fluid and counting for 5 minutes, to 20 one foot square random samples with 1 pint standard solution in each square foot. This recommendation is still widely used by the Advisory Entomologists throughout the country.

1.42 Salt and Hollick process.

This is a floatation process devised by Salt and Hollick

(1944) for the estimation of wireworm populations. There are three stages in this extraction process: wet sieving, floatation and an oil-separation stage where arthropods are separated from organic debris. This method is based on earlier methods devised by Morris (1922-3) and Ladell (1936). Morris extracted arthropods from soil samples by washing the soil through graded sieves, and collecting them from the material retained on the finer sieves. Ladell introduced a floatation stage to separate the arthropods and other organic material from the mineral and soil particles using a magnesium sulphate solution with a specific gravity of about 1·2. Salt and Hollick simplified the wet-sieving and floatation stages; and introduced an oil separation stage using xylene or benzene to separate arthropods from organic debris. By this method soil animals from 1 mm. long to 12-15 mm. long have been investigated. Further modification has been made by Stephenson (1962) using interchangeable wire gauze screens so that a final gauze can be used just fine enough to retain the animal in which one is interested.

This process is used for the 1st and 2nd instar larvae of crane-flies (Milne et al. 1958). It could be used forother instars too, but it is tedious as it involves breaking up the sample, teazing out and passing carefully under a jet of water.

Mayor and Browne (1964) devised a machine for the extraction of leatherjackets as they were not satisfied with the orthodichlorobenzene method. Their machine consists of a round bottomed dairy washing-up trough, the outflow of which is extended to direct the flow of water through a bank of two sieves (8 and 30

meshes per in.). The sample is placed in a container where it is agitated as water is fed through a hose. Water, plant debris and larvae pass over the top of the container to a 5 mesh per in. sieve inside the trough which retains most of the plant material, the other small sieves retain other smaller plant material, arthropods and other organism. The contents in the three sieves are washed and brine floatation is used to separate material from which the leatherjackets are collected by hand.

1.43. Hot water process.

In investigating the repellent method of extracting leatherjackets from the turf to get the absolute population of larvae for ecological and other scientific studies, Milne et al. (1958) developed this method. The apparatus consists of two galvanized metal boxes, one within the other, the space between being a water-jacket. The inner box has a bottom of fine-meshed wire gauze through which water can pass. The turf fits the inner box tightly. The water is heated and the level is raised slowly driving the leatherjackets to the surface from where they can be picked up. The efficiency of this method is 100 per cent. The efficiency of St. Ives method was checked by this one.

1.44. Tullgren funnel technique.

This is a well known method in which the soil sample is put on a sieve. An electric bulb is fitted in a reflector above the sieve, heat advances from the surface downwards and drives the insects to the bottom of the funnel from where they drop into a tube containing preservative. Prasad (1960) collected T.paludosa

larvae by this method while investigating the insects of upland pastures. This method was used in the north of Scotland (Shaw and Blasdale, 1966) where it gave much better results than the St. Ives method which failed to give results of the accuracy obtained by Milne et al. (1958). In this method 100 per cent extraction was obtained from 4 in. to 6 in. diameter cores.

1.45. Core sampling.

This method is used for Advisory Service (George, 1966a). In 1961/62 it was found that cores gave more accurate results than orthodichlorobenzene methods. A wide area of the country was sampled by both cores and ODCB methods and the number of larvae recovered by each method was tabulated by George (1966a). The result shows that the efficiency of the ODCB method varies from place to place. On the whole cores gave much better results. Cores were collected from near the ODCB sample and taken to the laboratory. Samples were either washed according to Mayor and Browne (1964) machine or hand sorted.

George was of the opinion that both the methods have their advantages. The ODCB method gives an immediate estimate of the leatherjacket population in a field and some indication of the distribution within the field, the information is immediately available to an adviser, whereas core samples are useful when fields are examined for experimental purposes or in adverse weather conditions.

1.5 Leatherjacket damage and control

1.51 Damage

A wide range of agricultural crops are attacked by leatherjackets. Curtis (1849) reported that T. oleracea was injurious to cabbage, scarlet beans, beet, lettuce and potatoes. They even damaged carnations and dahlias in flower gardens. Theobald (1929) reported severe infestation of strawberries, oats and turnips by the larvae of T. paludosa and T. oleracea. Warburton (1935) observed loganberries heavily damaged by larvae of Tipula sp. Leatherjackets also damage sugar beet (Jones et al. 1955).

Grassland is the natural habitat of leatherjackets. Most of the experiments for the control of leatherjackets have been carried out on grassland. Heavy infestation causes a loss of yield in dry matter. They cause considerable economic damage in golf-courses. Dawson (1932) reported widespread damage to golf courses in the south of England. When attacked the turf becomes thin and dies out in irregular patches, due to destruction of shoots. Willis (1963, 1965) reported damage to pastures in Northern Ireland. Grennan (1966) also found heavy infestation of leatherjackets in a pasture following virgin-bog. The yield of grass was reduced by about 50 per cent in a heavily infested pasture. French (1966) obtained 45 per cent and 25 per cent increase in silage and hay cuts in 1963, but a 68 percent and 73 per cent increase in hay in 1962 and 1964 by controlling leatherjackets with DDT. The DDT also gave a 275 per cent increase in a very early cut.

Cameron (1945) described the injury caused by leatherjackets to ley pastures, cereal crops, bowling greens and city lawns in Scotland. Damage appeared in winter wheat at the end of March and on oats at the end of April and the beginning of May. Re-sowing of wheat, oats and barley was required where insecticidal treatments were delayed. In parts of West Lothian the numbers of larvae in low land pastures, that had been stripped almost bare, were estimated at $2\frac{3}{4}$ million per acre in June.

Cereals, as already described, suffer most from leatherjacket damage. Thomson (1926) reported an attack on a wheatfield where patchy damage had been caused by leatherjackets. Hodson and Beaumont (1926) investigated the damage to various crops, particularly the serious damage to barley, oats and strawberries. Rennie (1927) also reported leatherjackets on oats. These are some of the early observations on the damage to cereals by leatherjackets, and from then onwards it is hard to get a single year when there was no report of damage by leatherjackets to a certain extent. In Northumberland (Bull. Min. Agric. 1965) 200,000 larvae per acre were responsible for wiping out broadcast barley, also wheat following ley was damaged in Hertfordshire.

Bardner (1966) carried out micro-plot experiments to estimate the damage by larvae. He used 0, $\frac{1}{4}$, $\frac{1}{2}$ and 1 million larvae per acre but could not get a significant difference in the yield of barley. With all treatments far more shoots were produced than those which bore ears at harvest. In attacked plots leatherjackets reduced the mean yield per plot by 14 per cent and the 1 million per acre treatment lessened shoot numbers by about 27 per cent but ear

numbers by only 9 per cent. George (1966b) also could not get a consistent relationship between yield of grain and presowing count of leatherjackets or plant damage. In the experimental fields, where leatherjacket populations ranged from 40,000 to 500,000 per acre, the mean yields were 28·8 cwt. per acre from untreated and 30 cwt. per acre from plots treated with dieldrin. White (1966) made eight trials on spring barley where populations of larvae varied from 240,000 to 450,000 per acre, and mean yields were 23·0 cwt. for control and 27·6 cwt. for treated areas.

Newbold (1966) also reports that 40 per cent of all spring cereals were treated with insecticides and that in many cases complete or partial loss occurred in the west of Scotland due to lack of control of leatherjackets.

It is obvious from this evidence that very little work has been done on the type of damage leatherjackets cause in the cereal field. None of the observers gives in detail the continuous record of crop damage in the field and the reaction of plants to overcome the damage. Bardner and George frankly admit that they intend to do these experiments in the field when opportunity occurs, as the population of leatherjackets is low in south of England compared to other parts of the country.

More information about the damage to crops is given with the review of the control of leatherjackets.

1.52 Control of leatherjackets.

1.521 Chemical Control

For many years paris green has been used as one of the most

popular and effective chemicals to control leatherjackets. Packard and Thomson (1929) recommended the use of paris green to control the damage caused by Tipula simplex and Tipula quaylei to pastures, grain and lucerne fields in California. The infested field should be scattered uniformly with poisoned baits consisting of 25 lb. bran, 1 lb. paris green and about 3 U.S. gals. of water per acre. West of Scotland Agricultural College (1925) also recommended paris green and bran bait for the control of the larvae of T. paludosa and T. oleracea.

Thomson (1926) applied a poison bait with 1½ oz. sodium fluoride per gallon of water to 20 lb. bran, which was ineffective, but successfully applied 20 lb. bran with 1 lb. of paris green with 1 gal. water per acre. An average of 77 per cent of larvae were killed after 2-3 days from application. Bait remained effective longer. Hodson (1927) also recommended the paris green and bran-bait for leatherjackets, cut worms and slugs. Miles (1927) while controlling wire-worms with baits in conjunction with calcium cyanide found that leatherjackets were also attracted to it. Theobald (1929) successfully controlled the infestation of T. oleracea with paris green and bran bait. He was also successful in controlling leatherjackets with commercial naphthalene at the rate of 2 cwt. per acre.

In addition to paris green, Hodson and Beaumont (1926) got 95 per cent control in young oat fields with 2 cwt. naphthalene per acre. Dawson (1932) recommended, naphthalene at 2 to 3 ozs. per sq. yard; ammonia solutions, orthodichlorobenzene, lead arsenate, Jeye's fluid etc. in addition to paris green for golf

courses. After investigating with different concentrations of lead arsenate, Dawson and Ferro (1936) concluded that 2·7 cwt. per acre was enough to control leatherjackets. Warburton (1935) heavily watered the turf infested with leatherjackets then left it overnight covered by a tarpaulin. Leatherjackets came to the surface and were collected by hand on the following morning. He also used paris green and bran bait and commented that the latter method would be only used when weather is mild and damp and the grubs are likely to be near the surface.

Maercks (1939) said that leatherjackets could be controlled by strewing a poison bait consisting of 0·9 lb. paris green or sodium fluosilicate and 22·5 lb. bran per acre. The bait should not be applied in dry, frosty, or rainy weather. Bait should be scattered before injury. In laboratory experiments he found that calcium cyanamide in moorland soil, in plots at a rate equivalent to 270 lb. per acre, killed all the eggs and first instar larvae and 50 per cent of the second instar larvae.

With the introduction of chlorinated hydrocarbon insecticides it was found that paris green could be replaced by DDT or BHC and White (1963) reported that there was no difference found between 1 lb. of paris green, 1 lb. of 20 per cent wettable DDT and 1 lb. of 50 per cent wettable BHC, all in 25 lb. of bran per acre on arable land. Cohen and Steer (1946) first reported the control of leatherjackets with DDT. A drench of 0·05 per cent DDT at 1 gal. per square yard yielded 180 larvae. They also got good control by applying 5 per cent DDT dust about 2 oz. per sq. yard followed by a gallon of water. Escritt (1947) tried DDT and BHC in different

formulations. He found that 1 gallon of solution containing 1 per cent of 5 per cent DDT emulsion per square yard gave good control; the same result was obtained with $\frac{1}{2}$, $\frac{3}{4}$ and 1 oz. BHC per sq. yard. DDT dust, $\frac{1}{2}$ oz - 2 oz. also gave very good results in square yard turves.

Saaltink and Tickeler (1954) in Holland tried insecticides with bran baits at 22·5 lb. per acre and compared them with parathion, both in bait and spray. The count was based on the number of dead larvae on the surface 3 days later. A spray of 0·08 per cent of a product containing 25 per cent parathion and bait containing 1·8 cc. of the same product per pound bran were significantly better than BHC or paris green in baits. Baits containing derris or DDT were unsatisfactory. Tests were conducted in arable land with baits containing 1 per cent actual BHC, 4 per cent paris green or the parathion product at the rate of 1·8 cc. per pound. The numbers of larvae per square metre found dead on the surface were 4, 1 and 9 respectively; but 54, 77 and 46 per cent of the larvae were found dead in the soil within 14 days as compared with 9 per cent in the control. A bait containing 4 per cent chlordane also gave promising results.

Rodriguez (1953) investigated a heavy infestation of an oat field with larvae of Tipula cunctus. As control measures in test plots, he used toxaphene 45 per cent emulsion 2 lb., BHC 10 per cent wettable powder 0·3 lb., DDT 50 per cent wettable powder 3 lb., chlordane 40 per cent wettable powder 2 lb., parathion 15 per cent wettable powder 0·45 lb. all in 50 gallons of water per acre and the percentages of mortality got three days

after treatment were 7, 65, 46, 64, 86 and 98 respectively. Subsequent application in the field of 0·3 lb. parathion per acre gave excellent results within 48 hours. It was evident however, that in the parathion experiment control depended on the amount of spray mixture used per acre. Ten to 50 gallons of spray per acre were used satisfactorily.

White (1963) got no difference in control of leatherjackets by using 1 lb. of 50 per cent wettable BHC in 25 lb. bran and a spray of 6 pints 20 per cent miscible DDT. Each gave a reduction of approximately 90 per cent of the population. As chlorinated hydrocarbons gave good results, 2,4 and 8 pints of 30 per cent aldrin and 15 per cent dieldrin in 50 gallons of water per acre were used in replicated trials. No significant differences were obtained. A comparison was also made with 2 and 4 pints of aldrin and 16 oz. 80 per cent mecarbam, all in 50 gallons of water. Mecarbam gave a poor result. Willis (1963) got good results by using 4 pints of 25 per cent DDT emulsion or 4 pints of 30 per cent aldrin emulsion per acre; compared to DDT, aldrin was better.

To get a less toxic organophosphorus compound rather than persistent chlorinated hydrocarbons, White (1963) also made tests with larvae in petri dishes in the laboratory with diazinon, dimethoate, demeton methyl, malathion, phosphamidon, trichlorphon, sevin and mecarbam, All showed some degree of control, but failed in grass plots. Tests were also made in barley crops to compare trichlorphon, dimethoate, diazinon, malathion and mecarbam with aldrin. The effectiveness of all these compounds varied from 0 with

diazinon to a maximum of 57 per cent with dimethoate against 96 per cent with aldrin. On further investigation (White, 1966) with thionazin, chlorfenvinphos, parathion, A 12968 (Bayer) and folithion, all gave good results in controlling leatherjackets. Chlorfenvinphos and folithion seemed to be more promising for the control of leatherjackets and about as effective as chlorinated hydrocarbons.

To find good alternative organophosphorus compounds to replace organochlorine ones, Dunn (1966) treated a barley field with folithion and birlane both in spray and baits, parathion granules, and BHC baits; and the numbers of leatherjackets counted on the surface 4 days after treatment were 124, 100, 34, 77, 108 and 106 respectively against none in control and the numbers still alive determined by 4 in. diam. cores were 5, 8, 16, 14, 21 and 7 respectively against 37 in control. This result shows that folithion spray gave better control than the other insecticides. In repeated trials in the following year, he also found that folithion is the insecticide which has the prospect of replacing organochlorine compounds.

It has already been mentioned (Warburton 1935, Marrcks, 1941) that weather is an important factor in the application of insecticides. Saaltink and Tickeler (1954) said that insecticides they used for the control of leatherjackets should be applied when the night temperatures were expected to exceed about 7°C (44°F) as the larvae are then more active. White (1963) mentions that harrowing is of value after the application of insecticide under dry and cold conditions if the crop is drilled, but it is

unnecessary in warm weather. It is already obvious from the control measures that bait is very efficient in a damp and humid night when leatherjackets mostly come out on the surface.

1.522 Mechanical control measures

Mechanical methods for the control of leatherjackets were used in early days before insecticides took over. Ritzema Bos (1915) reported that small holes of about 8 in. deep and the same diameter with the vertical sides were found very useful as traps for leatherjackets. Copley (1918) recommended the control measures of thorough drainage of grass land and cleansing of water courses. Orthodichlorobenzene application advocated by Dawson (1932) should also be followed by sweeping away the larvae from the surface of the turf or rolling with a heavy roller to kill them. Maercks (1941) attached more importance to drainage to control leatherjackets in pastures. He also advised that during the flight periods of T. paludosa grass should be kept as short as possible, so that adults were blown by wind. Manuring ensures a thick covering of grass which hampers oviposition.

1.523 Biological control

Leatherjackets have a wide range of enemies which prey on them. Alexander (1919, 1920) gave a list of different species of vertebrates and invertebrates attacking leatherjackets. Investigating the food of the common mole (Talpa europa) in North Wales, White (1914) found that leatherjackets were one of the staple diets. A mole eats an average of 20 leatherjackets a day. Alexander (1919) mentioned the larvae of an unidentified Tipula sp.

were eaten by the arctic fox. Birds are very well known to the farmers of this country in controlling leatherjackets. Rennie (1927) gave a list of bird species feeding on leatherjackets in the north of Scotland. Dawson (1932) reported that rooks and starlings removed the replaced divots in golf courses in search for leatherjackets. Dunnet (1955) found that in the breeding season, starlings feed chiefly on leatherjackets (T. paludosa larvae) a food which is available and utilized through the winter and spring. Out of the feeds recorded, leatherjackets represented 91 per cent of the diet in the middle of May and 76 per cent at the end of June.

The diseases of T. paludosa will be described elsewhere as this also includes a topic of investigation in this study. No record has yet been found that beetles are predatory on the larvae of T. paludosa and T. oleracea.

These various methods of the control of leatherjackets indicate that the integration of natural and chemical measures are of great importance for the successful control of the pest as suggested by Milne (1965).

SECTION 2. SURVEY OF LEATHERJACKET POPULATION AND THEIR DAMAGE IN SOUTH EAST SCOTLAND.

2.1 Introduction

The populations of leatherjackets have been recorded in S.E. Scotland since 1953, by random sampling of grass fields during autumn by the Advisory Entomology Section of the School of Agriculture for forecasting possible attack on crops by the larvae. There is a considerable variation of the population from year to year. The years of low incidence were 1953, 1957, 1960 and 1966 when populations varied from 20,000 to 150,000 per acre, whereas the years of high incidence were 1955, 1959, 1962, 1963, 1964 and 1965 when widespread damage to crops was reported and populations varied from 100,000 to 800,000 per acre (Dunn, 1966). The abundance of larvae in a particular area was related to the August and September rainfall as obtained by Milne et al. (1965). This is also true in this area. The wetter part is the west which usually has higher leatherjacket populations.

2.2 Estimation of populations

A survey was made in 1964-65 and 1965-66 in grass fields in widely separated farms in four of the counties in S.E. Scotland. Table 1 shows the data. The populations were determined by St. Ives method (Dawson, 1932).

2.21 Berwickshire

In general populations were low in this area. Four fields sampled in November 1964, showed low populations

(Table 1, Blackhouse and Blackerstone). Populations varied from 32,000 (Blackerstone 2) to 125,000 per acre (Blackhouse 1). This range of population is too low to cause damage to cereals or grass. In the period 1965-66, the populations were still lower (Blackhouse and Mungo's Walls).

2.22 Midlothian

Three fields at Balerno showed high populations of larvae, varying from 313,000 (Balerno, 3) to 756,000 per acre (Balerno, 2). The field with the highest population required to be sprayed. Barley was drilled in this field in April 1965. The field in Crofthead Farm showed a high autumn population (Table 1).

In 1965-66 the fields at Balerno and at Crofthead Farm showed a population of 114,000 and 144,000 respectively in autumn sampling.

2.23 West Lothian

A field in grass was sampled at Dykeside Farm and the population was 174,000 per acre. An insecticidal trial was laid out in this field.

In 1965-66 a field at Bishopry showed a population of only 43,560 per acre. Though West Lothian has a bad record of leather-jacket damage no record of high incidence or damage was recorded in the two years of my investigations.

2.24 Kinross

Three fields at a farm near Dollar (Solesgirth, Table 1) showed a population varying from 49,000 to 163,000 per acre.

TABLE 1

Total number of larvae collected from one foot square turves by St. Ives method in 1964-65 and 1965-66.

County	Farm	Year 1964-65	Population per acre	Year 1965-66	Population per acre
Berwickshire	Blackhouse (1)	46	125,235	13	35,392
	(2)	42	114,345	18	49,005
	Blackerstone (1)	44	119,790		
	(2)	12	32,650		
	Mungo's Walls (1)			6	16,355
	(2)			13	35,392
Mid Lothian	Lady Thomson's (1)	198	539,055		
	Farm, Balerno (2)	278	756,855		
	(3)	115	313,087		
				42	114,345
	Crofthead	111	302,197		
				53	144,292
Kinross	Solsgirth (1)	60	163,350		
	(2)	18	49,005		
	(3)	48	130,680		
West Lothian	Dykeside	65	176,962		
	Bishopry (1)			16	43,560
	(2)			11	29,947

All samples in 1964-65 collected in October and November except Solsgirth which was in February (1965).

All samples in 1965-66 collected in February and first week of March (1966).

Fields in Blackhouse were the same in both years.

These are the northernmost fields sampled during the course of investigation.

2.3. Damage to cereals and population of larvae.

This investigation was carried out during the spring of 1965.

2.31 Method and material for investigation.

It was decided to investigate the damage to crops in the field. A 4 in. diameter core was used throughout the field investigations. Samples were taken at random to a depth of 3 in. The soil was put on a tray and broken with a piece of perspex rule 6 in. long. The transparent perspex rule was used because while breaking the soil it would not obstruct vision. The number of plants with the aerial parts damaged (leaves cut or shredded) and the number of stems cut were noted. Soil was gathered at a corner of the tray and again investigated. The operation was repeated thrice and larvae present were carefully sorted out and their numbers noted.

2.32 Leatherjackets in oats.

At Mavis Hall Farm near Humbie (East Lothian) an oat crop had been reported to be heavily infested with leatherjackets. On the day (15 April 1965) of visit to the farm, the farmer started spraying with Aldrex 30 (Aldrin) at the rate of 3 pints per acre. The plants were about 2½ ins. high. An area of 11 x 33 yards was left unsprayed in the middle of the field. Monthly estimations of crop damage and populations of larvae were made (Figs. 1 to 3).

2.321 Population of larvae.

To estimate the extent of crop damage and population of larvae, the treated part was divided into two sections (A and B) for the convenience of field study. Thirty cores were taken independently from each section and the control. Fig. 3 shows the total number of larvae from 30 cores in all observations.

2.322 Variation in population

It is remarkable to notice no sudden drop in population (Fig. 3) in May after spraying. Larvae collected did not appear very healthy. It seems that aldrin did not kill quickly but made them less active. The population was greatly reduced from May to June. This period was very dry (Appendix IV, Rainfall, 1965), either they had moved downwards into moister soil or died due to drought. To test the former hypothesis other samples were taken (Appendix I, Table 3, 14.6.65). Each sample was taken in two parts each 3 ins. deep, which parts were examined separately. No larvae were found in the lower 3 in. and so it was probable that the reduction of population was due to the mortality of larvae caused by dryness.

The aldrin at the dosage used appears not to have killed the larvae quickly, but by the time of the June observations the larvae in the treated area were only about half as numerous as in the control area.

2.323 Examination of the rate of mortality in laboratory conditions.

To compare with the mortality of larvae found in field conditions, a group of larvae were reared in the laboratory to

examine how they behaved.

(i) Material and method:- The larvae were collected from treated and untreated parts of the field and reared separately in groups of 30 in 3 replicates each of control and treated ones. They were reared in laboratory-made 12 x 6 x 4 in. perspex cages having 18 in. mesh wire gauze at the bottom and a lid of the same on the top. In each cage 30 larvae were put. They were fed on green dry powdered grass. Observations were taken weekly. They were reared in sea-sand which was cleaned weekly with teepol + chlorine water (Laughlin, 1958). Thrice in a week the top of the sand in each cage was examined to ensure that there was enough grass on the surface. Cages were kept on wet sand.

(ii) Results:- Fig. 4 shows the number of larvae alive in weekly observations. There is a considerable drop in June, just before pupation amounting to a 52 per cent reduction in treated and 30 per cent reduction in control (Appendix I, Table 7) in the laboratory against the 70 per cent reduction in control and 80 per cent in treated in the field.

Out of the total larvae 55 pupated in the control against 35 in treated. In 9.7.65, 2 larvae in cage 2 in control and 3 larvae in cage 2 in treated were suffering from nuclear polyhedrosis. They were kept separately. The diseased larvae could not pupate and died with virus infection.

To investigate the diseased larvae in the field, 103 larvae were collected on 10 and 11 June, 1965, and two of them were found to have polyhedra in them.

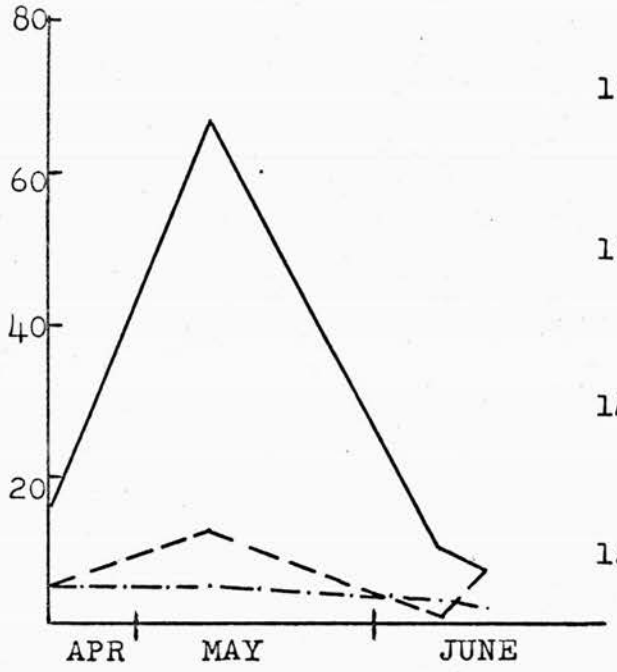


Fig. 1.

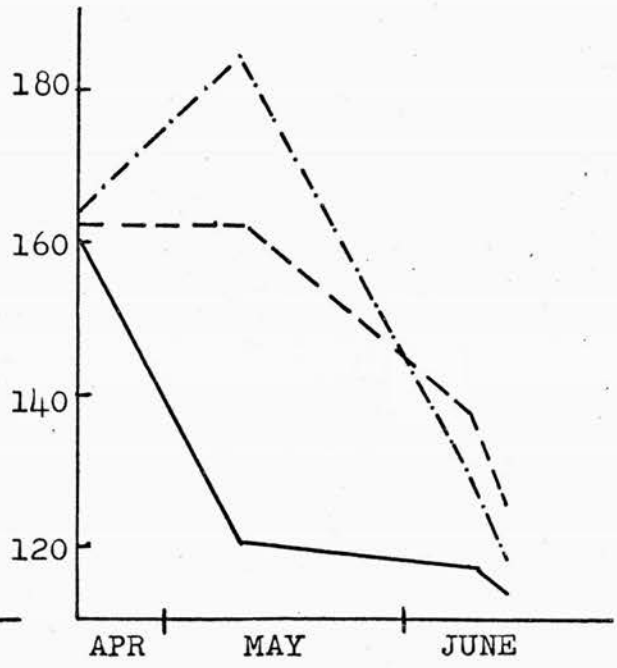


Fig. 2.

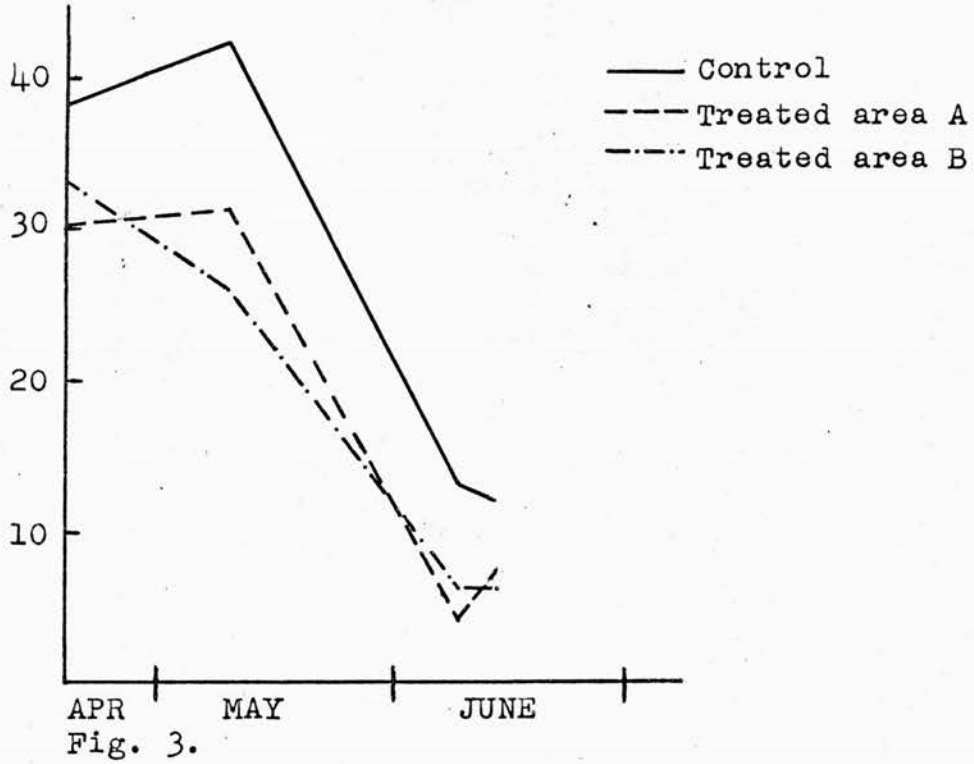


Fig. 3.

Fig. 1 - 3, showing number of damaged plants, undamaged plants and larvae per 30 cores at Mavis Hall Farm.

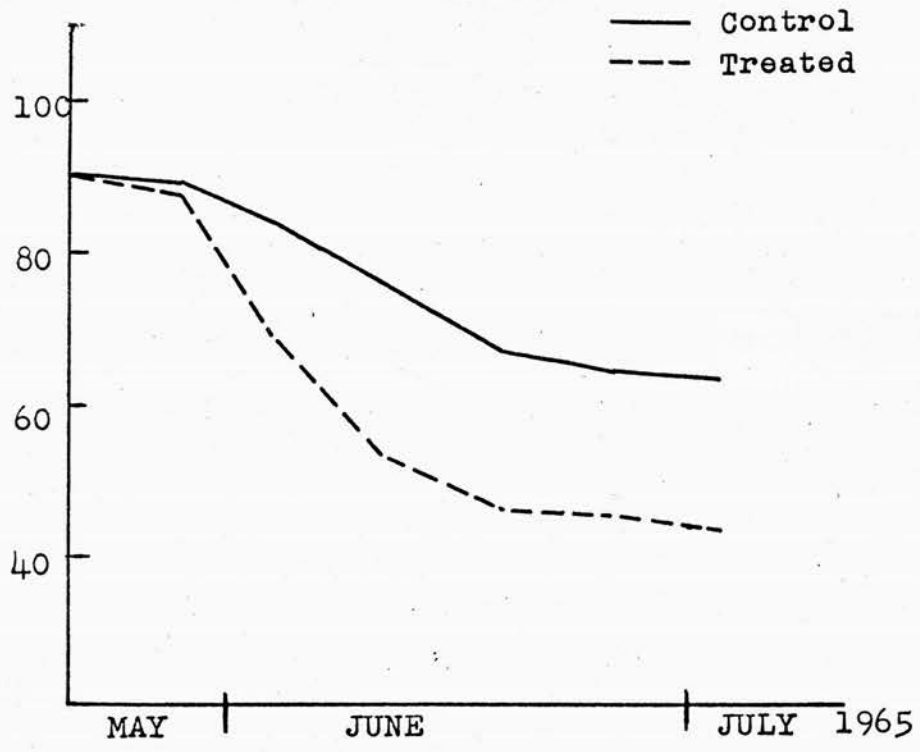


Fig. 4. Decrease in the population of larvae in weekly observations in laboratory. Larvae collected from Mavis Hall Farm.

2.324 Leatherjackets other than T. paludosa Meigen.

One larva of Nephrotoma flavescens was found on 19.4.65 and a pupa (female) on 10.5.65. During the middle of May Nephrotoma spp. were seen flying in the field. A female emerged on 7.6.65 and died on 13.6.65 in the laboratory.

2.325 Damage to oats

Fig. I shows the damaged plants. The damage was not at all serious. At the time of the first sampling very little damage was observed. The month of May showed the maximum including a few cut stems. During June no damage was observed, because of the high rate of mortality of larvae and the rapid growth of the plants.

2.326 Undamaged plants.

Fig. 2 shows the population of undamaged plants throughout the season. In the control area there was, compared with treated areas, a considerable decline in plants in May and a much smaller decline in June.

2.33 Damage to Winter Wheat.

Generally the damage to winter wheat is very uncommon. The reasons for this are discussed by White (1966) in his introductory review in "Leatherjacket Conference" as follows:-

I "It is very common practice where wheat is to follow grass-land that the ley or permanent pasture is ploughed before oviposition occurs.

II When wheat is in a young susceptible stage over the winter months, the larvae are relatively small and feeding is

consequently at a reduced level.

III Wheat has powers of recovery greater than any other cereals and compensatory growth is considerable."

But still considerable damage can occur as was observed in a field of winter wheat at Crofthead Farm (Mid Lothian). The early damage and the high population of larvae escaped the notice of the farmer and in spring, while investigating the trials in a barley field (Figs. 4 to 7), patches bare of plants and numerous tunnels of larvae were observed in the wheat fields. The percentage of damaged plants was calculated against the healthy ones (Table 2) and the population of larvae per acre estimated.

TABLE 2

Total numbers of damaged, undamaged plants and larvae in the Crofthead field of winter wheat.

Date of observation	No. of samples (4 in. diam. core)	No. of undamaged plants	No. of damaged plants	No. of larvae	% plants damaged	No. of larvae per acre
6.4.65	90	289	137	97	32	533,947
22.4.65	90	212	46	30	18	166,005

The damaged plants were those which had stems cut, and most of these were only found by searching below the soil surface. Some were decaying. The field was sprayed after the first observation (on 8.4.65) with 25 per cent miscible DDT, 3 pints per acre. The observation after spraying (Table 2, 22.4.65) showed that the population of larvae was greatly reduced. The damaged plants as shown in Table 2 against 22.4.65 were old damaged plants, no freshly damaged plants were noticed. Damage was so serious

that bare patches occurred, as no plants remained there for compensatory growth. The maximum number of larvae found in one core was 12, the sample being taken to a depth of 6 in., due to the presence of decaying sod down to that depth.

2.34 Damage to barley.

Barley is the common cereal which suffers most from leatherjacket damage. Barley is drilled mostly in the beginning of April, By the end of April and the first part of May the plants have brairded and are well above ground. At this time the larvae undergo their last moult (Laughlin, 1967) and the final instar larvae feed voraciously as the weather becomes warmer causing greatly increased damage.

2.341 Insecticidal trials on Crofthead Farm (Mid Lothian)

The population of larvae was estimated in winter (Table 1). Three insecticides were sprayed on 21.12.64. BHC (80 per cent w/v) ½ pint, DDT 25 per cent emulsion 4 pints and diazinon (20 per cent) 4 pints each in 20 gallons of water per acre. One acre was sprayed with BHC, ½ acre with DDT and 1 acre with diazinon, and about ½ acre of the crop remained untreated as a control.

Barley was drilled in the first week of April and observations were made from 29 April to estimate population of larvae and damage to crop.

2.3411 Population of leatherjackets.

Observations were made as previously recorded (see 2.321), The results are graphed in Fig. 8 and the figures are in Table 6 of Appendix I. The DDT treatment appeared very effective, but BHC and diazinon showed little or no effect.

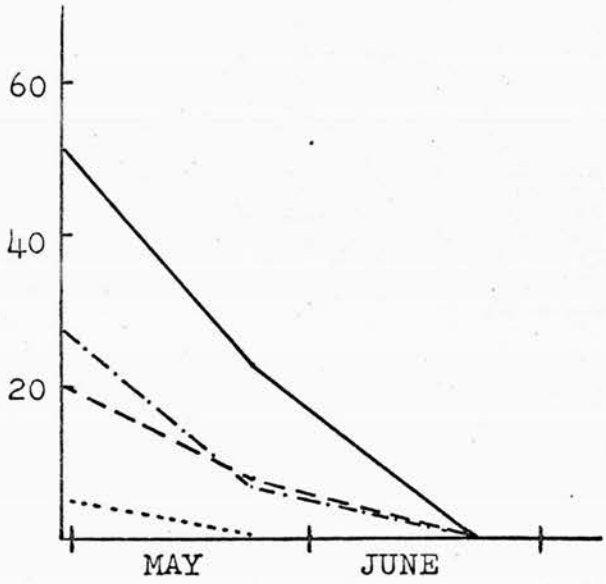


Fig. 5. No. of plants with shredded and/or cut leaves.

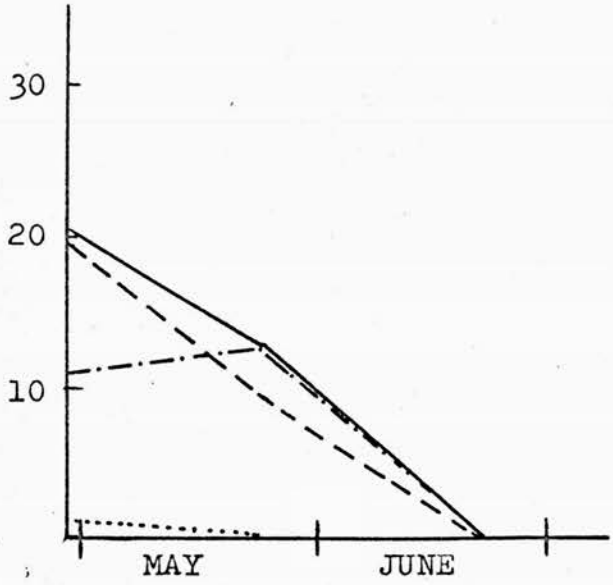


Fig. 6. No. of stems cut

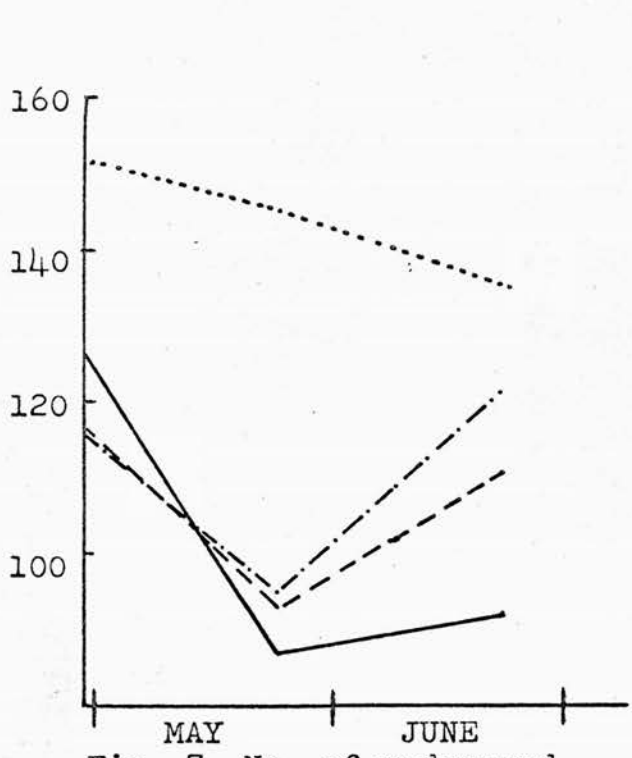


Fig. 7. No. of undamaged plants.

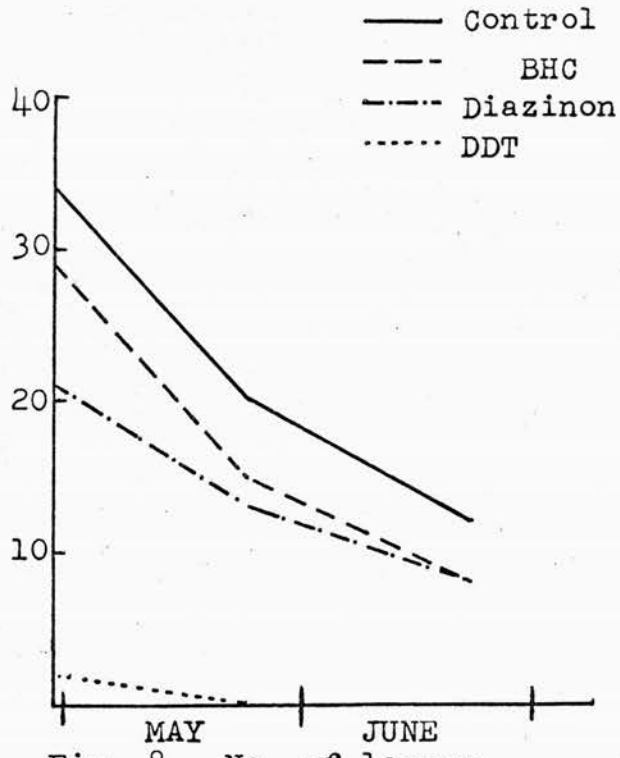


Fig. 8. No. of larvae

All the figures (5 - 8) showing observations (per 30 cores) at Crofthead Farm.

Decline in population (Fig. 8) of larvae was mainly due to drought. One larva was found suffering from Tipula iridescent virus. Numerous carabid beetles were found in the field. They were noticed to go in and come out of the tunnels of leatherjackets. They might have played some part as possible predators of larvae (see Section 9).

2.3412 Effect of insecticides on the rate of mortality of larvae

Groups of larvae were reared in the laboratory. These were collected from BHC, diazinon and control plots, but insufficient larvae were left to collect from the DDT plot (Fig. 8).

(i) Material and method:- Polypots (height 3 in., diam. 2½ in. on top and 2 in. at the bottom) were used for rearing them. Each polypot had a small 100 mesh wire gauze at the bottom, and lid with 100 mesh gauze. Washed sea-sand was used and larvae were fed on dry powdered grass, and remainder of technique was followed as in 2.323. Each polypot had 6 larvae. The treatments were replicated six times. Weekly observations were taken.

(ii) Results:- Fig. 9 shows the populations throughout the weekly observation periods. In Appendix I, Table 8 shows the number of larvae in each polypot. There is no significant difference between any of the treatments. There was a very low rate of mortality which indicates ineffectiveness of both of these insecticides. This result shows the same as obtained in the field.

2.3413 Number of plants damaged.

Figs. 5 and 6 show the number of damaged plants observed in the field throughout the season. DDT is very effective as the

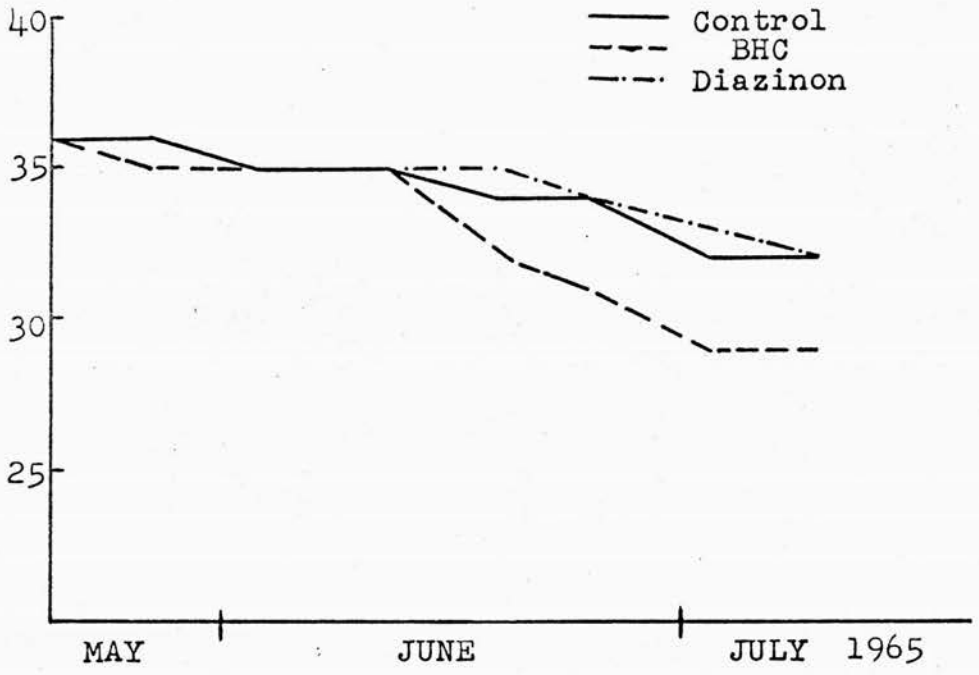


Fig. 9. Decrease in the population of larvae collected from Crofthead Farm, as observed in the laboratory.

minimum damage was obtained, of course this corresponds with the number of larvae (Fig. 8) in this treatment. The number of damaged plants in June was very few (Appendix I, Table 4).

2.3414 Undamaged plants

As can be seen from Fig. 7, the maximum number of undamaged plants was observed with DDT. The control, diazinon and BHC differed little from each other. The month of May shows a certain decline in undamaged plant population, as the size and activity of the larvae increased. Many of the plants later outgrew this damage and appeared normal and so the population of undamaged plants increased in June (especially in the plots treated with BHC and diazinon) at which time the population of larvae was also decreasing.

2.342 Insecticidal trial at Balerno (Mid Lothian)

The second field (Table 1) in Balerno showing a population of over $\frac{3}{4}$ million per acre, was sprayed with DDT, BHC and diazinon at the same dilutions as in the Crofthead trial (see 2.341).

The same technique was followed to estimate the number of damaged plants. Table 3 shows the total number of damaged and undamaged plants and the larvae collected in each of the treatments. Observation was made in May, when the larval population was found to be high in all treatments except DDT. This result corresponds with Crofthead Farm observations. No more observations were made, because the farmer sprayed the field with DDT to check further damage to the crop.

TABLE 3

Total number of plants and larvae recorded in each treatment at Balerno field (per 30 cores)

Date of observation	Type of observation	Control	BHC	DDT	Diazinon
5.5.65	No. of leaves shredded and cut	28	22	2	36
	No. of stems cut	15	15	0	17
	Undamaged plants	89	95	120	78
	No. of larvae	20	17	1	21

2.35 Other observations

A field in Solsgirth Farm (Table I, Field 1) near Dollar was sprayed with diazinon (3 pints per acre). An observation was made on 13.5.65. The total number of plants damaged per 30 cores, undamaged and the number of larvae are given in Table 4.

TABLE 4

Total number of damaged, undamaged plants and larvae at Solsgirth Farm (per 30 cores)

	Plants with leaves shredded and/or cut	Plants with stems cut	Undamaged plants	Larvae
Treated	12	12	94	10
Control	4	8	90	11

A field of oats at Dykeside Farm, West Lothian (Table 1) was sprayed with 20 per cent diazinon in two dilutions i.e. 6 pints per acre and 3 pints per acre. Observations were made on 14.5.65 to find the effectiveness of this insecticide.

TABLE 5

Total number of undamaged plants and larvae at Dykeside Farm (per 30 cores)

Type of observation	Diazinon 3 pints/acre	Diazinon 6 pints/acre	Control
Undamaged plants	143	142	157
Larvae	6	3	5

The result is shown in Table 5. There was no damage observed in this field.

SECTION 3. INVESTIGATION OF THE POPULATION OF LEATHERJACKETS IN A GRASS FIELD

3.1 Introduction

It has been suggested that permanent sites are useful to give an indication of a decline in the population of larvae (George, 1964). Moreover this investigation was carried out to compare the two methods of sampling i.e. St. Ives method and 4 in. diameter core. It is possible that the greater estimation of the population at Crofthead in the spring as compared with the previous autumn may have been due to the latter estimations having been made by the St. Ives method and the former by 4 in. diameter core (see Table 1 and Fig. 8).

3.2 Material and method

The field was a 3 year ley often grazed by cattle. The field was divided into 5 areas in each of which 4 random samples were taken by the St. Ives method using 1 pint normal strength solution on 1 square foot for each sample. The samples were worked in pairs so as to observe all the larvae which came to the surface. The estimate of population was obtained from these 20 samples, the taking of which occupied about 4½ hours.

Two 4 in. core samples 3 in. deep were also taken near the St. Ives samples. These samples were removed to the laboratory for examination. The leatherjackets were removed by hand sorting. Checks were made on the November and December samples subsequently submitting them to extraction by the Salt and Hollick method; but it was found that hand sorting recovered all the larvae and wet-

extraction was abandoned thereafter.

3.3 Results

The result is shown in Fig. 10. The total number of larvae collected by each method is shown in Appendix 1 (Tables 9, 10). The core method gave the more reliable result and so the figures obtained by this method are used in comparing the population throughout the period of November to June. Table 6 shows that in 1965-66, there is no significant difference between the November and December observations. The population of larvae in February is significantly less ($p < 0{\cdot}01$) than in November or December. There is no significant difference between the populations in February and April; but the figure for June is significantly ($p < 0{\cdot}01$) less than any of the previous observations.

TABLE 6

Mean number of larvae recovered by (A) cores (B) St. Ives method (per 8 cores and 4 ft.^{2})

	Year	Nov.	Dec.	Feb.	Apr.	May	Jun.	L.s.d. between two means	Value of "F"
A.	1965-66	8·6**	7·4**	4·8**	4·0**		1·2	a, 1·75 b, 2·38	25·64
	1966-67	10·2**	8·2**	5·8**	5·4**	4·6**	1·2	a, 2·40 b, 3·26	14·5
B.	1965-66	28·0**	22·4**	14·6**	13·2**		0·8	a, 5·37 b, 7·29	31·5
	1966-67	33·6**	27·8**	16·0**	7·6	6·2	0·6	a, 12·99 b, 17·66	44·0

** Significant at $p < 0{\cdot}01$

A = Least significant difference (L.s.d.) at $p = 0{\cdot}05$.

B = " " " " at $p = 0{\cdot}01$.

F = Treatment variance ratio.

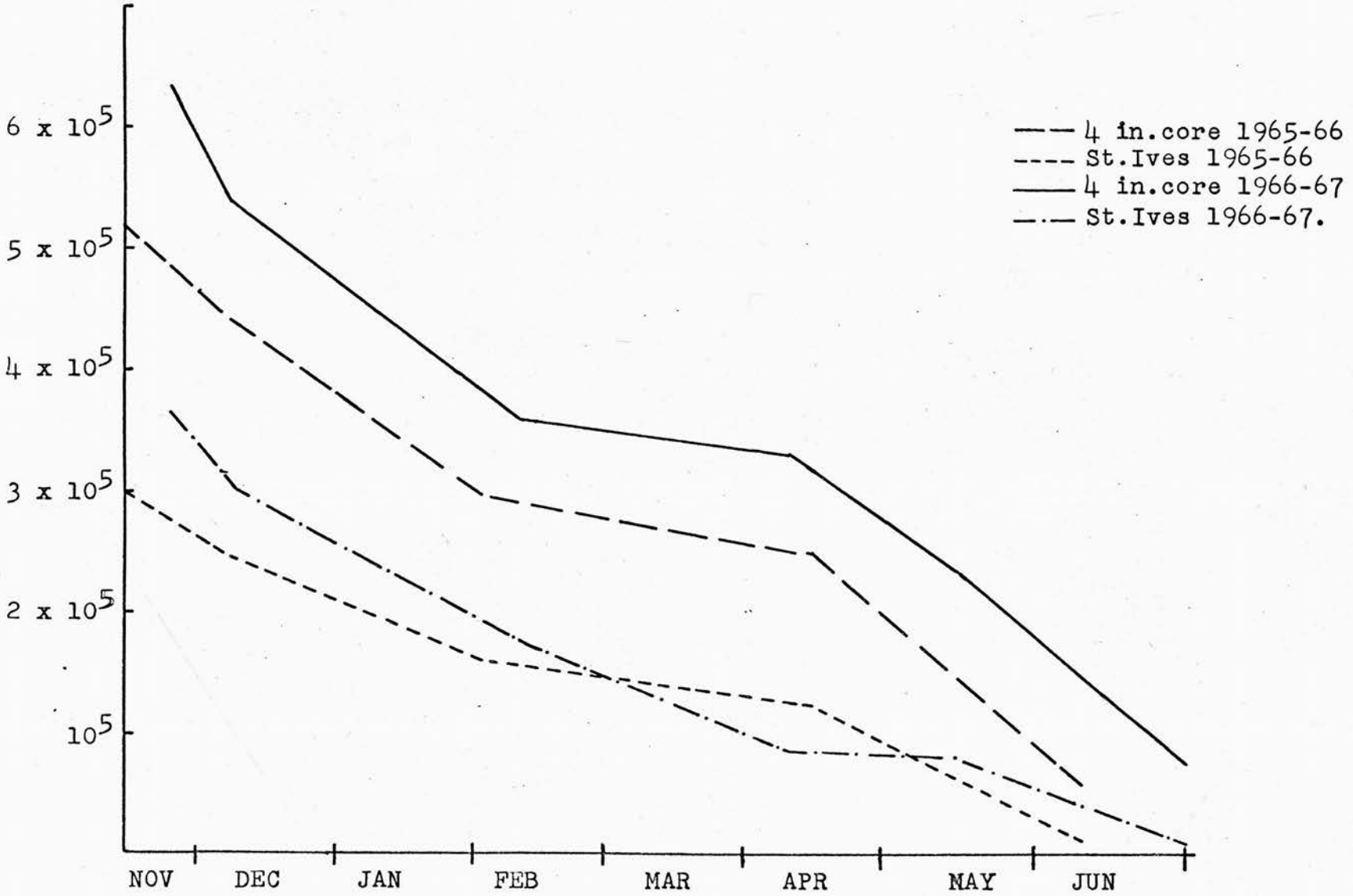


Fig. 10. Population per acre of leatherjackets in a field at Crofthead Farm estimated by 4 in. diam. core and St. Ives method.

The population of leatherjackets sampled by cores in 1966-67 shows similar results except that the December population differs at $p < 0{\cdot}05$ compared with February, April or May populations. The decline in the population of leatherjackets estimated by the St. Ives method also shows a similar pattern.

It is obvious from Fig. 10 that there are two distinct declines in population, the first in the months of December and January, this could be called winter mortality (White, 1963; George, 1964) which accounted for about 50 per cent of the reduction in population. The second decline is in the months of April to June which accounted for about 60 per cent of the mortality. The most important factor is dreught in May and June and others are parasites and diseases. It could be mentioned here that most of the diseased larvae were found in field observations during this time of the year.

The estimation of population by cores has been taken as cent per cent in this experiment; and Fig. 11 shows the percentage efficiency of the St. Ives method. The maximum efficiency is about 60 per cent in November and December but this efficiency declined considerably in April and the lowest was recorded in June (8·72 per cent)

The June sampling in 1966-67 with the St. Ives method showed a population of 12,130 per acre. Another set of core samples were taken inside each 1 ft.^{2} ring (4 cores/ft.^{2}). The cores gave a residual 50,000 larvae per acre in the soil. This showed a great inefficiency of the St. Ives method during that time of the

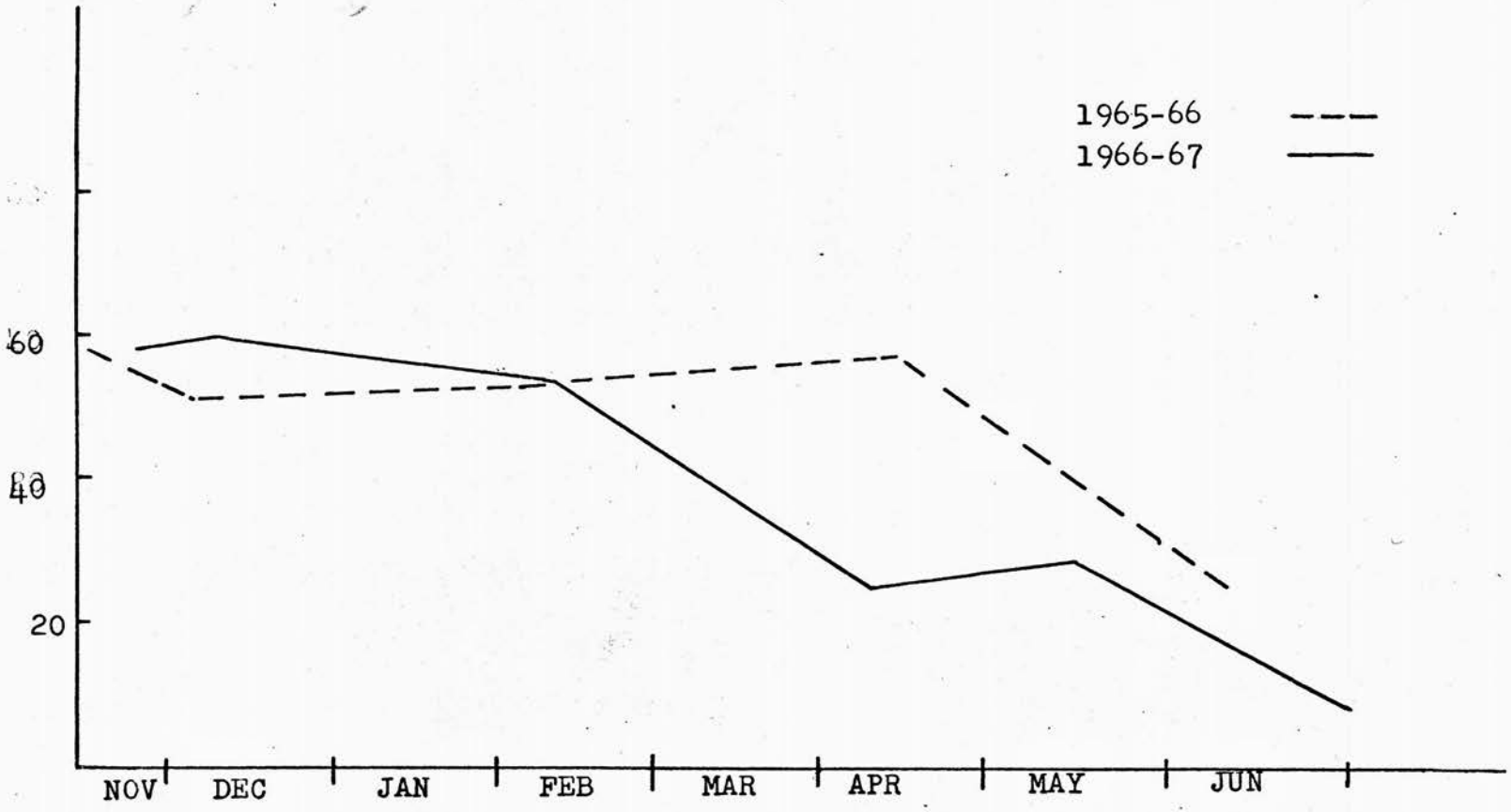


Fig. 11. Efficiency of St. Ives method Crofthead Farm, Midlothian expressed as a percentage of the results obtained from 4 in. diam. cores.

year. One larva from these samples was found to be suffering from nuclear polyhedrosis.

3.4 Discussion and conclusions

The maximum efficiency of the St. Ives method as shown in this experiment was 60 per cent, whereas Milne et al. (1958) claimed 85·5 per cent and Barnes (1941) 80 per cent. But Barnes did not show any figure to justify his statement. The differences of population between the two methods, in my findings, could be compared with George's (1964, Table 5) who had shown that there was a great variation of population estimates based on the two methods in different regions.

It explains the discrepancy in results of Table 1 and Fig. 8 between autumn sampling by St. Ives method and spring sampling by cores. In this investigation the St. Ives method was followed exactly as done by the Advisory Service Department; so it could be suggested here that for advising the farmer during the autumn the St. Ives method could be considered sufficiently accurate and it is quicker and gives a result on the spot, but its discrepancy should be kept in mind.

SECTION 4. EXPERIMENT IN INSECTARY TO STUDY LEATHERJACKET DAMAGE TO BARLEY

4.1 Introduction

Two experiments were set up, (A) one in the insectary (B) the other outside, to investigate more closely some of the damaging behaviour of leatherjackets. These experiments were carried out to investigate further in seminatural and controlled conditions some of the field findings.

The larvae of T. paludosa were used for all the experiments

4.2 Material and method

Tins (measuring 9 x 8½ x 4½ in.) were used for these experiments. These were painted with aluminium paint to prevent rusting. All the tins had numerous 1/16 in. holes drilled in their bases and sides to ensure free drainage. Sandy soil up to a depth of 3 in. was put in each tin and barley plants were grown. The number of plants was adjusted in each tin to 80 by hand thinning.

The following treatments were applied:-

(a) Insecticide sprayed on the surface (IS).

(b) Insecticide sprayed on the surface and mixed with top inch of soil (IM).

(c) Control A (CA).

(d) Control B (CB) in which the surface soil was disturbed as if insecticide were being mixed with it as in (b).

Aldrin 30% miscible liquid of the rate of 4 pints per acre in 50 gallons of water was used. The number of tins in each

treatment was 12.

Spraying.

Spraying was done with an compressed-air atomizer which was made up in the laboratory as the commercial hand sprayer was not very satisfactory for this purpose. The quantity of insecticide used was 1·35 cc. mixed with 133 cc. of water to get the required rate per acre for 24 tins. Each treatment was sprayed separately. Barley plants were 2-3 in. high at the time of treatment.

The treatment IS/is a normal method of application of insecticide in the field; this method is most effective when larvae come onto the surface or insecticide finds its way into the soil; the second method makes the whole living environment of leatherjackets poisonous allowing greater efficiency.

Just after spraying in the afternoon, five 4th instar larvae were put in each tin to give a field population of about 400,000 / acre which is expected to cause serious economic damage to a crop.

4.3 Experiment A

The tins were put on a cemented table in two rows inside the insectary in a randomized way. Water was supplied to each tin by an adjustable dropper fed by rubber tubing from a bucket (plate 1). Each dropper was adjusted to keep the soil suitably moist. Additional light was provided during daytime by electric bulbs to compensate for shading by the insectary roof.

PLATE 1. The tins with barley plants of experiment A. The arrangements for adequate moisture and light are shown.

PLATE 2. Showing the tins with barley plants in experiment B.

The experiment was started on 19 April 1966.

4.4 Experiment B

The treatments were exactly the same, but it was set outside the insectary. Each tin was sunk in the soil so that the soil levels inside and out were the same. The tins were randomized and arranged in groups each covered by a wire netting cage. The tops of the cages were movable to facilitate observation. The sides of the cages were sunk 2 inches in the soil. The experiment was left in natural conditions.

The experiment was begun on 1 May 1966.

4.5 Factors investigated

The principal objective of the experiment was to study the different types and degree of damage caused by a known population of leatherjackets. The types of damage were observed and classified as below:-

a. Surface damage

(i) Plants with shredded leaves.

Plants with little damage to the leaves are also classified in this group. Serious shredding may result in the yellowing of leaves which ultimately die off.

(ii) Plants with cut leaves

Damage is slightly more serious where leaves are mostly or partly cut off.

In both of these groups damage was not very serious. It is

common in leatherjacket infested fields to see cut leaves partly drawn into the soil due to feeding activity.

(iii) Stems cut at or above the soil surface

Usually when leatherjackets cut stems they try to pull them below ground. Sometimes they go on eating on the surface till the stem is cut completely through. Partly cut stems are also included in this group. The completely defoliated plants are also grouped under this heading. This type of damage contributes to bare patches in the field. This damage is considered serious in cereal fields as heavy thinning results in crop failure.

b. Sub-surface damage

Most of the time leatherjackets live below surface causing damage to the plants. It is very difficult to estimate the extent of damage to the root system of plants. The number of plants with completely or partly cut stems underground was determined. Plants with stems cut underground have very little chance to survive. Decaying stems as observed in the field of winter wheat (see 2.33) are common in a heavily infested field. Permanent bare patches in fields are mostly due to this type of damage.

The plants may compensate by producing more tillers mostly when damage is above the surface.

c. The number of undamaged plants.

d. Weights of shoots and roots at the end of experiment.

e. The number of larvae on the surface at night.

An endeavour was made to count the numbers of larvae on the surface at different periods of the night by using an electric torch. The light, however, quickly disturbed the larvae and made them behave unnaturally and retreat into their burrows. For this reason the experiment made by the use of time lapse cinematography was devised (see Section 6).

The experiments were continued for two months. Damage was estimated twice weekly. All larvae used in the experiments were reared in the laboratory.

4.6 Results

The damaged plants in experiment A were analysed by summing up total damage per fortnight in each treatment. The undamaged plants were analysed weekly.

In experiment B, the number of damaged plants was not enough for weekly or fortnightly analysis, so these were analysed on the total of damage throughout the experimental period.

4.61. Experiment A.

4.611. Damaged on surface.

4.6111. Plants with shredded leaves.

Plants with shredded leaves were very common. The leaves on the surface had been injured by the larvae from the soil. Some leaves were found to have been drawn partly into the soil and their tips were missing. Wilting was noticed in leaves as a result of serious shredding by the larvae.

Fig. 12 shows that the shredding was noticed at the beginning

of the experiment, but the peak of damage was on 31 May. The shredding of leaves was continued till 21 June. This showed a long period of activity by the larvae.

TABLE 7.

Mean number of plants with shredded leaves in Experiment A (1966)

Date	Treatments				L.S.D.	Value of F
	CA	CB	IS	IM		
1/4-4/5	0·41	0·66	0·16	0·25	ns	1·23
4/5-22/5	1·08**	0	0·08	0·08	a, 0·59 b, 0·79	6·36
22/5-7/6	4·83**	5·50**	0	0	a, 1·42 b, 1·92	35·62
7/6-24/6	3·41**	2·83**	0·33	0	a, 0·49 b, 0·66	9·97

** Significant ($p < 0·01$)

Value of "F" = Variance ratio

Value of a is the least significant difference (L.S.D.) at $p = 0·05$.

Value of b is the least significant difference (L.S.D.) at $p = 0·01$.

n.s. = not significant.

The activity of the larvae was noticed in IS and IM treatments up to 7 May, so there is no significant difference between any of the treatments during this period (Table 7). There was a significant ($p < 0·01$) decline in damage even in CB, compared to CA, but soon the damage increased sharply and in the period

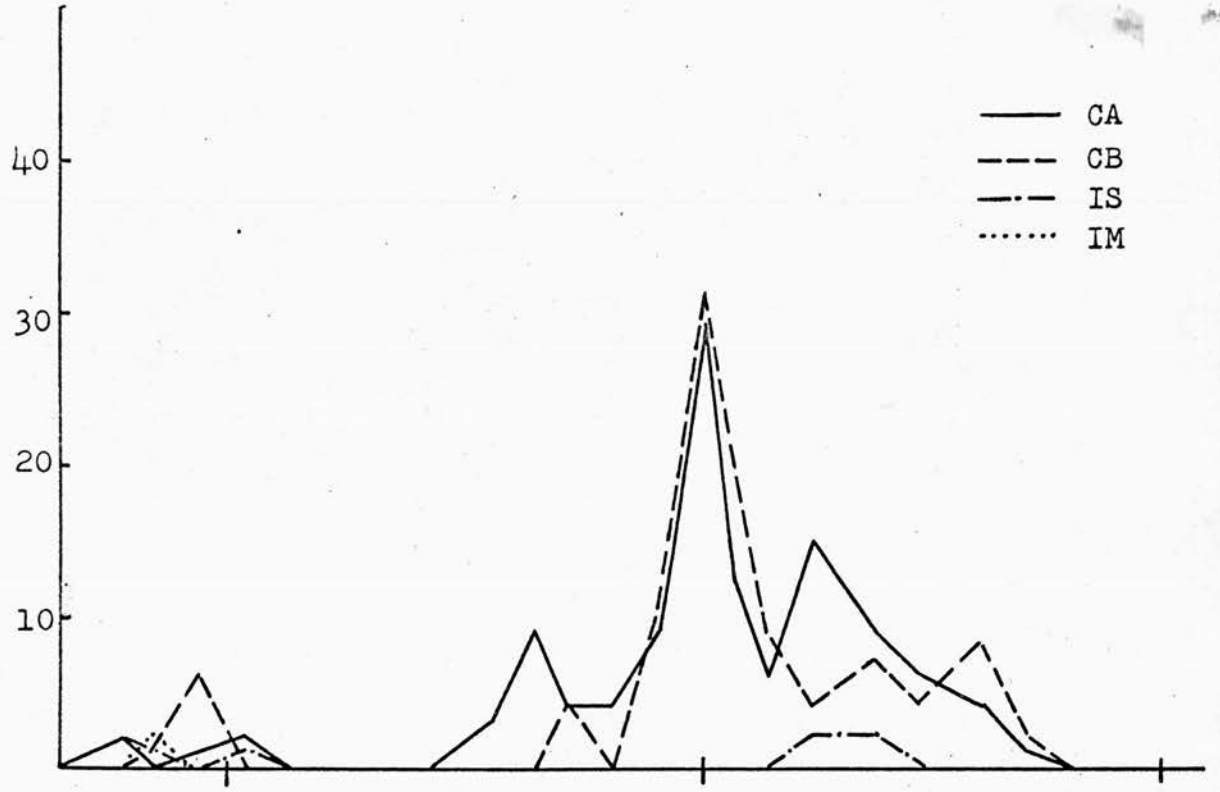


Fig. 12. No. of plants with shredded leaves

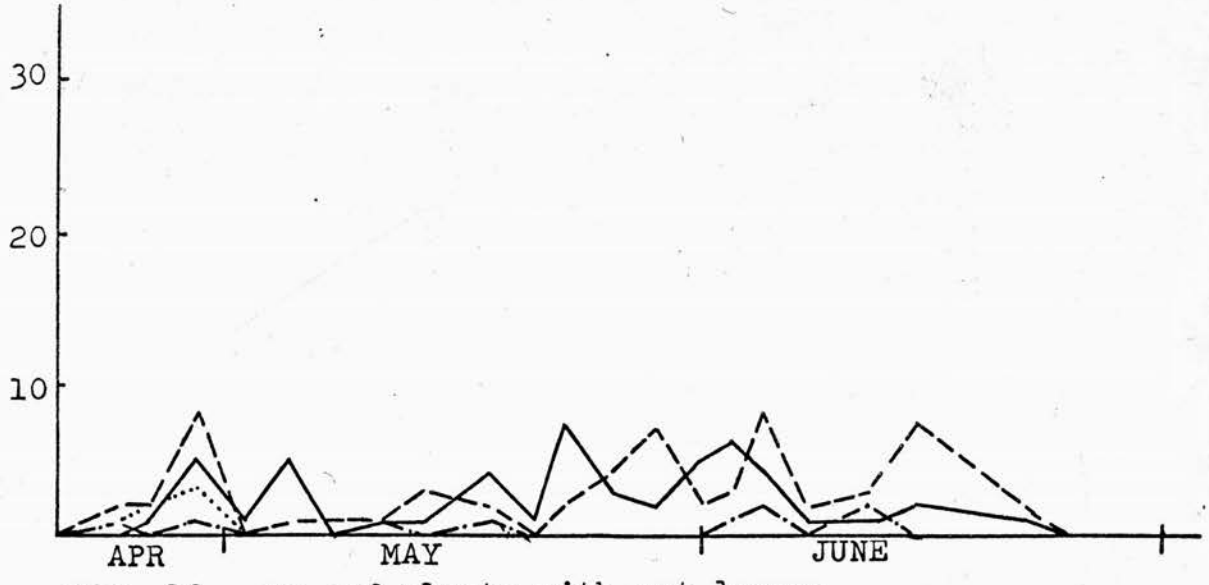


Fig. 13. No. of plants with cut leaves

between 22 May and 7 June, the activity showed significantly ($p < 0{\cdot}01$) more damage in controls, but there was no variation between the two controls. The next period of observation also showed a significant ($p < 0{\cdot}01$) decline in damage in IS and IM treatments compared to controls.

4.6112 Plants with cut leaves

The number of plants with leaves cut did not show a definite peak (Fig. 13), rather it was more or less uniform throughout the experiment except one week (7 to 13 May). The period of activity was the same as with the plants with shredded leaves. The number of leaves cut in the 1st fortnight did not show any significant difference (Table 8) between any of the treatments, but in the 2nd period of analysis both controls showed significant differences ($p < 0{\cdot}05$) from IM treatment. The significant difference ($p < 0{\cdot}01$) between controls and IS or IM continued until 7 June; but in the last observation on 24 June,

TABLE 8

Mean number of plants with cut leaves in experiment A (1966)

Date	Treatments				L.S.D.+	Value of "F"
	CA	CB	IS	IM		
19/4-4/5	1·0	1·0	0·25	0·41	n.s.	2·11
4/5-22/5	0·66*	0·66*	0·25	0·08	a, 0·48 b, 0·66	3·11
22/5-7/6	1·91**	1·50**	0·16	0	a, 0·91 b, 1·23	8·94
7/6-24/6	0·75	2·16**	0·16	0	a, 0·89 b, 1·21	9·77

* and ** significant at $p < 0{\cdot}05$ and $p < 0{\cdot}01$ respectively.
+ See Table 7.
n.s. = not significant.

the CB showed a significant difference ($p < 0{\cdot}01$) from CA as well as from the IS and IM treatments.

4.6113 Stems cut at or above the soil surface

The number of stems cut at or above the soil surface was much higher than other types of damage. Fig. 14 shows that the great activity of larvae lasted for a long time (7 May to 14 June). Most of the stems partly or wholly cut were noticed to have been drawn into the soil. This phenomenon was noticed in the field but not so often as in the insectary. The first sign of damage was noticed within the first week, and the observation on 4 May showed a significant difference ($p < 0{\cdot}01$) between the number of stems cut in controls and IS or IM (Table 9). The damage within

TABLE 9.

Mean number of stems cut at or above the soil surface in experiment A (1966)

Date	Treatments				L.S.D.+	Value of "F"
	CA	CB	IS	IM		
19/4-4/5	3·16**	2·41**	0·50	1·00	a, 0·95 b, 1·29	13·44
4/5-22/5	6·83**	2·41	0·41	0·25	a, 2·32 b, 3·13	24·84
22/5-7/6	5·83**	6·58**	0·25	0·08	a, 1·57 b, 2·11	41·81
7/6-24/6	6·66**	7·75**	0·08	0	a, 4·05 b, 5·47	8·80

** Significant ($p < 0{\cdot}01$)

+ See Table 7.

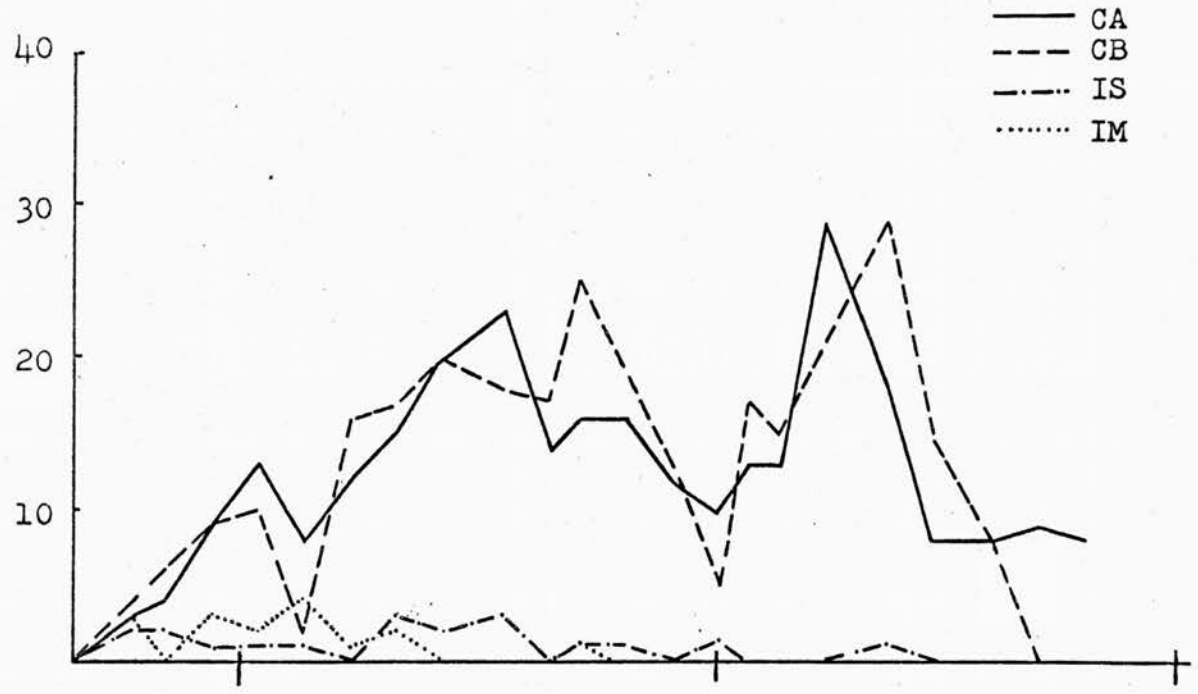


Fig. 14. No. of stems cut at or above the soil surface

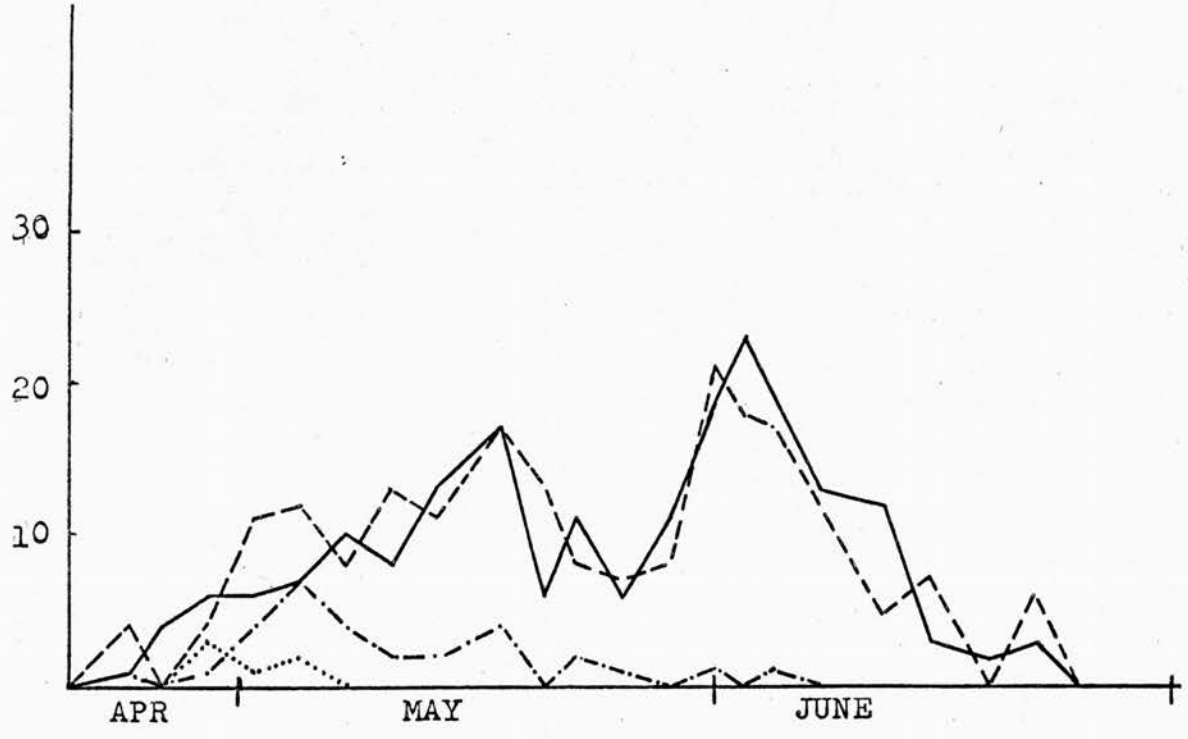


Fig. 15. No. of stems cut sub-surface

the period up to 22 May showed that larval activity had greatly increased in CA which was significantly greater ($p < 0{\cdot}01$) than CB and also IS or IM treatments; but there was no difference between CB and IS or IM treatments. The other two periods of observations did not show any significant difference in damage between the two controls, but both of them varied significantly ($p < 0{\cdot}01$) from IS or IM treatments. There was very little damage in IM on 25 May, but damage though little was observed until 11 June.

In the tables those plants with stems completely or partially cut were not distinguished, but it was noticed that the larvae usually fed on a plant long enough to cut the stem right through.

4.612 Damage sub-surface

Fig. 15 clearly shows that larvae had been active from the beginning till the end of the experiments, but with distinct peaks of greater activity on 17 May and 2 June; the latter date had the maximum activity below surface. The general pattern of damage sub-surface was the same as on the surface. The determination of cut stems was made by pulling out those reclining plants, which had been partly drawn into the soil by leatherjackets. In the case of plants which had been cut at soil level and subsequently drawn below, the presence of the cut stump indicated the position of the damage.

The total damage up to 4 May shows (Table 10) that both CA and CB are significantly greater than IM ($p > 0{\cdot}01$) and IS ($p < 0{\cdot}05$).

TABLE 10

Mean number of stems cut sub-surface in experiment A (1966)

Date	Treatments				L.S.D.+	Value of "F"
	CA	CB	IS	IM		
19/4-4/5	2·08**	2·50**	1·16	0·50	a, 1·08 b, 1·45	5·50
4/5-22/5	4·41**	5·25**	1·0	0	a, 1·59 b, 2·14	21·80
22/5-7/6	6·25**	4·91**	0·33	0	a, 2·04 b, 2·69	20·81
7/6-24/6	4·00**	3·91**	0·08	0	a, 2·50 b, 3·38	6·73

** Significant ($p < 0·01$)

+ See Table 7.

The damage was greatly increased after 4 May showing significant ($p < 0·01$) differences between the controls and IS or IM treatments. Significant differences ($p < 0·01$) continued till the end of the experiments between the controls and IS or IM treatments, but there was no difference between insecticidal treatments, but little activity was shown in IS till 4 June whereas activity had completely ceased in IM treatment by 4 May.

As was observed above ground there were also very few plants with stems partly cut underground, throughout the whole experiment. The total of damaged stems showed that there was less damage sub-surface than on the surface.

4.613 Number of undamaged plants

Table 11 shows the gradual decline in the number of undamaged plants. The lack of significant difference in the first week's

observations between IS and all others clearly showed that initial damage was not checked by the insecticide. From the second week

TABLE 11

Mean number of undamaged plants in experiment A (1966)

Date	Treatments				L.S.D.+	Value of "F"
	CA	CB	IS	IM		
19/4-25/4	78·91	79·0	79·66	79·75	n.s.	2·83
25/4-1/5	75·91	76·4	79·08**	79·0**	a, 1·28 b, 1·73	14·16
1/5-7/5	78·08**ø	73·0	78·03**	78·41**	a, 1·91 b, 2·58	20·28
7/5-13/5	68·58	67·80	77·25**	78·25**	a, 2·12 b, 2·86	56·94
13/5-22/5	63·58	61·91	76·66**	78·25**	a, 3·10 b, 4·18	63·47
22/5-28/5	59·66	57·25	76·08**	78·25**	a, 3·48 b, 4·70	81·74
28/5-4/6	54·91	53·75	76·25**ø	78·41**ø	a, 4·03 b, 5·44	90·17
4/6-11/6	49·58	48·58	76·08**	78·58**	a, 4·14 b, 5·58	129·20
11/6-18/6	43·75	43·08	76·08**	78·58**	a, 5·89 b, 7·94	90·83
18/6-24/6	40·41	39·91	76·08**	78·66**	a, 6·99 b, 9·43	78·55

** Significant ($p < 0·01$)

ø This greater number was due to the recovery of plants which had shown slight damage previously.

+ See Table 7.

onwards, except for the week ending 7 May, where there was no significant difference between CA and the insecticidal treatments; all other observations showed a highly significant difference

($p < 0{\cdot}01$) between the insecticidal treatments and both controls. At the end of the experiment the reduction of plant population in the controls was 50 per cent against 3 per cent in the insecticidal treatments. The result is highly significant.

4.614 Weights of shoots and roots

The weights of shoots and roots were determined at the end of the experiment. There was great variation ($p < 0{\cdot}01$) between the weights of control and insecticidal treatments (Table 12). There was no significant difference between IS and IM treatments, but there was difference ($p < 0{\cdot}05$) between CA and CB. As is to be

TABLE 12.

Mean weights (in grams) of shoots determined at the end of the experiment A (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
8·33*	4·64	16·75**	15·3**	a, 2·97 b, 4·01	30·89

* Significant at $< 0{\cdot}05$ ** Significant at $p < 0{\cdot}01$

\+ See Table 7.

expected, these results are similar to those attained from the counts of undamaged plants.

The development of the root systems was rather poor in all treatments but the roots of control A were significantly lighter

TABLE 13

Mean weights (in grams) of roots determined at the end of the experiment A (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
1·18	0·86	1·80**	1·60**	a, 0·51 b, 0·68	5·91

** Significant ($p < 0{\cdot}01$) + See Table 7

($p < 0{\cdot}05$) than those of IS, and lighter than those of IM, but not significantly so. The roots of CB were significantly lighter

($p < 0{\cdot}01$) than those of both insecticidal treatments.

4.615 Number of larvae at the end of experiment

The population of the larvae in each tin was determined by hand-sorting. The number of larvae recovered was 50, 55, 5 and 0 in CA, CB, IS and IM respectively.

TABLE 14

Mean number of larvae alive at the end of experiment A (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
$4{\cdot}17^{**}$	$4{\cdot}58^{**}$	0·42	0	a,2·01 b,2·72	132·0

** Significant ($p < 0{\cdot}01$)

+ See Table 7.

The difference between controls and IS or IM treatments is significant ($p < 0{\cdot}01$). There was no variation between the two controls or the two insecticidal treatments (Table 14).

In the insecticidal treatments some larvae were found moribund or dead on the surface. The dead larvae on the surface were found from 7 July to 25 July usually in IM, but one moribund larva was recorded as late as at the end of experiment (24 June). The first dead larva in IS was recorded on 28 April and the last on 18 June, but most of them were on the surface dead between 7 May to 7 June. The total of larvae which died on the surface was 25 in IM and 26 in IS respectively.

The reduction of 17 per cent population in CA and 9 per cent in CB was possibly due to two virus diseases as 5 larvae in CA were

found suffering from disease, 1 with Tipula iridescent virus and 4 with nuclear polyhedrosis; and 2 in CB, both of them having polyhedrosis. This incidence of disease was very high, showing 10 per cent of live larvae in CA and 4 per cent in CB suffering from disease.

When larvae are as few per area as in this experiment cannibalism does not normally occur.

4.62 Experiment B.

This experiment showed less damage than experiment A.

4.621 Damage on surface

4.6211 Plants with shredded leaves

The shredding of leaves was little compared to the population of plants. This damage was also noticed mostly at the beginning of the experiment. The larvae caused maximum damage on 12 May (Fig. 16) and the activity had completely ceased by 11 June. The analysis in Table 15 of total damage shows that CB is significantly

TABLE 15

Mean number of plants with shredded leaves in experiment B (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
1·41**	2·00**	0	0·33	a, 0·89 b, 1·21	9·05

** Significant ($p < 0·01$)

+ See Table 7.

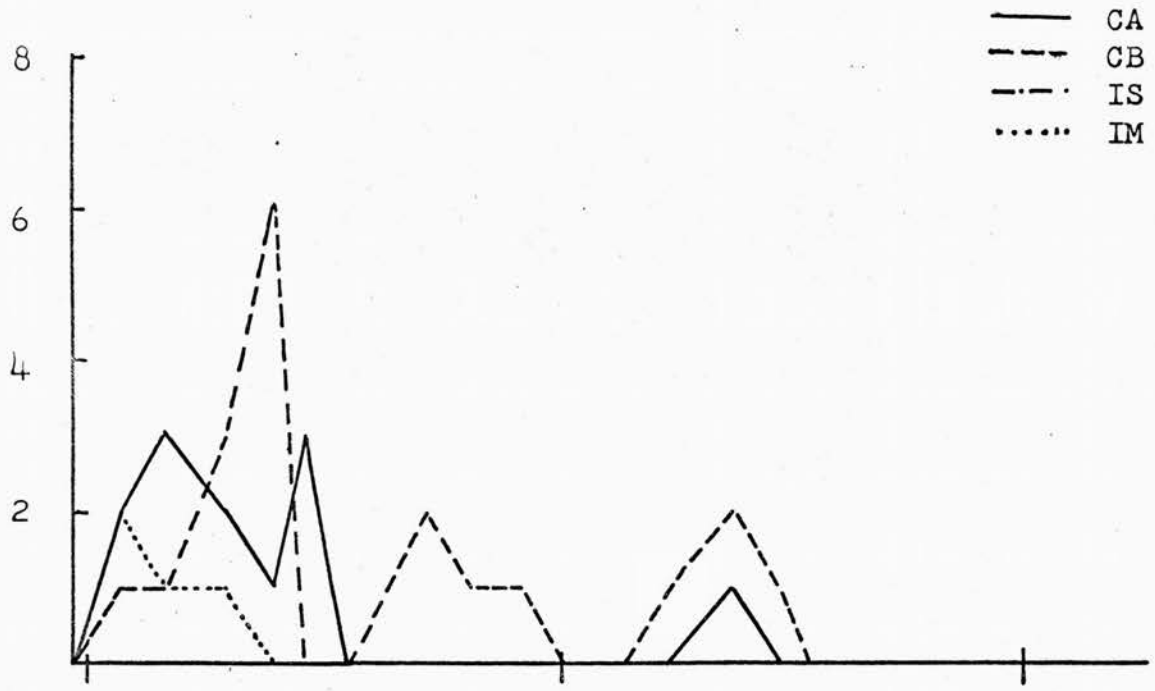


Fig. 16. No. of plants with shredded leaves

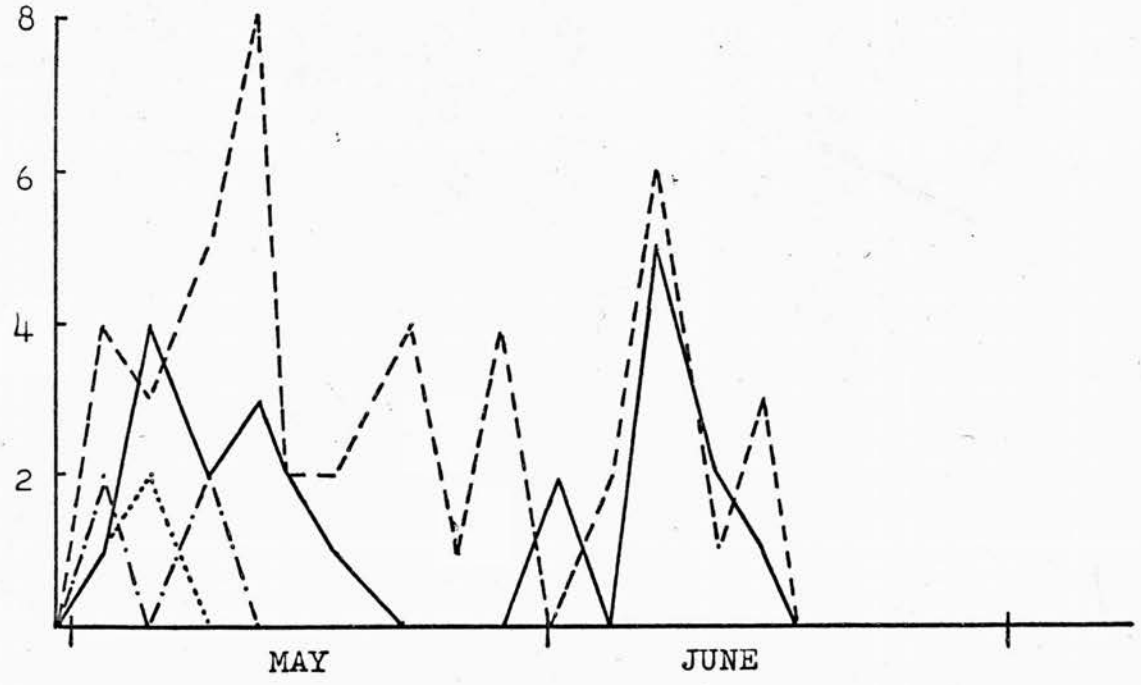


Fig. 17. No. of plants with cut leaves

different ($p < 0{\cdot}01$) from IS and IM treatments. The CA treatment is also significantly different from IS ($p < 0{\cdot}01$) and IM ($p < 0{\cdot}05$) treatments. There was no difference between the controls or between the insecticidal treatments.

4.6212 Plants with cut leaves

The cutting of leaves was observed just after the experiment started. The controls showed two distinct peaks (Fig. 17) of activity of the larvae. Initially the larvae in the insecticidal treatments were also causing some damage, but it had completely ceased by 5 May in IM and 9 May in IS treatments. Damage ceased

TABLE 16

Mean number of plants with cut leaves in experiment B (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
1·66*	3·5**	0·41	0·25	a, 1·34 b, 1·81	4·87

** Significant ($p < 0{\cdot}01$) * Significant at $p < 0{\cdot}05$

+ See Table 7.

in controls after 14 June.

The total damage by cutting of leaves in CB was significantly different ($p < 0{\cdot}01$) from all other treatments. CA was also significantly different ($p < 0{\cdot}05$) from IM treatment but not from IS treatment (Table 16).

4.6213 Stems cut at or above the soil surface

There was little thinning of the plants on the surface. The pattern of damage showed as in the other types. More stems

were cut at the beginning of the experiment and the number gradually declined till completely stopped by 14 June. The peak of activity was in the first two weeks (Fig. 18). Partly damaged stems were fewer than completely cut stems. The treatment IM had more stems cut than IS but activity ceased by 12 May.

TABLE17

Mean number of stems cut at or above the soil surface in experiment B (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
3·5**	2·66**	0·25	0·75	a, 1·69 b, 2·28	6·98

** Significant ($p < 0·01$)

+ See Table 7

The extent of damage in CA was significantly different ($p < 0·01$) from IS and IM, and CB was also significantly different from IS ($p < 0·01$) and IM ($p < 0·05$) treatments. There was no variation between the damage within controls or insecticidal treatments (Table 17).

4.622 Damage sub-surface

The leatherjackets were not very active even sub-surface. Most of the plants with stems cut were noticed within two weeks of starting the experiment (Fig. 19). The activity had completely ceased by 28 May which was even much earlier than the damage on the surface. Little activity was noticed also in insecticide-treated tins, but this also was mostly in the first week of May.

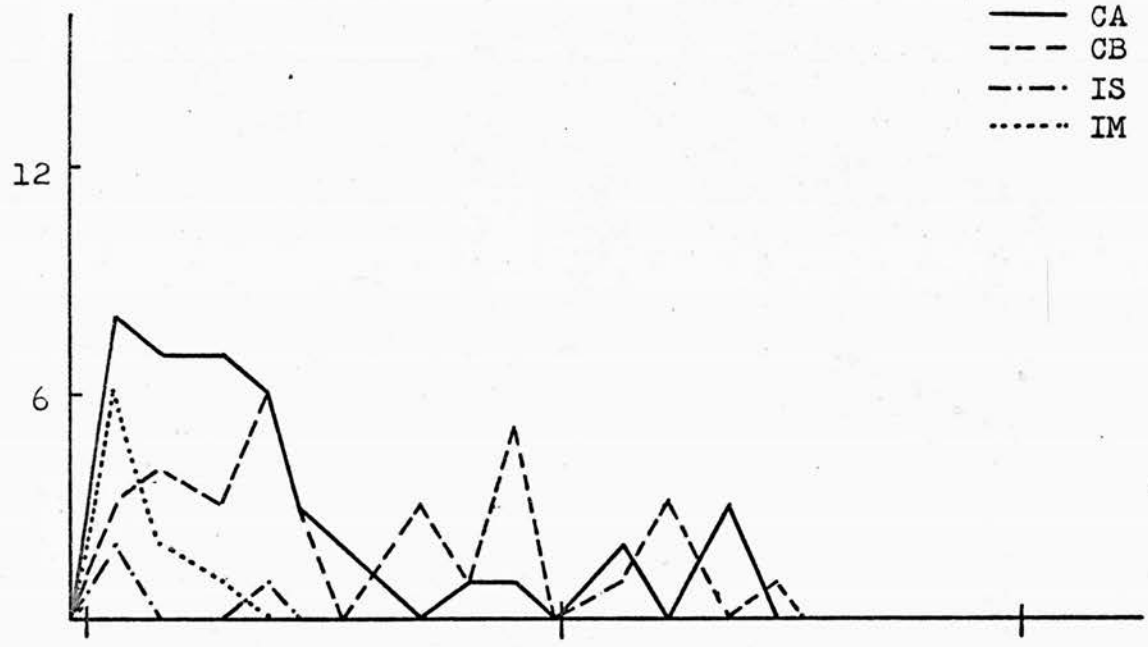


Fig. 18. No. of stems cut at or above the soil surface

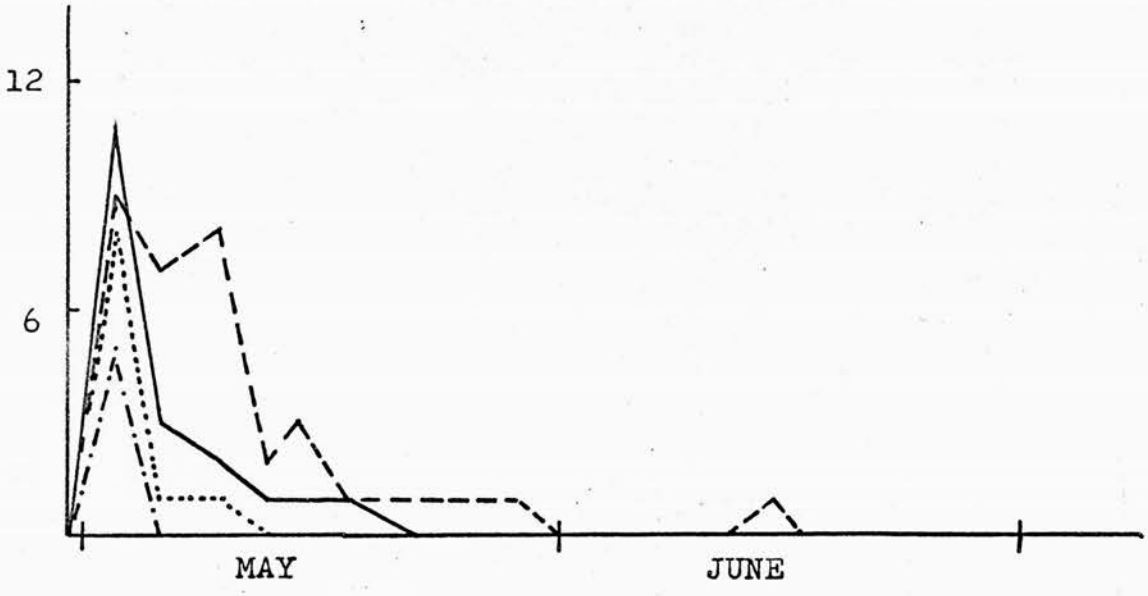


Fig. 19. No. of stems cut sub-surface

TABLE 18

Mean number of stems cut sub-surface in experiment B (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
1·58*	2·58**	0·41	0·75	a, 0·97 b, 1·32	8·13

** Significant ($p < 0·01$) * Significant ($p < 0·05$)

\+ See Table 7.

The activity in CB was more ($p < 0·01$) compared to IS and IM treatments and also to CA ($p < 0·05$). The CA differed only from ($p < 0·05$) IS, but not from IM treatment. There was no difference between the damage in IS and IM treatments (Table 18).

4.623 Number of undamaged plants

From the accounts of the different types of damage it is obvious that there was no marked gradual reduction in the population of undamaged plants, but Table 19 shows the mean number

TABLE 19

Mean number of undamaged plants at the end of experiment B (1966)

Treatments				L.S.D.+	Value of "F"
CA	CB	IS	IM		
76·50	76·0	79·50**	79·33**	a, 1·65 b, 2·22	7·86

** Significant ($p < 0·01$)

\+ See Table 7

of undamaged plants in each treatment at the end of the experiment. The difference between controls and insecticidal treatments was significant ($p < 0·01$); but there was no variation within controls or insecticidal treatments.

4.624 Weights of shoots and roots.

After the experiment, the weights of the shoots were determined. Table 20 shows that there was no significant

TABLE 20.

Mean weights (in grams) of shoots at the end of experiment B (1966)

Treatments				Value of "F"
CA	CB	IS	IM	
42·12	45·5	44·75	45·0	1·34

difference between weights in any of the treatments.

The weight of roots was determined to see whether larvae were feeding on these as the damage above ground was very little.

Table 21 shows that there was no significant difference between the weights of roots in any of the treatments. This table

TABLE 21

Mean weights (in grams) of roots at the end of experiment B (1966)

Treatments				Value of "F"
CA	CB	IS	IM	
7·25	8·77	8·5	8·12	< 1

shows that there was much less damage by the larvae in this experiment than in experiment A.

4.625 Number of larvae at the end of experiment

The population of larvae was determined in the same way as in experiment A; the number of larvae in each treatment were 30, 43, 2 and 0 in CA, CB, IS and IM treatment respectively. So, the reduced populations in the controls explain the lesser damage in experiment B.

The population in CB was significantly greater ($p < 0{\cdot}01$) than in all other treatments (Table 22); and the population in CA ($p < 0{\cdot}01$) than in IS or IM treatments. There was no

TABLE 22

Mean number of larvae alive at the end of experiment B (1966)

Treatments				L.S.D.+	VAlue of "F"
CA	CB	IS	IM		
2·5**	3·58**	0·16	0	a, 0·67 b, 0·90	58·37

** Significant ($p < 0{\cdot}01$)

+ See Table 7.

significant difference between IS or IM treatments.

No larvae were found suffering from diaease.

The number of larvae found dead on the surface was 19 in IS and 12 in IM treatment being 32·75 and 20 per cent of total dead larvae in each treatment respectively. The first dead larva on the surface was on 2 May and the last on 25 May in IM and first on 5 May and last on 25 May in IS treatments respectively. Most of the dead larvae were found by the second week after spraying.

4.63 Number of larvae on the surface at night.

The number of larvae found on the surface in experiment A was 2, 3, 9, 10 and 11 at 22.00, 23.45, 01.15, 01.30 and 02.30 hours G.M.T. at night respectively. Only the larvae in control were considered as some of the larvae in the insecticidal treatments were already seen to be moribund during the daytime.

Some of these counts may not be accurate to a larva, as the effect of using a torch was to cause the larvae to go below, and observation had to be made very rapidly.

The controls in experiment B were also observed but no larvae found; this might have been because of the dry condition of the surface.

4.7 Discussion and conclusions

The experiments were carried out during the two months, when spring barley is liable to suffer from leatherjacket damage in the field. The date of the last observation was chosen so that all the larvae in the tins could be collected before pupation and the exact population of larvae determined.

The difference between the mortality of larvae in the experiments A and B indicated that the dry spell during the end of May or first week of June was responsible for the late spring population decline of leatherjackets in the field. The 39 per cent average mortality in controls in experiment B is highly significant from 12·5 per cent average mortality in controls in experiment A. No other logical explanation could be given in the former other than dryness, and in the latter diseases as already discussed were the main factor causing death.

The number of stems damaged sub-surface in the experiments may have benn an under-estimate as compared with field observations, where the whole plants were removed in the cores and examined so slight damage was counted; whereas in the experiments only some sub-surface damage which showed by abnormality of the plants above ground, could be observed, also in the experiments the proportion of partly cut stems to severed stems was less than in field observations.

There was much more damage caused by the larvae in experiment A than in experiment B. This was due to the soil in the former being kept moist and in ideal condition for the larvae, which for the same reasons, were more numerous at the end of the experiments. Similarly the larvae outside were in less favourable conditions and in consequence the plants were less damaged and weighed more at the end of the experiments.

Total mortality was achieved in IM compared to IS treatments, although the difference was not significant, but it is likely that insecticide mixed with the soil gave better results. The long period over which the larvae died in insecticidal treatments in experiment A was due to the long survival of moribund larvae on the surface. The larvae on the surface in fields get quickly dried (if not eaten by birds), but this could not happen due to moisture in experiment A. The results of experiment B coincide with field findings as the moisture or other conditions of both are more or less the same.

SECTION 5. THE FIELD EXPERIMENTS

5.1 Field experiments in 1966

5.11 Introduction

Leatherjackets are a common pest in S.E. Scotland. They are responsible for causing frequent damage to cereal crops. The years of high incidence cause great concern to the farmer.

Spring barley is the cereal which suffers most from leatherjackets. White (1966) mentions the reasons as warmer weather conditions which make them more active and also they have their 3rd moult at this time and then feed voraciously for faster growth. In this area of the country, more reports are received of damage to spring barley than any other crop so it was decided to evaluate the extent of damage to spring barley.

5.12 Site of experiment

During autumn sampling of 1966, no completely suitable place was obtained for laying out an experiment. The field eventually chosen was on Crofthead Farm (Mid Lothian). The initial count gave a population just below $\frac{1}{4}$ million per acre.

The field was ploughed in autumn from 3 years ley. The barley was drilled in the first week of April. The area of the field is 11 acres, soil-type is a heavy-loam.

An area of $\frac{3}{4}$ of an acre was selected for experiment.

5.13 Procedure of investigation

The area was marked out into 18 plots, 20 x 10 yards each. Randomisation was done for the following three treatments:-

1. Control

2. Aldrin (30 per cent miscible liquid)

3. DDT (25 per cent miscible liquid)

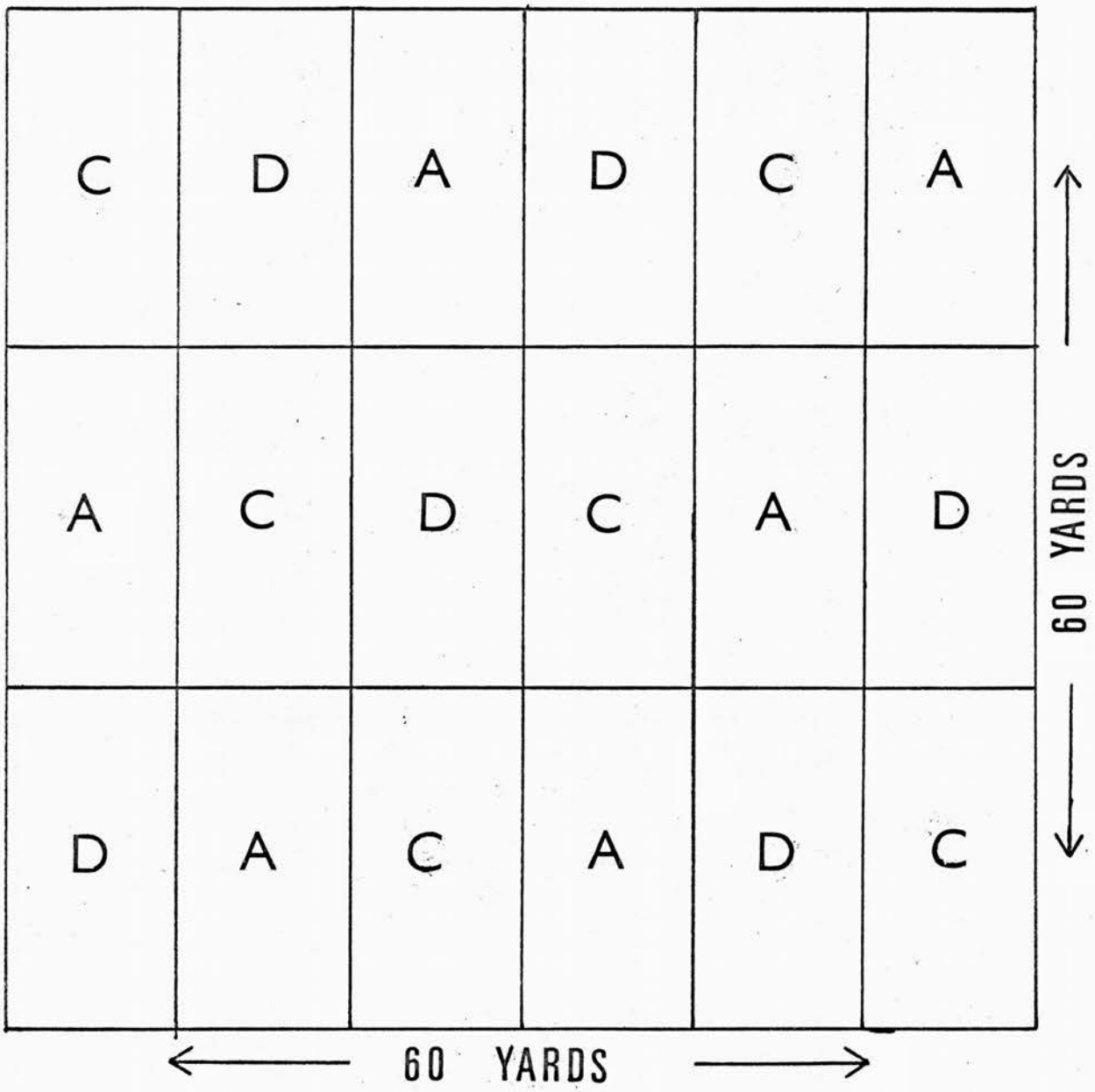
DDT is the most commonly used insecticide for the control of leatherjackets. Aldrin was tried against it for comparison. The design of randomisation is shown in Fig. 20. Each of the three treatments had six replicates. The edges of the field were avoided because of the lack of uniformity in plant population. At the time of setting out the experiment, the barley plants were 1½-2 in. high, and damage had not yet appeared. There were, however, numerous larval tunnels in the soil.

The number of larvae and plants in Fig. 21 and Table 23 against 29 April show the initial larval and plant populations in each treatment after randomisation. After marking out the plots and taking samples to estimate populations of plants and leatherjackets on 29 April, spray treatment had to be delayed for a week as the soil had become very dry and the leatherjackets in consequence were not active on the surface. Spraying was commenced on the afternoon of 4 May and completed on the forenoon following, using 94 cc. of insecticide in 2 gallons of water per plot corresponding to 4 pints in 50 gallons per acre.

5.131 Sampling method

For all purposes in the field experiments, a 4 in. diameter core was used, 8 cores being taken per plot, i.e. 48 per treatment. The position for each sample was selected at random. The samples were not collected from the rows of plants only. The investigation

Fig. 20. Plan of randomised plots in 1966.field experiment.



C = Control, A = Aldrin, D = DDT.

of the samples was carried out exactly in the same way as in the survey of leatherjackets (See 2.31) A depth up to 3 in. was maintained in each sample as minimum, but it has already been reported that leatherjackets do not live below 3 in. at this time of the year in cereal fields (see 2.32).

5.132 Factors investigated

To investigate the extent of damage caused by various populations of leatherjackets the following observations were made: (i) Number of larvae, (ii) Damage at or above the surface of the soil and (iii) Damage below the surface. To record these factors weekly observations were made throughout the season.

5.1321 Number of larvae

It was not practicable to carry the samples to the laboratory for examination and they were examined in the field. At this time of the year the larvae are too large to be missed in examination, being in the 4th instar (Laughlin, 1967) and weighing over 200 mg. (Dunnet, 1955; Laughlin, 1967). Previous experience had shown that no further larvae were obtained by washing techniques from samples from which larvae had already been removed by hand-sorting (see 3.2).

All the larvae were taken to the laboratory as before, and their species determined according to Chiswell (1956) and Brindle (1957, 1958 and 1959).

The number of larvae suffering from any disease was also recorded. Examination was also made to determine if any of the larvae were parasitised.

5.1322 Damage on surface

To get the exact number of plants damaged on the surface, the area to be sampled was marked with the cores and the number of plants with each type of damage was counted separately. The types of damage were classified in exactly the same way as in the laboratory experiments (See 4.5).

5.1323 Sub-surface damage

In the field it was easier to determine the sub-surface damage than in the laboratory, as the soil sample was removed and broken up in the tray for examination.

It was necessary to examine the samples in the field as transporting them to the laboratory would have disturbed the soil and made it difficult to distinguish damage above from that below the surface. This method has also the advantage of completing the investigation on the spot and putting the sample of soil and plants back in the site from where collected. When plants are young they have a chance of survival, thus minimizing the loss of crop by extensive sampling. The only disadvantage is that it is a long and laborious process.

The time taken to investigate one sample is dependent on weather conditions. It takes about 2-5 minutes to investigate one core, the drier the soil the quicker it is to examine.

In sampling, the extreme edges of the plots were avoided.

5.14 Results

The results of the field experiments are given in tables 23 to 48, which show the average of weekly observations on the

six replications or the totals of these replicates for the whole experiment; but where the numerical values of the weekly averages proved small only the totals for the experiment are given. The observations are given in detail in Appendix II.

The periodic changes, as shown by weekly observations, are also given in graphical form in figures 21 to 33.

The meanings of "a", "b" and "F" when they appear in the tables, are always as indicated below, Table 7.

5.141 Decline in the larval population.

The first estimation of population was based on 32, 4 in. diameter core samples in the area selected for experimentation. The number of larvae obtained was 15, equal to a population of 235,000 per acre. The year 1966 was a year of low incidence of leatherjackets (Table 1) in this part of the country. This field was the only one found suitable for an experiment in leatherjacket damage and control, although a field with a much higher population would have been preferable.

The second count of leatherjackets was made on 29 April after randomisation (Table 23). The populations in each treatment were 240,000 per acre in control, 250,000 per acre in aldrin and 230,000 per acre in DDT respectively. The mean number in each treatment and the analysis of variance is shown in Table 23.

The second observation (as in Table 23, 8 May) of larvae was taken 4 days after spraying. A large number of larvae were found on the surface either moribund or dead. A rapid count for five minutes was made in each plot and the total numbers on the

surface were 0, 147 and 53 in control, aldrin and DDT respectively. Of the larvae obtained from the core samples 5 of the 10 from the aldrin plots were dead on the surface and 3 of the 13 from the DDT plots. On the next sampling the figures for cores were 3 in 4 and 6 in 13 respectively. In all later sampling no larvae were found on the surface.

Fig. 21 shows the number of leatherjackets collected throughout the experimental period. The population of larvae remained more or less the same in the control till the last day of May; then there was a sharp decline. The second period of decline was noticed on 11 July, from which date the population declined progressively towards nil. The first decline was due to the extreme dry days (Appemdix IV; rainfall 1966) in the last week of May and first few days of June. This was a common reduction factor during this time in cereal fields as well as in grassland (Fig. 10). The second decline was due to emergence of adults. Table 20 (Appendix II) shows that pupation had already started in the field. Adults were seen flying in the field in the 3rd week of July (18), but the first evidence in the experimental plots was found on 8 August when a pupal skin was collected in a sample. There was a rapid decline in population of larvae in the aldrin and DDT plots. The rate of mortality was greater with aldrin than with DDT. There were no larvae found in treated plots from 15 June and onwards, so it could be presumed that a total control of leatherjackets was obtained during this period.

Table 23 shows the weekly analysed population in each treat-

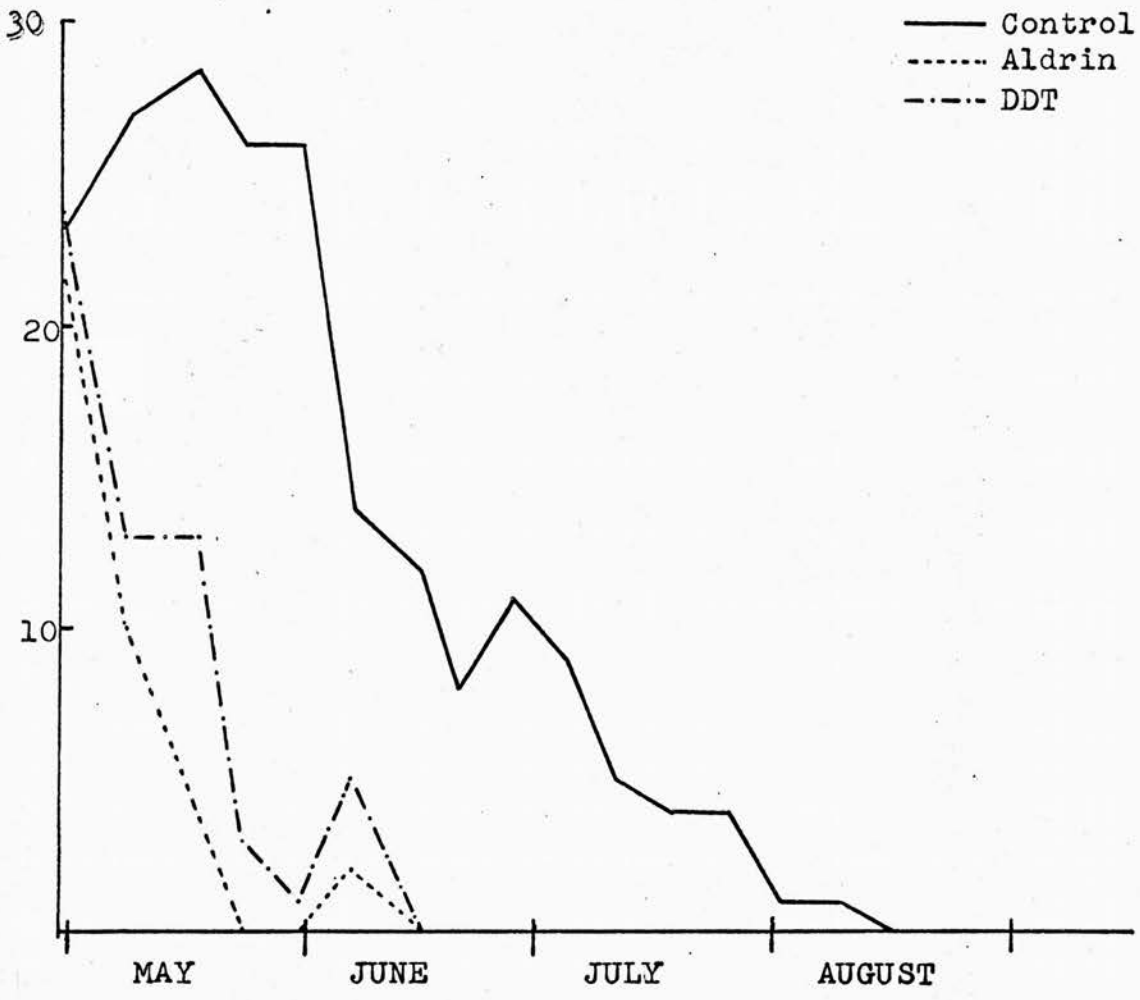


Fig. 21. No. of leatherjackets

ment. The reduction of population is significant ($p, <0.01$) in treated plots compared to control. There is no significant

TABLE 23

Mean number of larvae in each treatment in weekly observations

Date	Treatments			L.S.D.	Value of "F"
	Control	Aldrin	DDT		
29.4.66	3·82	4·0	3·66	n.s.	C1
8.5.66	4·5**	1·66	2·16	a, 1·71 b, 2·47	7·97
17.5.66	4·75**	0·66	2·16*	a, 1·51 b, 2·17	19·49
23.5.66	4·33**	0	0·50	a, 1·67 b, 2·40	20·43
30.5.66	4·33**	0	0·16	a, 0·98 b, 1.43	62·20
6.6.66	2·33*	0·33	0·83	a, 1·49 b, 2·14	5·00
15.6.66	2·0**	0	0	a, 1·29 b, 1·83	7·78

* Significant at $p < 0.05$

** Significant at $p < 0.01$

n.s. = not significant

difference between the insecticidal treatments. But the observation on 17 May shows difference at significant level ($p < 0.05$) between aldrin and DDT. The four pints of 30 per cent emulsified aldrin seemed to be excessive. The significant difference ($p < 0.01$) between insecticidal treatments and control

continued till 30 May when the population of the control was, as already stated much reduced. Table 20 in Appendix II shows the last date on which a pupa was collected in the field. After 15 June the results were not entered as no larvae were found in the aldrin and DDT plots.

TABLE 24

Mean ~~number of~~ larval population in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	Aldrin	DDT		
33·41**	6·50	9·83	a, 7·47 b,10·61	33·13

** Significant at $p < 0{\cdot}01$.

Analysis of total larvae per plot shows (Table 24) the great variation between control and insecticidal treatments. There is no significant difference between aldrin and DDT plots.

5.142 Damage on surface

5.1421 Plants with shredded leaves

The number of plants with shredded leaves was estimated in the same way as in laboratory experiments. The first sign of damage was noticed at the time of spraying. The peak of shredded leaves was noticed in 17 May (Fig. 22) in the control. Shredding of the leaves had ceased by the middle of June. During this period plant growth was very rapid and they recovered from damage. Serious shredding in the leaves causes yellowing (Plate 3) and

PLATE 3. Showing shredded leaves.

PLATE 4. Showing plants with cut leaves.

PLATE 5. Showing plants with stems partly or wholly cut at or above the soil surface.

PLATE 6. Showing the plants with stems partly or wholly cut sub-surface.

ultimately the leaf dies off. The number of plants with leaves damaged was not sufficiently high to cause any harm to the plant population. The number of damaged plants was very small in treated plots. Damaged ceased a fortnight after spraying except for the few plants shown on 6 June.

TABLE 25

Mean number of plants with shredded leaves in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	Aldrin	DDT		
9·0**	2·0	2·33	a, 2·89 b, 4·16	12·42

** Significant at $p < 0{\cdot}01$

Table 25 shows that there is a great difference between the control and treated plots.

5.1422 Plants with cut leaves

Fig. 23 shows the total plants with cut leaves in each treatment. The number is not very high as compared to shredded leaves. The month of May had the maximum injury. The damage stopped after the first week of June in control. The treated plots showed little damage.

TABLE 26

Mean number of plants with cut leaves in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	Aldrin	DDT		
11·83**	1·0	1·33	a, 1·96 b, 2·82	99·72

** Significant at $p < 0{\cdot}01$

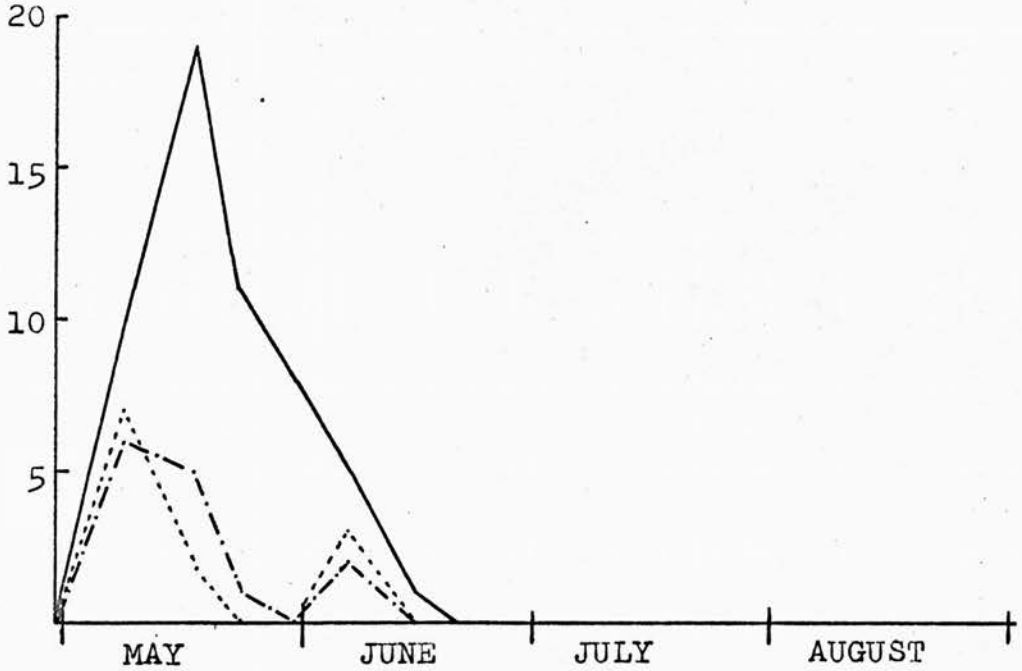


Fig. 22. No. of plants with shredded leaves

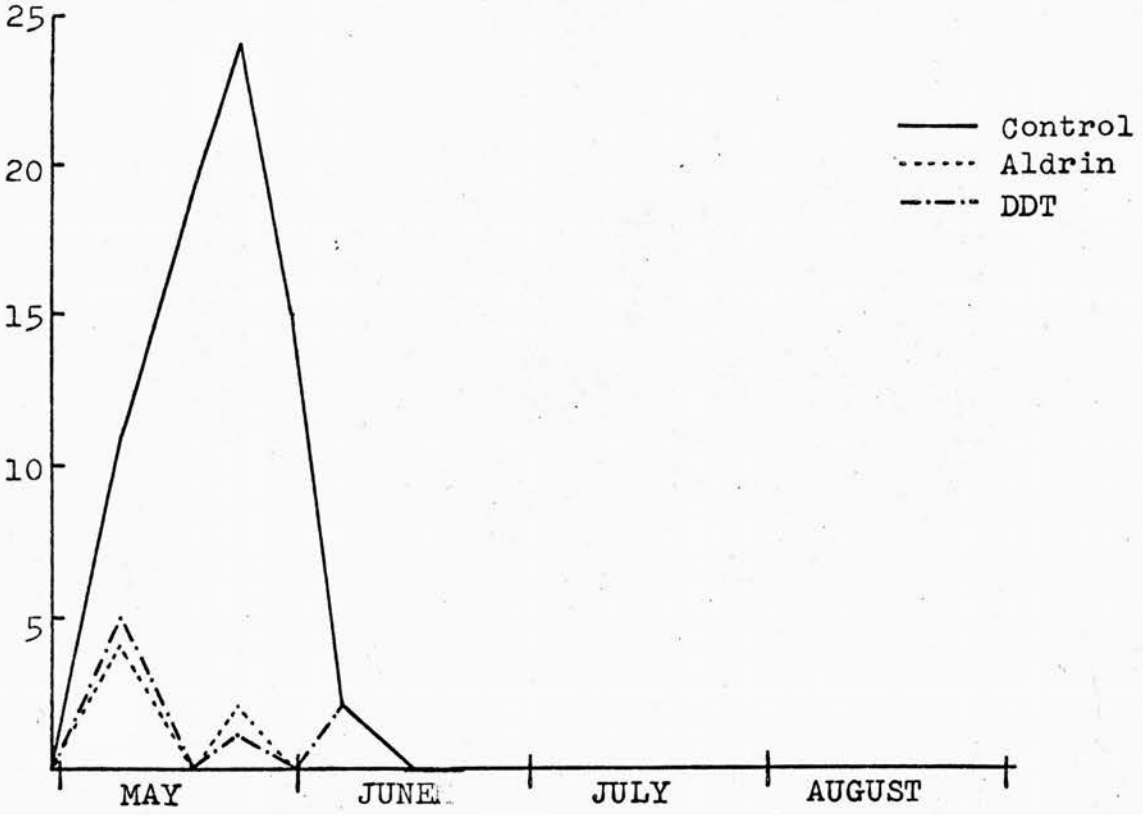


Fig. 23. No. of plants with cut leaves

The analysis was based on the same principle as with shredded leaves. The difference is very significant ($p < 0{\cdot}01$) between control and treated plots. But no variation was found between aldrin and DDT (Table 26).

5.1423 Stems cut at or above the soil surface.

This type of damage in cereal fields is very serious, heavy cutting of stems results in patchy thinning of the crop. This is a common sight in heavily infested fields. But the experimental field thinning on the surface was not serious. Fig. 24 shows the number of plants with stems cut on the surface in different treatments. The damage ceased by 6 June.

Table 27 shows that cutting of stems on the surface is

TABLE 27

Mean number of cut stems at or above the soil surface in each treatment throughout the experiment

Treatments				
Control	Aldrin	DDT	L.S.D.	Value of "F"
3·16**	0·33	0·16	a, 0·65 b, 0·94	65·91

** Significant at $p < 0{\cdot}01$

significantly more ($p < 0{\cdot}01$) in the control than in aldrin or DDT, where there was almost none.

5.143 Sub-surface damage

From observation of the number of stems cut under the surface of the soil it was found that more damage was caused below than above the surface and the damage, moreover, continued longer (Figs. 24 and 25).

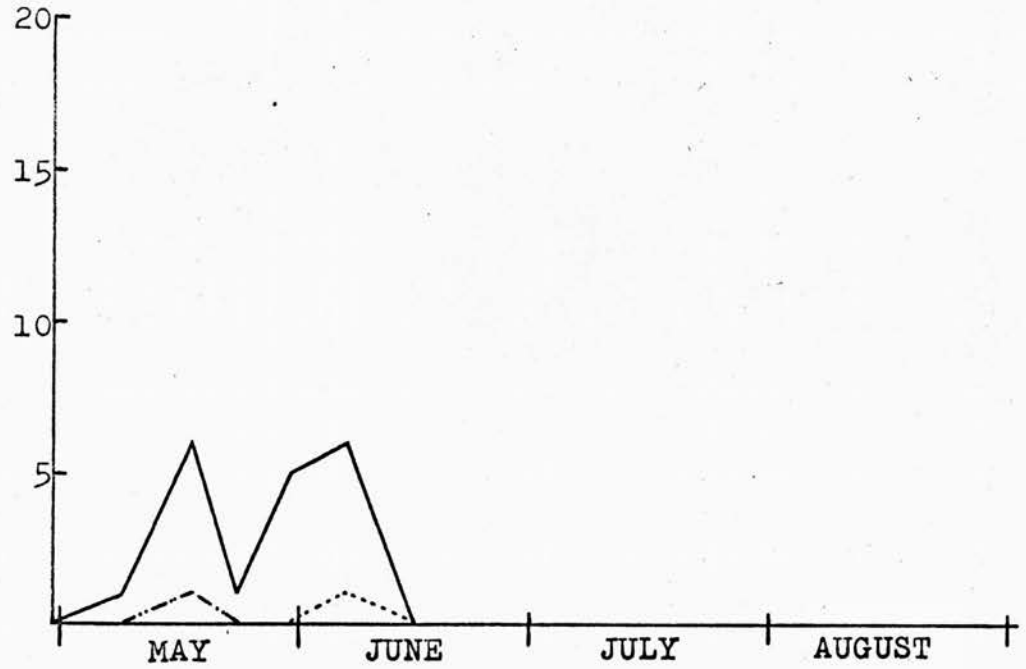


Fig. 24. No. of stems cut at or above the soil surface

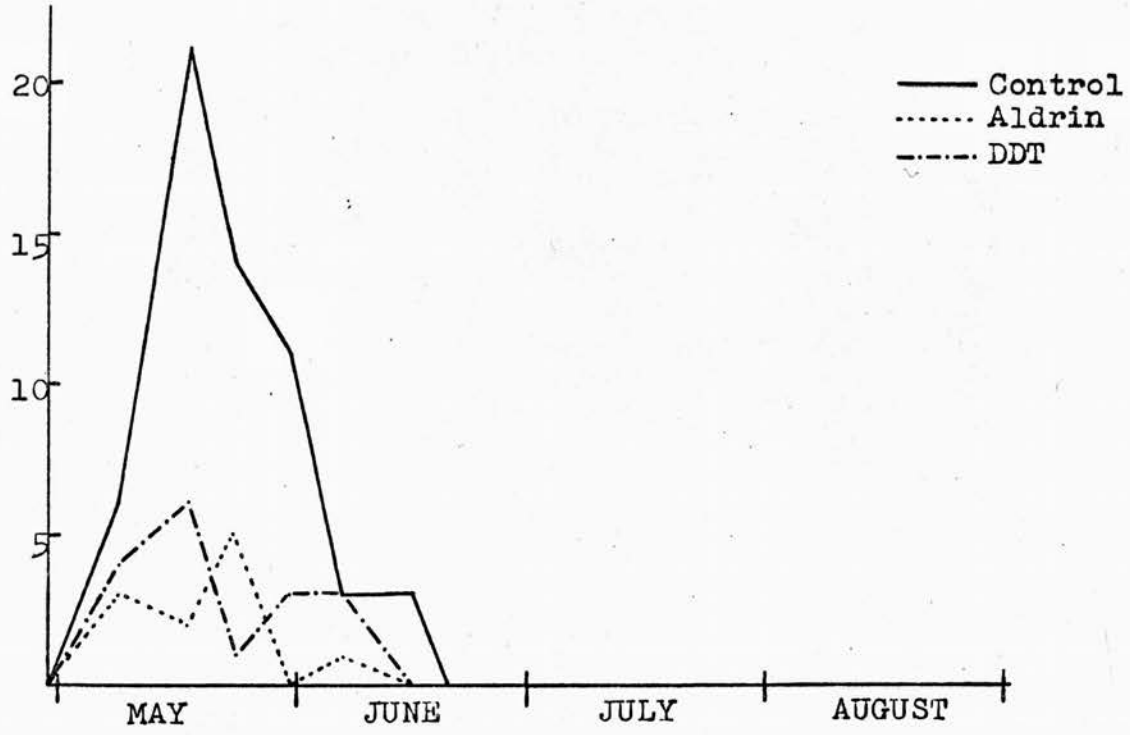


Fig. 25. No. of stems cut sub-surface

TABLE 28

Mean number of stems cut sub-surface in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	Aldrin	DDT		
9·83**	1·83	2·83	a, 3·25 b, 4·62	15·4

** Significant at $p < 0{\cdot}01$

Table 28 shows that the control was much more damaged ($p < 0{\cdot}01$) than the treated plots, between which there was no difference.

In the control plots there were signs of patchy damage in May, but in June plants made rapid growth and compensated for the damage, sometimes producing more tillers. Afterwards there was no obvious damage in the field.

In the control the sub-surface damage was three times (59:19) that on the surface. There was never any obvious damage in the sprayed plots.

5.144 Efficiency of insecticides

The foregoing results indicate that the insecticides were both highly efficient at the dosages employed, aldrin appearing slightly better but seldom significantly so.

5.145 Number of undamaged plants

Observations before spraying did not show significant difference between any of the plots. The first observation after spraying showed the highest plant population because of some late

germination. Up to 17 May Fig. 26 shows variation in the numbers of plants between the treatments, but they are not significant (Table 29). It was obvious from the damage to the plants that during the month of May the larvae were active. The 30 May observation in Fig. 26 shows the minimum number of plants in control

TABLE 29.

Mean number of undamaged plants in each treatment in weekly observations

Date	Treatments			L.S.D.	Value of "F"
	Control	Aldrin	DDT		
29.4.66	26·16	22·33	26·16	n.s.	2·77
8.5.66	26·66	23·83	28·16	n.s.	1·15
17.5.66	20·66	23·66	21·83	n.s.	< 1
23·5·66	19·83	21·50**	19·50*	n.s.	1·15
30.5.66	17·83	24·33**	21·83*	a, 2·89 b, 4·16	13·35
6.6.66	21·33	22·16*	23·33**	n.s.	< 1
15.6.66	20·50	23·50*	23·66**	a, 1·46 b, 2·11	14·17
20.6.66	22·33	24·16	22·83	n.s.	1·96
27.6.66	24·5	23·33	23·0	n.s.	< 1
4.7.66	22·83	23·50	23·33	n.s.	< 1
11.7.66	24·00	23·16	22·50	n.s.	< 1
18.7.66	23·66	21·83	22·33	n.s.	2·1
25.7.66	23·66	22·83	23·66	n.s.	< 1
1.8.66	23·33	22·66	22·50	n.s.	< 1
8.8.66	21·83	22·16	22·83	n.s.	< 1
15.8.66	23·66	23·00	23·33	n.s.	< 1
25.8.66	21·83	23·50	22·16	n.s.	2·91

* Significant at $p < 0·05$

** Significant at $p < 0·01$

n.s. = not significant.

and it is significant at 5 per cent level from the treated plots (Table 29). Each week's results were analysed to see if there were significant differences between the treated and control plots; but it was only on 30 May and 15 June that such were found. This was due to the repair of the damage by compensating growth by the

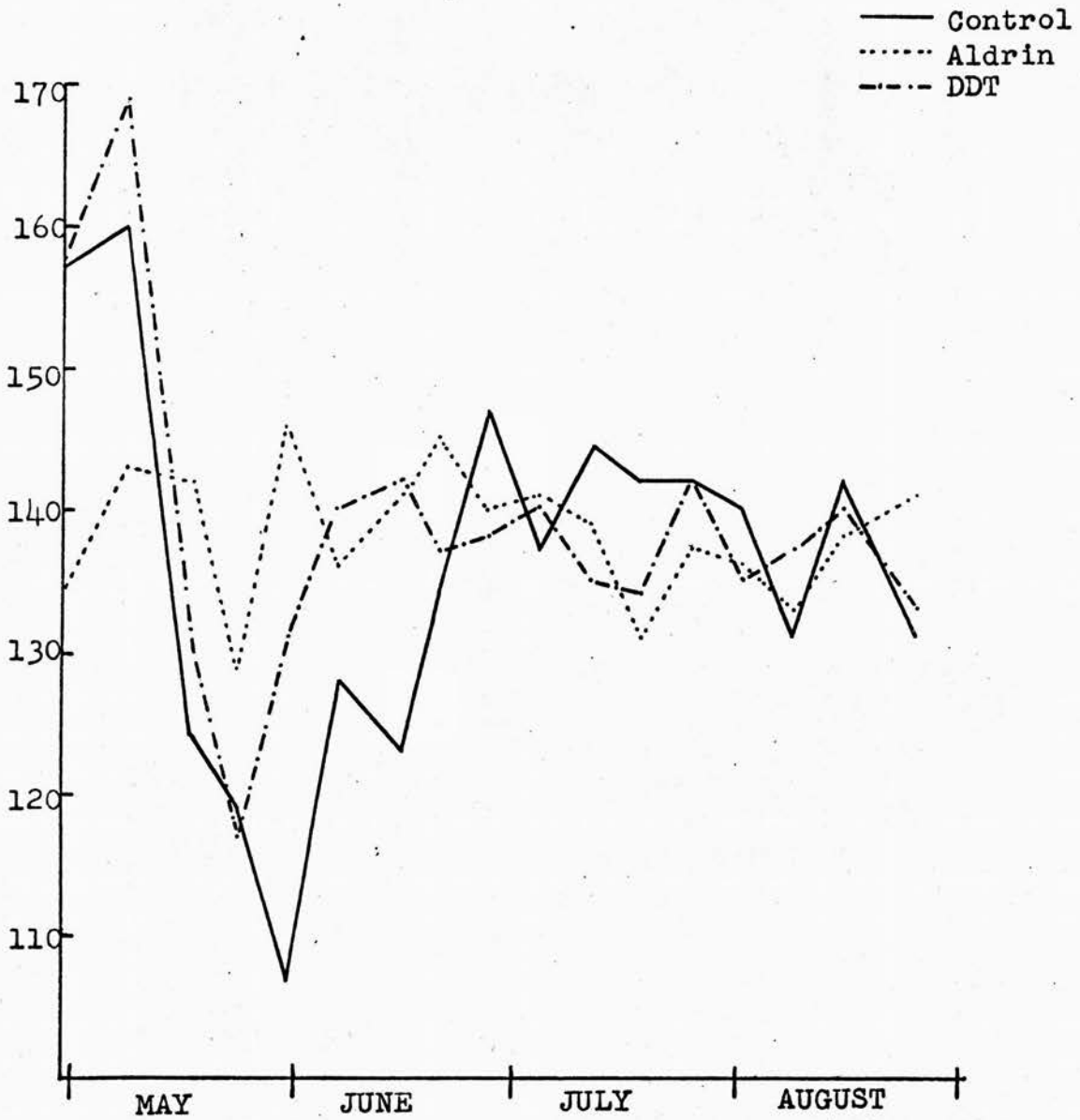


Fig. 26. No. of undamaged plants

plants. There was also no difference in the undamaged plants populations of the aldrin and DDT plots.

TABLE 30

Mean number of undamaged plants in each treatment throughout the experiment

Treatments			Value of "F"
Control	Aldrin	DDT	
384·66	392·0	393·0	< 1

As shown in Table 30, the summation for the whole experiment shows no significant difference between any of the treatments.

5.146 Yield of barley

The barley was harvested on 21 September. First each plot was separated from adjoining ones and from the neighbouring field crop by passing the combine between, then a swath through each plot was combined. The area of this swath was 49 square yards and constituted the sample from each plot.

TABLE 31

Mean weights of grain (in lbs.) in an area of 49 square yards in 1966 field experiment

Treatments			L.S.D. at $p < 0{\cdot}05$	Value of "F"
Control	Aldrin	DDT		
25·88	27·11	31·39	5·26	3·02

Table 31 shows the mean weight of grain in each treatment. There is no significant difference between any of the treatments, but the control shows less grain than the treated plots, the

difference between the control and the DDT plots approaching significance at the $p < 0{\cdot}05$ level. Table 27 in Appendix II shows the yield of grain per plot. The yield varied from 22·73 lbs. to 30·18 lbs. in control, 20·50 lbs. to 34·82 lbs. in aldrin and 27·34 lbs. to 34·50 lbs. in DDT respectively. The average yield in cwt. per acre was 22·82, 23·90 and 27·68 in control, aldrin and DDT treatment respectively. The plot yield varied from 21·10 cwt. to 30·65 cwt. in the experimental area.

The yield per plot in the control plots was not related to the populations of leatherjackets in the plots, so it could be assumed that the number of larvae per plot was not a factor in the variation of yields in control.

5.2 Field experiment in 1967.

The 1966 field experiment was repeated in 1967. The general trend of the population seemed to be very low in 1967 too. No field was found in the farm used in 1966 suitable for experimental work the following year.

5.21. Site of experiment

The farm was South Mains (West Lothian). The field was about 7 miles north of last year's field. Soil type was heavy loam. The field was ploughed in autumn after two years ley. The barley was drilled in the first week of April. At the time of setting out the experiment the height of the plants was 1½-2 in.

5.22 Procedure of investigation.

Exactly the same procedure was followed as in 1966, except that, as the use of aldrin had been discontinued (except for DDT susceptible barley), the organophosphorus insecticide folithion was used in its place. Folithion had already been reported to be promising in controlling leatherjackets in early trials (White, 1966; Dunn, in litt.). A comparison was made with DDT to evaluate its efficiency.

The quantity of DDT used per acre last year was enough to kill all the larvae within a short time, so this year the quantity was reduced to 3 pints DDT (25 per cent emulsion) of the same formulation.

The rate of folithion was 1 lb. of ~~A.I.~~ a.i. per acre, i.e. 8 fl oz. of 50 per cent folithion for 6 plots of 20 x 10 yards each. Both

the insecticides were diluted with water and applied at the rate of 50 gallons per acre.

One observation was made following randomisation and results are shown against 28 April in figures 27 to 32 and in the weekly observation tables 32 and 38.

The spraying was done in the same way as last year, but just following the initial count on the afternoon of 1 May. The day was wet, and spraying was finished by 7 p.m. the same evening.

The same factors were noted as in the 1966 experiment (see 5.132). Some additional information was also gathered, viz. (a) the count of tillers in each sample, (b) the proportion of ripe ears before harvest, (c) the number of grains in 20 grms. of the harvested samples and the proportion of ripe and unripe grains therein, and (d) their dry matter content. Results were analysed as in 1966.

5.23 Results

5.231 Decline in the larval population

A preliminary survey of the whole field showed that the population of larvae was 214,000 per acre. This estimation was based on 50 samples of 4 in. diameter to a depth of 3 in. After the plots had been marked out and randomised they showed populations of 260,000, 250,000 and 230,000 in the control, DDT and folithion plots respectively (Fig. 27, 28 April). The average population of the area under investigation was thus 247,000 per acre; which did not differ much from that of the 1966 experimental field (238,000

per acre). In both the years, general trends of population were very low.

The second estimation of larval population was made 4 days after spraying (Fig. 27, 4 May). In the control, DDT and folithion plots 0, 2 and 3 moribund larvae were found on the surface. But the total population of the area was not appreciably reduced (Appendix II, Table 28). The DDT showed rapid reduction of population compared to folithion. The second observation (Fig. 27, on 11 May) showed still more decline, the numbers in the treated areas being reduced to about 50 per cent of those in the control. Table 32 shows the mortality of larvae is higher in DDT, significant at $p < 0{\cdot}05$, on 4 May observation compared to control and folithion. The greater mortality in sprayed plots is highly significant ($p < 0{\cdot}01$) in 11 May observations, compared to control but there is no significant difference between the insecticidal treatments. The number of larvae dead or moribund on the surface was 0, 3 and 6 in control, DDT and folithion respectively. In subsequent observations after 11 May, no dead or moribund larvae were found on the surface.

Table 32 shows the weekly leatherjacket populations, and is summarised from Table 28 in Appendix II. There was a large drop in population by the fourth week (25 May) in the treated plots compared with the control, and subsequently these populations remained very small.

Fig. 27 for control shows the natural decline in the population of larvae which commenced after the beginning of June. These results agreed with those of the population of larvae in a

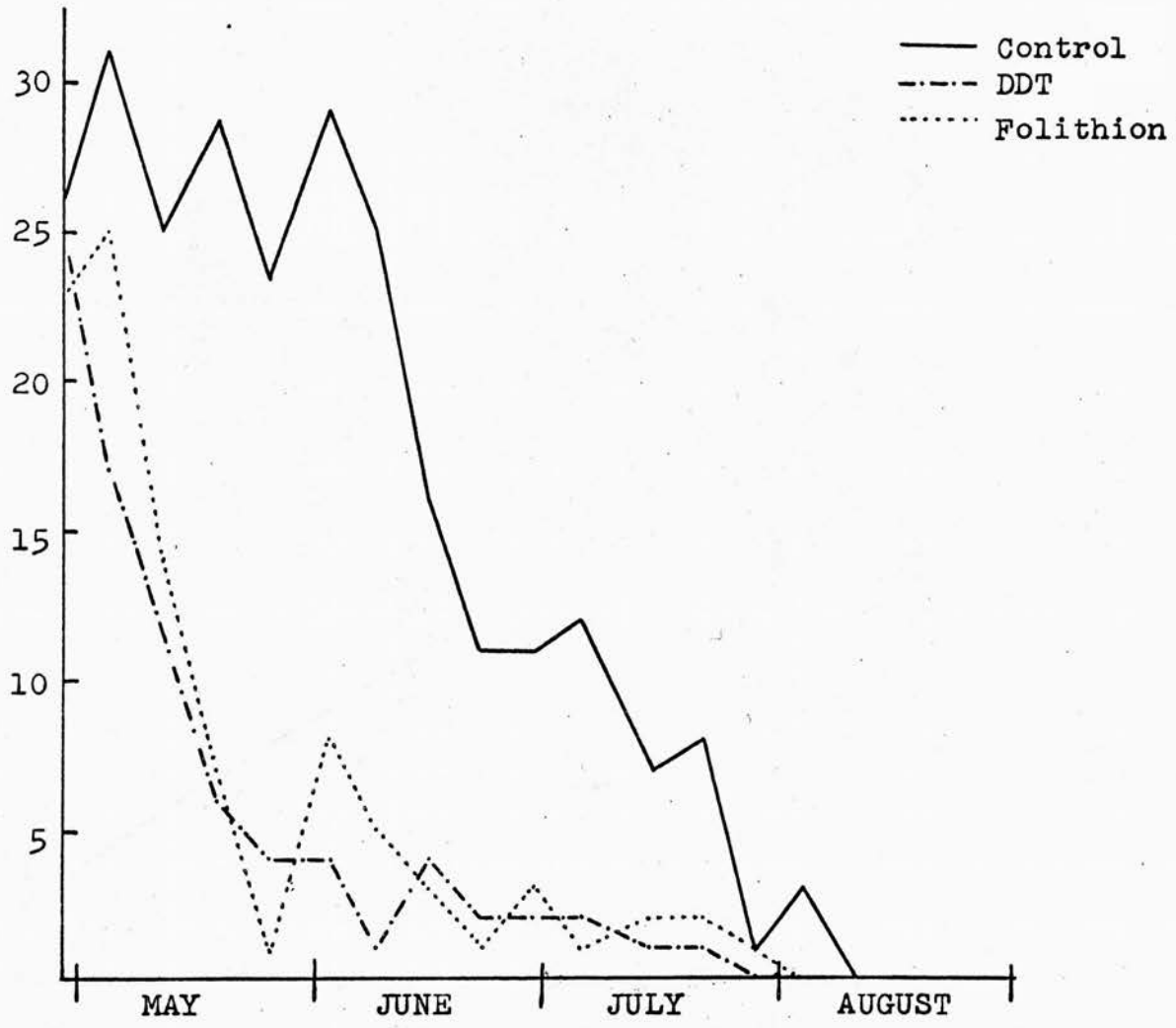


Fig. 27. No. of leatherjackets.

TABLE 32

Mean number of larvae in weekly observations of different treatments

Date	Treatments			L.S.D.	Value of "F"
	Control	DDT	Folithion		
28.4.67	4·33	4·16	3·83	n.s.	< 1
4.5.67	5·16**	2·83	4·36*	a, 1·49 b, 2·12	6·08
11.5.67	4·16**	2·0	2·33	a, 1·31 b, 1·87	7·92
18.5.67	4·75**	1·0	1·16	a, 1·73 b, 2·47	14·95
25.5.67	3·91**	0·66	0·16	a, 0·55 b, 0·79	124·35
2.6.67	4·83**	0·33	1·33	a, 1·82 b, 2·59	16·50
8.6.67	4·16**	0·16	0·83	a, 2·58 b, 3·67	6·85
15.6.67	2·66**	0·66	0·50	a, 0·75 b, 1·07	24·91
22.6.67	1·83**	0·33	0·16	a, 0·91 b, 1·29	9·67
29.6.67	1·83**	0·33	0·50	a, 0·78 b, 1·10	11·97
5.7.67	2·0**	0·33	0·16	a, 1·22 b, 1·74	6·84
14.7.67	1·16	0·16	0·33	n.s.	2·43
20.7.67	1·33**	0·16	0·33	a, 0·73 b, 1·04	7·50

** Significant at $p < 0·01$ n.s. = not significant.

grass field (Fig. 10), in the same period. This mortality of leatherjackets was due to the severe dry weather (Appendix IV, Rainfall 1967) and was also observed in the two previous years. It was also shown in the experiment outside the insectary (see 4.625). This is the second severe mortality of larvae and followed the winter mortality (Grass field population, Fig. 10). The last decline shown in Fig. 27 from about mid July was due to pupation and emergence of adults. The first field evidence of adult emergence was found in the presence of an empty male pupal skin in a sample on 27 July. Afterwards no further pupae were obtained in the samples and adults were seen flying in the field. No more larvae were collected from DDT plots after 20 July and from folithion plots after 27 July. No pupae or empty pupal skins were found in any of the treated plots indicating that no larvae completed their life cycles therein.

The analyses of weekly observations in Table 32 shows highly significant control ($p < 0{\cdot}01$) from 18 May to 2 June. The significance drops to $p < 0{\cdot}05$ on 8 June due largely to the natural decline in the control population. Afterwards there is again a high rate of significance ($p < 0{\cdot}01$) due to the reduction of population in treated plots until near the time of adult emergence, when the population was too low to show consistent differences.

The analysed results of total larval population (Table 33) in each treatment show highly significant ($p < 0{\cdot}01$) control by DDT

TABLE 33

Mean number of larvae in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
42·83**	13·50	16·0	a, 5·52 b, 7·86	87·90

** Significant at p < 0·01

and folithion. There is no significant difference between DDT and folithion treatments.

5.232 Damage on surface

5.2321 Plants with shredded leaves

The first sign of damage to the aerial parts of the barley was noticed in the first week of May, after spraying, but the damage was very slight. Table 29 in Appendix II shows the total number of plants with shredded leaves counted in each treatment. Fig. 28 shows that the peak of damage was in the first week of June. The peak of damage was late compared to last years results (Fig. 22). At the end of June, there was a decline in the damage due to the vigorous growth of the plants. No plant with shredded leaves was recorded after June in the control.

The damage was very slight in the DDT or folithion plots due to the presence of very few larvae which indicates that the

insecticides controlled the leatherjackets effectively.

Table 34 shows the difference between the damage in different treatments. The analysis is based on the total number of

TABLE 34

Mean number of plants with shredded leaves in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
16·60**	1·83	1·0	a, 3·63 b, 5·16	56·91

** Significant at $p \leq 0{\cdot}01$

damaged plants in each plot throughout the season.

There is significant difference ($p < 0{\cdot}01$) between the control and either of the insecticidal treatments. There is no difference between the DDT and folithion plots.

5.2322 Plants with cut leaves

Fig. 29 shows the number of leaves cut in each treatment throughout the season. It seems that peaks of both Figs. 28 and 29 appear at the same time, there is no great difference in numbers in both the categories of damage. No cut leaves were found in the field after the month of June.

So, both these categories of damage were not very serious and by July all plants recovered from these injuries.

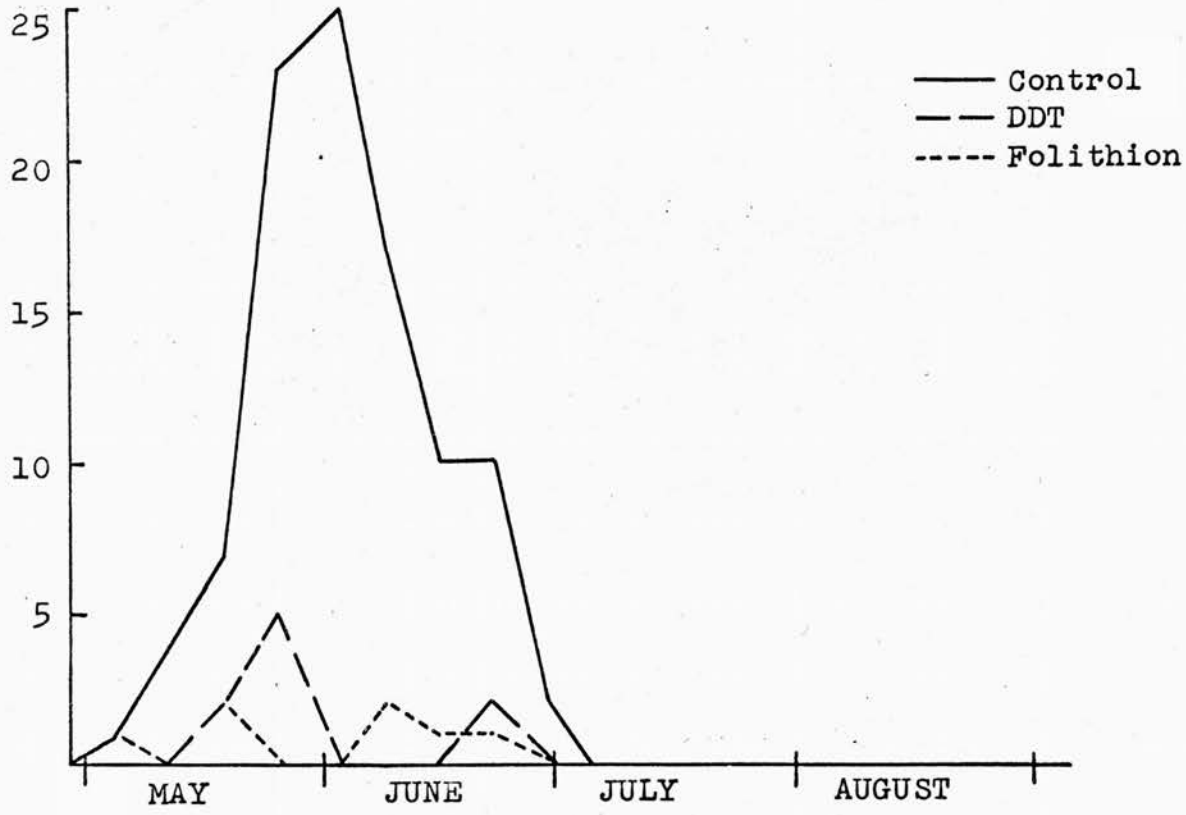


Fig. 28. No. of plants with shredded leaves

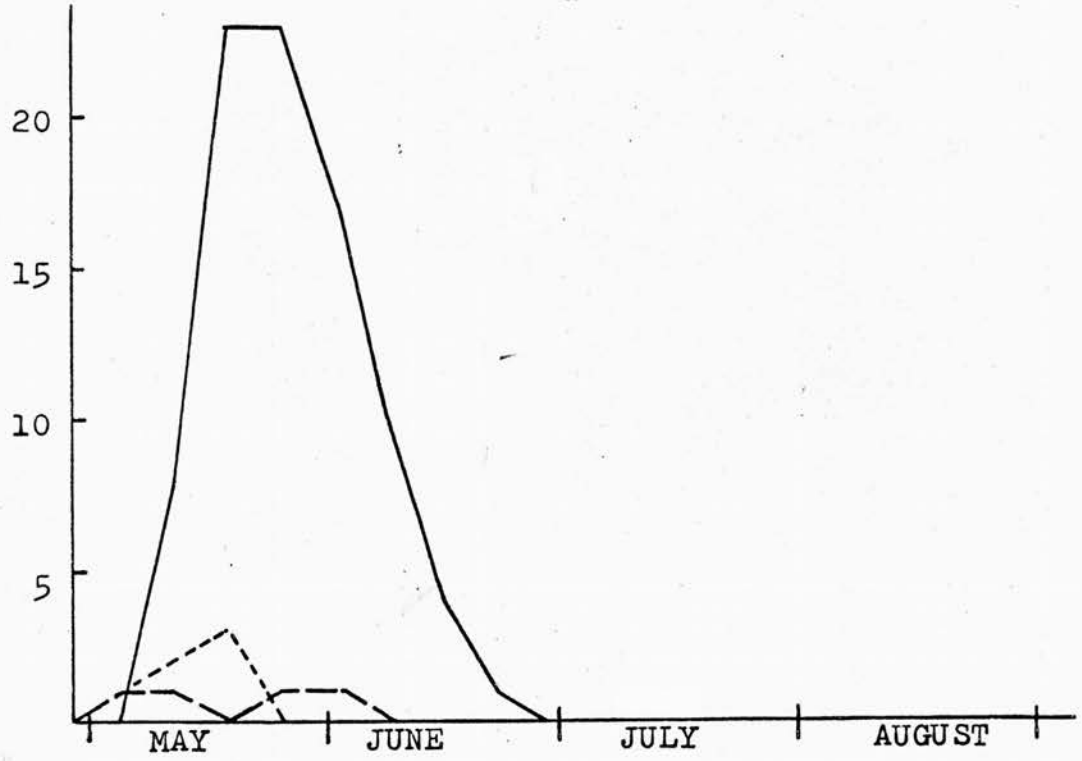


Fig. 29. No. of plants with cut leaves

TABLE 35

Mean number of plants with shredded leaves in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
17·0**	0·50	1·00	a, 4·14 b, 5·89	51·85

** Significant at $p < 0·01$

Table 35 shows the difference between treatments, based on the total observations. The damage in the control is significantly more ($p < 0·01$) than in the insecticidal treatments, but there is no difference between these. Table 30 in Appendix II shows the details of all observations.

5.2323 Stems cut at or above the soil surface.

These plants had either totally or partly cut stems (Plate 5) which is a much more serious type of damage. Fig. 30 shows that the number of stems cut on the surface is far less than the number of plants with the previous two types of damage. The maximum number of stem cut was recorded on 18 May. The patchiness in the field is due to this type of damage (Plates 7, 8). More plants killed in this way were noticed in control plots 1, 2 and 6. The number cut in treated plots was very small. No plants with cut stems were observed after 8 June.

PLATE 7. A bare patch in control 1. (1967)

PLATE 8. A general view of experimental plots, the distant bare patch in control 2.

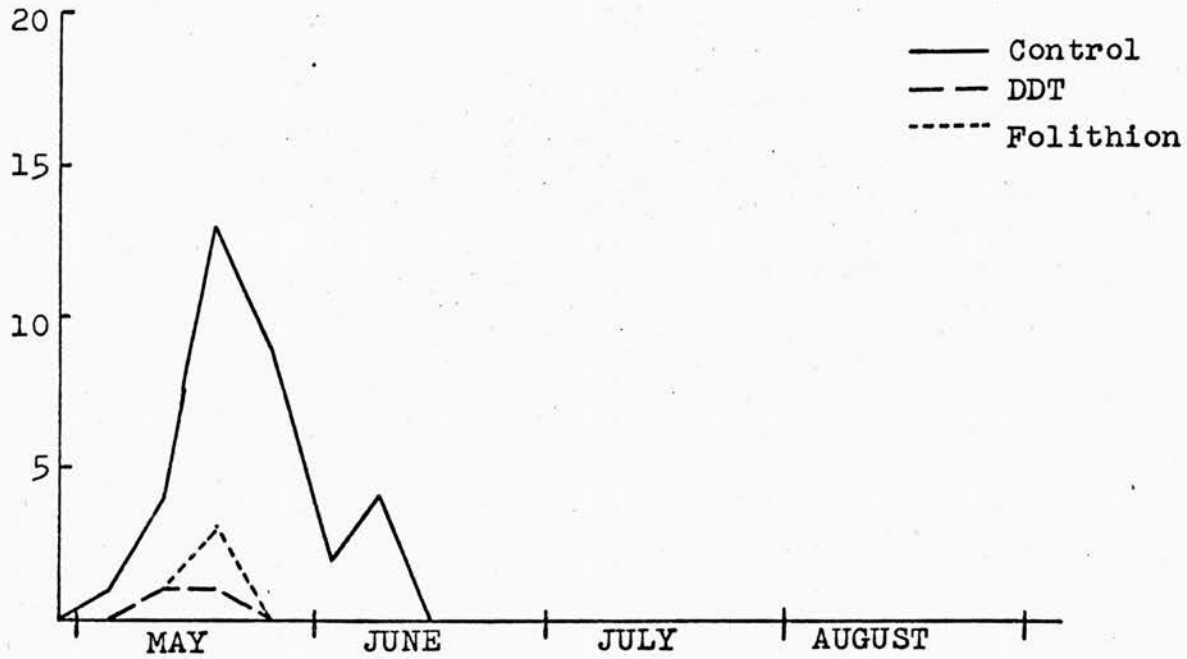


Fig. 30. No. of stems cut at or above the soil surface

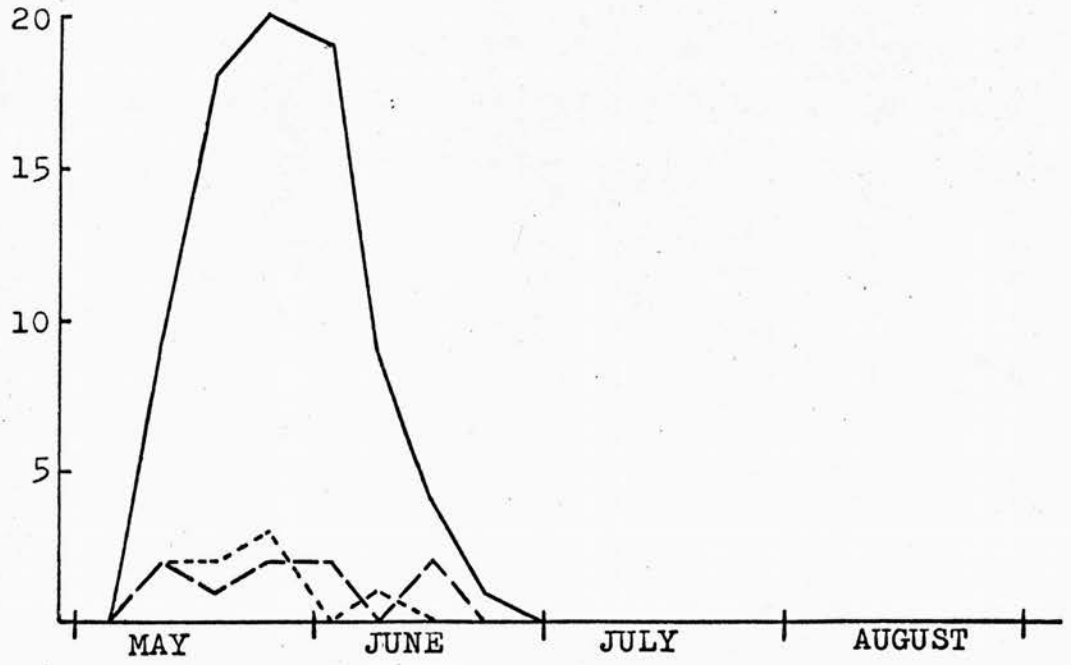


Fig. 31. No. of stems cut sub-surface

TABLE 36.

Mean number of stems cut at or above the soil surface in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
5·5**	0·33	0·66	a, 1·96 b, 2·76	13·10

** Significant at $p < 0·01$

Table 36 shows the analysed results of the observations in each treatment. There is no significant difference between DDT and folithion plots, but the control plots suffered much more damage ($p < 0·01$) than those treated.

5.233 Sub-surface damage

Fig. 31 shows that the damage started on 11 May and the peak of damage lasted for 2 weeks (18 May to 2 June). The damage continued with decreasing severity till the last week of June. The period when stems were cut underground was longer than that of the same damage on the surface.

Table 37 shows the analysed results from the total plants damaged per plot. It is obvious from the table that the degree of damage in the control was very high ($p < 0·01$) compared to the treated plots. There is no variation between DDT and folithion plots.

TABLE 37

Mean number of plants with stems cut underground in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
13·33**	1·16	1·33	a, 4·54 b, 6·46	23·21

** Significant at $p < 0{\cdot}01$

Apart from that, it is also important to notice that the number of stems cut underground is significantly greater ($p < 0{\cdot}01$) than those cut above ground. It was also noticed in the experiment with time lapse cinematography (see 6·32) that larvae fed more underground than on the surface.

5.234 Efficiency of insecticides

In the results immediately after spraying DDT proved significantly ($p < 0{\cdot}05$) better than folithion (4 May, Table 32), but thereafter their efficiencies ran almost parallel. It has already been shown that more dead larvae were collected on the folithion plots than on the DDT plots, but this difference was not significant. Dunn (in litt.) also got good results from folithion in contemporary experiments in the same county.

Folithion has a very low mammalian toxicity (White, 1966) and is proving to have a higher insecticidal value than other

TABLE 38

Mean number of undamaged plants in each treatment in weekly observations

Date	Treatments			L.S.D.	Value of "F"
	Control	DDT	Folithion		
28.4.67	25·83	28·0	28·50	n.s.	< 1
4.5.67	31·33	30·0	32·00	n.s.	1·02
11.5.67	28·50	31·0	29·00	n.s.	< 1
18.5.67	19·00	27·0*	24·66	a, 7·13 b,10·14	3·31
25.5.67	15·16	21·83**	21·33*	a, 4·46 b, 6·34	6·79
2.6.67	11·16	18·66**	20·50**	a, 3·05 b, 4·78	33·31
8.6.67	13·33	16·50	19·83**	a, 3·36 b, 4·78	9·81
15.6.67	16·00	18·50	20·66*	a, 3·83	3·72
22.6.67	15·00	19·00*	21·00**	a, 3·25 b, 4·62	9·39
29.6.67	12·00	19·00**	16·16	a, 4·41 b, 6·27	6·20
5.7.67	16·50	17·16	19·50	n.s.	< 1
14.7.67	13·33	18·33*	17·33*	a, 3·74 b, 5·32	4·96
20·7.67	15·16	17·33	18·50	n.s.	2·19
27.7.67	15·66	22·83**	19·66**	a, 2·74 b, 3·90	16·89
3.8.67	15·83	19·50*	17·66	a, 3·38 b, 4·81	2·92
10.8.67	14·33	22·00**	19·50*	a, 4·43 b, 6·30	7·82
17.8.67	15·00	19·16*	21·66**	a, 4·12 b, 5·86	6·59
24.8.67	15·33	19·66	18·00	a, 4·46	2·36

* Significant at $p < 0·05$

** Significant at $p < 0·01$

n.s. = not significant.

organophosphorus insecticides tried so far. It, therefore, seems to be a satisfactory substitute for organochlorine insecticides, abandoned on account of their deleterious side effects.

5.235 Number of undamaged plants.

The trends are shown in Table 38 and Fig. 32. The first observation in which the treated plots showed significantly ($p < 0{\cdot}01$) more undamaged plants than the control was on 2 June. This difference persisted throughout the experiment but to a lesser degree. As seen in the 1966 experiment the population of plants in all plots increased in early May due to late brairding. Populations tended to increase sporadically later in the experiment when compensating growth by the plants, in good growing weather, repaired the damage caused by larvae. The drop in numbers of larvae before the end of the experiment caused a general levelling up of the populations of undamaged plants but the treated plots retained their superiority.

TABLE 39

Mean number of undamaged plants in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
308·33	387·5**	384·33**	a, 33·20 b, 47·21	19·31

** Significant at $p < 0{\cdot}01$

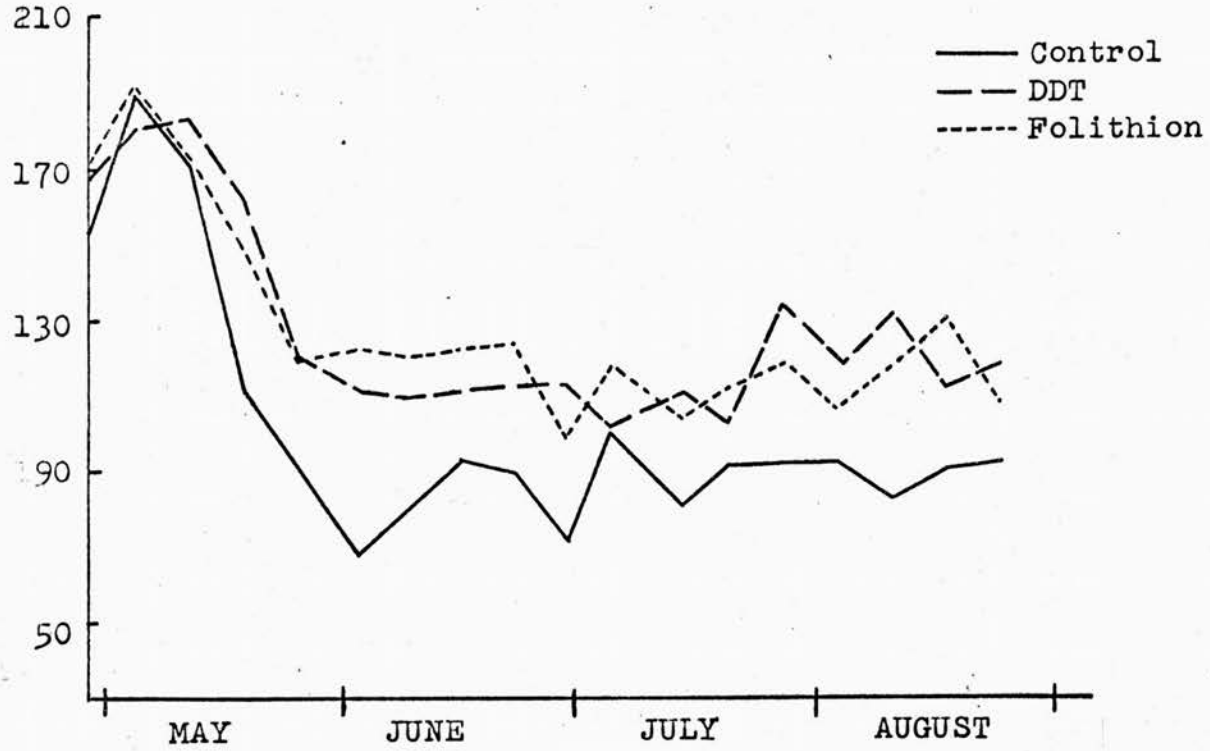


Fig. 32. No. of undamaged plants

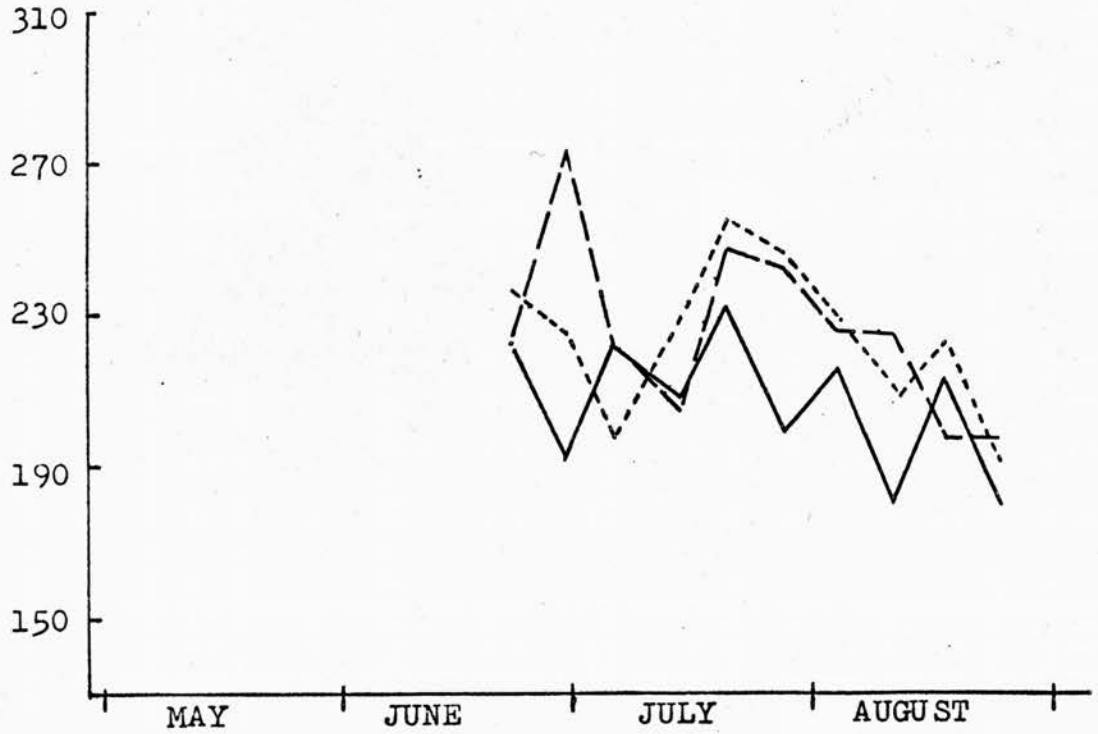


Fig. 33. No. of tillers.

Table 39 shows the result of total undamaged plants in each treatment. It shows that there is a great difference ($p < 0{\cdot}01$) between control and treated plots. There is no difference between treated plots. There was further indication in that the bared patches in the field remained (Plates 7 and 8).

5.236 Total plant population

No damage was observed to be caused to the plants from July, although bare patches, of course, remained. An analysis was also made of the total plant populations in each treatment (including damaged and undamaged plants) as indicated by the numbers of plants counted in all the cores of each date. The results are shown in Table 40 and indicate that the DDT treatment

TABLE 40

Mean plant population in each treatment throughout the experiment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
360·33	391·16*	389·0	a, 28·70 b, 40·79	3·58

* Significant at $p < 0{\cdot}05$

was better than the control at the 5 per cent level, but the folithion treatment just failed to reach significant superiority.

5.237 Population of tillers

The tiller population was estimated to find out the variation in different treatments as the yield of the crop is affected by the number of tillers each plant produces. The tiller count was begun on 22 June. Fig. 33 does not show much variation between treatments.

TABLE 41

Mean number of tillers in weekly observations in each treatment

Date	Treatments			L.S.D.	Value of "F"
	Control	DDT	Folithion		
22.6.67	37·00	37·16	39·33	n.s.	< 1
29.6.67	34·00	45·00*	37·00	a, 11·00	3·53
5.7.67	36·83	37·16	37·33	n.s.	< 1
14.7.67	36·33	32·33	38·16*	a, 5·46	3·16
20.7.67	38·50	41·16	42·33	n.s.	1·62
27.7.67	33·16	40·66*	41·16**	a, 5·75 b, 8·00	6·46
3.8.67	35·83	37·50	38·16	n.s.	< 1
10.8.67	30·00	37·33	34·83	n.s.	2·06
17.8.67	35·16	32·83	37·0	n.s.	1·60
24.8.67	29.83	32·66	30·16	n.s.	< 1

* Significant at $p < 0{\cdot}05$

** Significant at $p < 0{\cdot}01$

n.s. = Not significant.

The observation of 27 July (Table 41) showed that the number of tillers in the control was significantly less than in the DDT ($p < 0{\cdot}05$) and folithion plots ($p < 0{\cdot}01$), and the difference

between the control and DDT plots on 29 June and control and folithion plots on 14 July were significant ($p < 0.05$). Apart from these there were no significant differences between the treatments.

The sums of the total tillers in each treatment were analysed. But there was no difference between any of the

TABLE 42

Mean number of tillers from total of each plot in each treatment

Treatments			Value of "F"
Control	DDT	Folithion	
344·83	375·50	375·83	2·20

treatments (Table 42).

The number of tillers is in contrast with the number of undamaged plants (Figs. 32, 33). This shows that the plants damaged by the larvae compensated by producing more tillers.

The number of tillers in individual plants

To establish the relationship between the number of plants and numbers of tillers, the tillering by individual plants was calculated (Table 43). There is a great variation in results which clearly shows that the individual plants in the control produced more tillers. There is no variation in tillering

TABLE 43

Mean number of tiller per plant in each treatment.

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
2·33	1·98**	2·04*	a, 0·23 b, 0·34	10·16

* Significant at $p < 0·05$

** Significant at $p < 0·01$

between DDT and folithion plots. This confirms the compensation produced by tillering of the damaged plants.

5.238 Difference in ripening of barley

In the control plots, tillering was late; as a result of which it was observed in the field that the ripening of the grain was not uniform. At the time of harvesting of the other fields by the farmer, a count of ears was made. The count was based on the number of ears in one foot of row replicated 8 times in each plot. The numbers of ripe and green ears were noted. Table 39 in Appendix II shows the total number of green and ripe ears in each plot. The green ears were converted into the percentage of total ears and the analysis was done by angular transformation (Snedecor, 1950, p.448; Fisher and Yates, 1953, p.66).

Table 44 shows the angular means of the unripe ears in each treatment. There is a significant difference ($p < 0·01$)

TABLE 44

Mean number of unripe ears in 8 samples each of 1 foot of row in each treatment

Treatments			L.S.D.	Value of "F"
Control	DDT	Folithion		
22·13	11·96**	14·96**	a, 4·57 b, 6·78	12·80

** Significant at $p < 0·01$

between control and treated plots. But there is no difference between DDT and folithion plots.

The persistence of green ears in this crop caused the farmer to delay harvesting it by almost a fortnight.

5.239 Yield of barley

The crop was harvested on 7 October. The experimental plots being dealt with as in 1966; but a larger combine harvester was in use so the area of each sample was 58·8 square yards in 1967. The yield varied from 40 lbs. to 56 lbs. in control, 35·5 lbs. to 59 lbs. in DDT and 30 lbs. to 60 lbs. in folithion respectively (Table 40 in Appendix II).

TABLE 45

Mean yield (in lbs.) of barley per treatment harvested from an area of 58·8 sq. yds.

Treatments			Value of "F"
Control	DDT	Folithion	
48·91	47·41	43·33	0·70

Table 45 shows the mean weight of barley harvested in each treatment.

It is obvious from the table that there was no significant difference between the treatments.

The average yields in cwt. per acre were 35·81, 34·71 and 31·72 in control, DDT and folithion treatments respectively.

5.2310 Weight of grain

Twenty grams of grain from each plot were weighed on the day following harvesting. The numbers of ripe and unripe grains were counted. Table 46a shows the mean number of grains

TABLE 46a

Mean number of grains per 20 gms. in each treatment

Treatments			Value of "F"
Control	DDT	Folithion	
383·33	403·16	402·66	1·05

per twenty grams in each treatment.

There is no significant difference but there is a tendency for the grains in the control to be slightly heavier than in DDT or folithion plots. There is also no difference in the number of unripe grains in each treatment (Table 46b).

It is possible that if harvesting had not been delayed, there might have been some difference between the plots.

TABLE 46b

Mean number of unripe grains per 20 grm. in each treatment

Treatments			Value of "F"
Control	DDT	Folithion	
7·0	6·16	4·5	< 1

5.2311 Percentage of dry matter in grain

The percentage of dry matter was ascertained to find whether the quality of grain was affected in the control plots. Table 47 shows the means of the angular transformations of the percentage dry matter in each treatment. The actual dry matter percentages are shown in Table 37 in Appendix II.

TABLE-47

Mean of the angular transformation percentages of dry matter in the grain, ascertained from a sample of 150 grms. from each plot

Treatments			Value of "F"
Control	DDT	Folithion	
53·4	53·9	54·1	< 1

There is no significant difference between dry matter in any of the treatments, indicating that the quality of the grain was not affected by the damage caused by leatherjackets in the field.

5.3 Discussion and conclusions

The field experiments of years 1966 and 1967 were based on populations of leatherjackets which are considered marginal as far as causing economic damage is concerned. There is no previous published work on arable crops to explain the reasons for this view. This is a population level commonly met in arable fields in South East Scotland. As is obvious from the grassland observations, a higher population of larvae declines to this level from autumn to spring.

In the 1966 field experiment, the first significant decline in population was obtained in the first week of June and amounted to 50 per cent reduction in the control. This drop in population coincided with a dry spell from 25 May till 2 June. In 1967, the decline in the experimental field showed in the 15 June observation and amounted to about 60 per cent reduction in the control (the treated plots are not considered as populations were artificially reduced). This mortality was also associated with a dry spell from 8 June to 18 June (Rainfall 1967, Appendix IV). There is commonly a dry period about this time of year which contributes to the control of larvae in the field. Disease was also a controlling factor and predators could have been responsible for a small reduction in numbers. Virus diseases are more common in late 4th instar larvae and both fields showed the occurrence of diseased larvae, the earliest one found in 1966 being on 29 April. There was no

further marked reduction until that caused by pupation and emergence of adults.

Collections of pupae were made at the same time in both the years - from 11 July in 1966 and 14 July 1967. In neither case were the pupae newly formed. Adults had been seen flying in the 1966 field on 18 July and 1967 on 20 July. But the first pupal skins were collected in samples on the 8 August and 27 July in 1966 and 1967 respectively (Tables 20 and 28, Appendix II). In 1966 the latest larva was found on 8 August, but in 1967 complete pupation was observed by 3 August as no more larvae were found afterwards.

No pupae nor any pupal skins were found in treated plots. Thus the quantities of insecticides used per treatment were adequate to kill all the leatherjackets. This also explains the reason of using 1 pint less DDT per acre in 1967.

The reduction of population in the 1966 experimental field was over 87 per cent in aldrin and DDT plots in the third week after spraying, and the subsequent reductions were very sharp. In the 1967 experiment, larvae in treated plots decreased by about 50 per cent 2 weeks after spraying. Subsequent reductions of population though not very sharp, were sufficient to check the damage to the crop. The results show that folithion has good insecticidal properties in controlling leatherjackets and could be used as a substitute to chlorinated hydrocarbons.

The surface damage was less in 1966 (Figs. 22, 23 and 24) than 1967 (Figs. 28, 29 and 30). The initial population in

1967 was a little greater, but the damp and warm nights might have contributed to the greater damage on the surface as the May rainfall in 1966 was 2·95 inches and in 1967, 4·58 inches. This factor has been known for many years (Bull, West Coll. Agric., 1925). Earlier decline of larval population might be another probable reason for less damage. In 1966, the surface damage in the control plots in the form of shredded and cut leaves was 23·5 per cent of the total plants on 17 May, and in 1967 33·5 per cent on 25 May. In 1966 the number of plants with cut stems (both surface and sub-surface) was 18 per cent of the total plant population on 17 May, and in 1967 it was 21·4 per cent on 18 May. The period of damage in both the years was about the same. More patchy damage was observed in 1967 in the control plots. There were very few plants damaged in treated plots.

The barley was observed to recover considerably from the damage. The percentage of visibly undamaged plants showed the extent of total damage and the ultimate recovery of the plants. In 1966, the lowest percentages of undamaged plants in control were 65·6, 72·3 and 73·5 in 17, 23 and 30 May respectively; and plants recovered fully by 20 June. In 1967, the percentages were 64·3, 50·3, 53·2 and 60·1 on 18, 25 May and 2 and 8 June respectively in the control, and the plants recovered fully from the damage by 5 July (see Table 34, Appendix II). It is obvious from these figures that barley suffered more in 1967 and the period of damage was longer. Table 38 shows that the level of

significance of the differences between treated and untreated plots dropped from $p < 0.01$ at the peak period of damage to nil at the end of the experiment.

While investigating these factors in 1967 it was noticed in the field that the control plots with less plant population had more tillers. This factor was not obvious in 1966 as there was lack of variation in plant population in different treatments (see Table 29). In 1967 it was found that the number of plants in the control plots was significantly less ($p < 0.01$) than in the treated. Against that the plants in the control plots had a greater number of tillers ($p < 0.01$) and this compensated in part for the damage done (Table 43).

Although the plants recovered, the late tillering in the control plots caused late shooting and the ultimate result was uneven ripening which was clearly observed in the field. In consequence this field had to be harvested later than other barley fields by the farmer.

There was no significant difference in yield of barley between any of the treatments in both year's experiments. So, it can be safely concluded here that this population of leather-jackets would not normally cause the farmers any economic loss, and so not justify expenditure on chemical treatment.

Plates 7 and 8 show the general damage in control plots 1 and 2 as seen at the end of the second week in June. This damage was more apparent to the eye than that in the other control plots but Table 40 in Appendix II shows that these plots did not

yield less than the other control plots.

In 1967, investigations were also carried out to see whether the quality of the grain was affected. But the weight per grain, the proportion of ripe and unripe grains and the dry matter contents did not show any significant differences between the treatments. So, it is concluded from these data that even the quality of the grain between the treatments was not affected.

As already mentioned, there is no exactly comparable work, tracing the effect of leatherjackets on the crops throughout the growing season. The 1966 and 1967 experiments showed that damage does not necessarily result in a loss of yield owing to compensatory growth by the plants. White (1967) considered that such populations as occurred in the experimental plots would cause measurable damage. Allowance, however, for compensatory growth by the plants should be made before forecasting a drop in eventual yield by the crop.

SECTION 6. NOCTURNAL BEHAVIOUR OF LEATHERJACKETS RECORDED BY TIME-LAPSE CINEMATOGRAPHY

6.1. Introduction

Very little is known about the activity of leatherjackets. Being nocturnal creatures, they are very sensitive to light, and attempts to observe them at night were made, but these were inevitably unsuccessful because they withdrew to their tunnels as soon as a hand torch was switched on (see 4.7). Nielsen (1957) found that mosquitoes reacted to the light of flash-bulbs but were not disturbed by an electronic flash. He recorded the periodic activities of mosquitoes photographically using a camera synchronised with an electronic flash.

Gilbert (1965) described the use of infra-red time-lapse photography to investigate the tunnelling of Tribolium.

Newell (1966) recorded the behaviour of slugs by using high speed flash illumination and a cine camera, triggered to expose one frame every 15 seconds. This method enabled him to study crawling, feeding, copulating and resting behaviour of each individual at night.

The success of these techniques justified an attempt to utilise similar recording methods to study some of the more important aspects of leatherjacket behaviour contributing to the damage to cereal crops in the field e.g. (i) time of first appearance on the surface after dark, (ii) duration of their presence on the surface associated with movement and feeding,

(ii) mode of feeding, (iv) the stimulation to feeding due to the proximity of plants to the holes from which larvae emerge, (v) proportion of a known population occurring on the surface at any given time, (vi) the crawling of the larvae on the surface and the speed of motion. It was subsequently discovered that it was possible to study some part of their underground movement traced from the surface by small upheavals and movement of soil and plants.

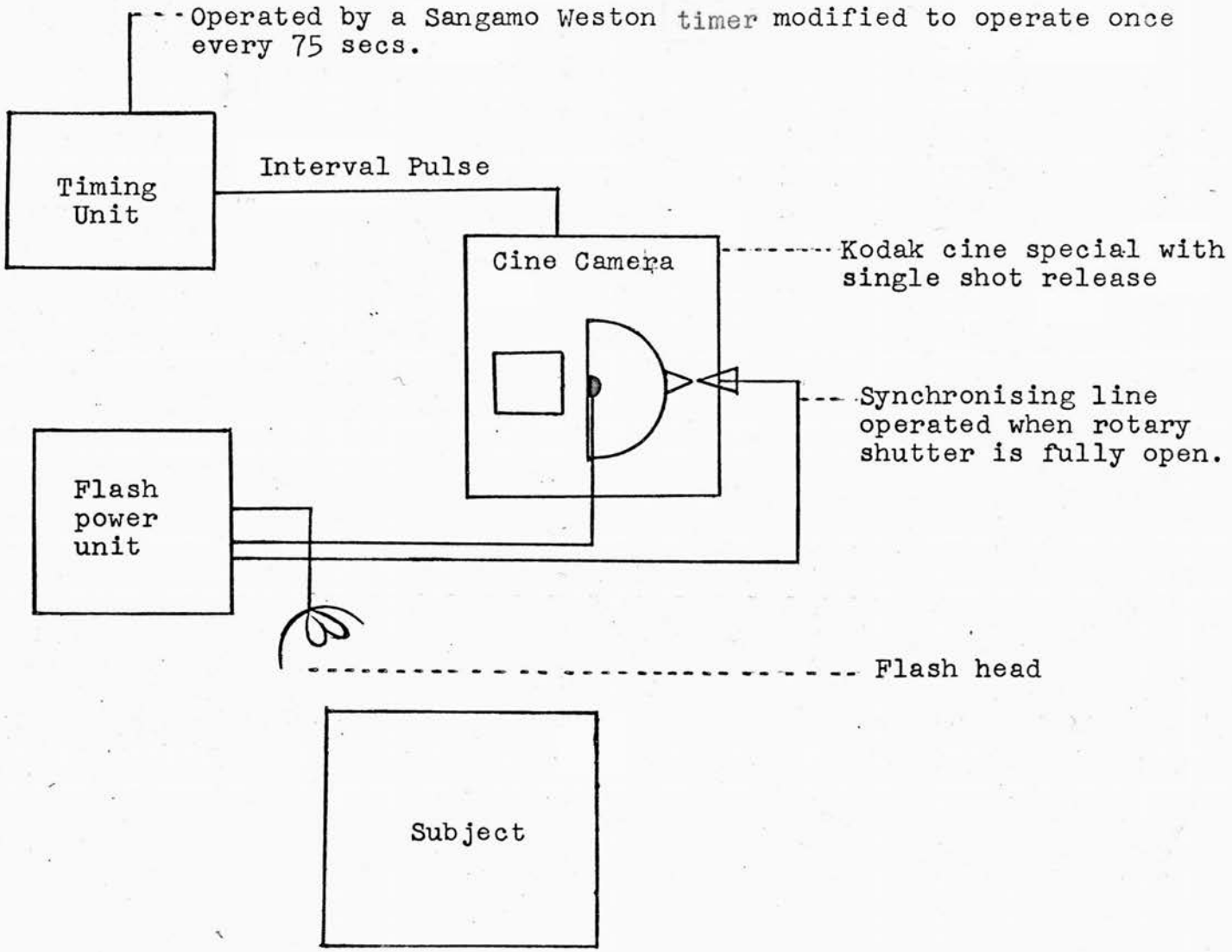
6.2 Material and method

Two boxes each one foot square were made from 5 in. deep frames placed in shallow sheet metal trays. From the area of each a strip 3 in. wide was separated by a glass partition to confine the leatherjackets in an adjusted area of 12 x 9 in. to fit the field of view for filming. Adequate moisture was maintained to prevent the soil drying out.

Box I. Soil with barley plants *in situ* was collected from the field and trimmed to fit the box. The depth of the soil was 3 in. and the soil type, a heavy-loam. Any weeds were removed and the barley plants were shortened to about 2 in. to get a clear view of the leatherjackets. Ten larvae were put onto the soil to ensure the presence of leatherjackets.

Box II. This box was prepared in the laboratory using sandy soil and barley plants were grown in it. As the aim of this investigation was related to the insectary experiment on the

Diagram of time lapse cinematography apparatus.



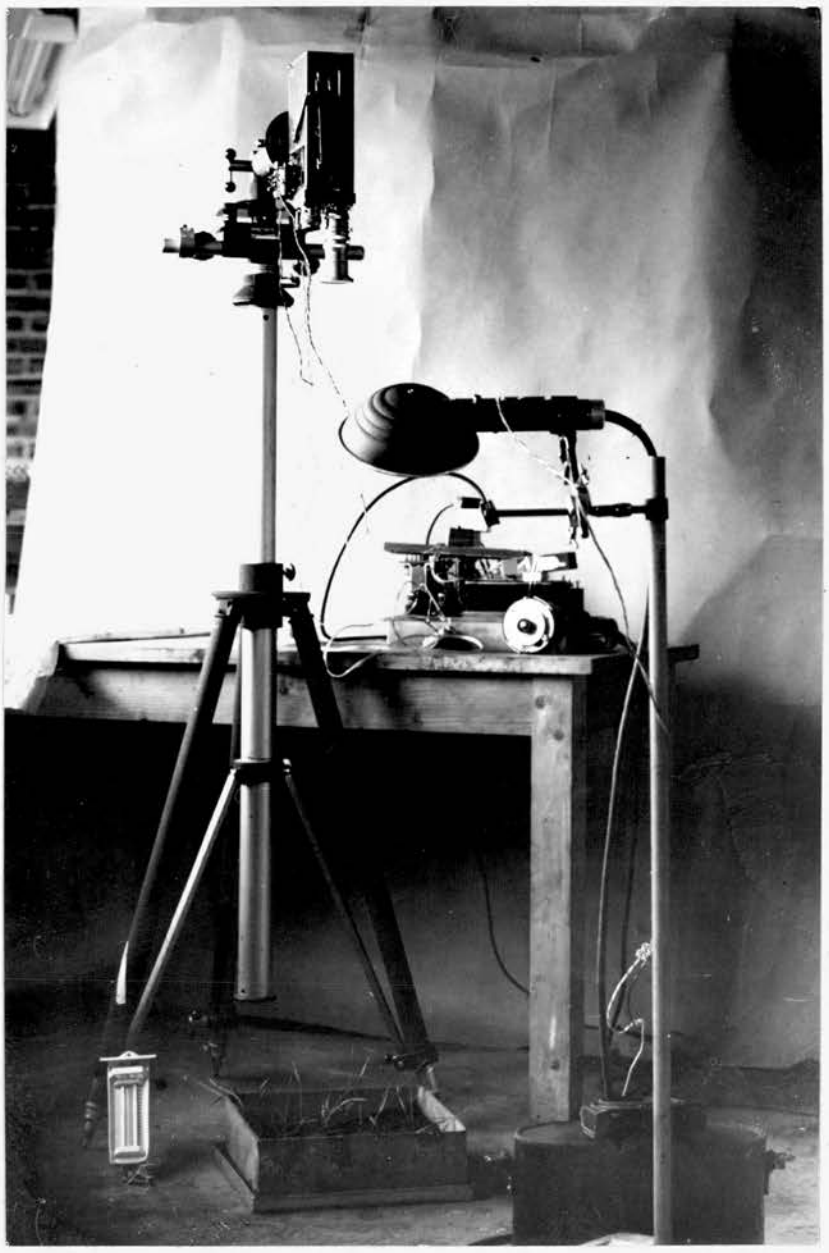


PLATE 9. The set up of the experiment for the investigation of the nocturnal behaviour of leatherjackets.

damage to barley (see 4.63), the same type of soil was used. The number of larvae added in this case was 14, to give the equivalent of a population of just over $\frac{3}{4}$ million per acre which is sufficient to cause considerable damage in a cereal field. The nightly maximum and minimum temperatures were recorded.

Each box during filming was placed on the floor of the insectary which had solid walls and roof except for wire gauze above a height of 3 feet on the north side only. The plants were thus protected from wind, and the internal temperature was the same as outside.

At the end of filming of each of the boxes the soil was examined and the larvae counted. There were 15 in the box with the sod from the field, indicating that it must have contained 5 larvae when collected. All 14 larvae from the prepared box were recovered.

A Kodak Cine special (16 mm) camera was used, set to expose single frames at 75 second intervals, timed by a Sangamo-Weston timer. Synchronisation of the electronic flash to fire when the shutter was fully open was conveniently arranged by a microswitch fitted to the rotary shutter (Plate 9).

The film recording took place in June. Each observation period started at 20·00 hours, G.M.T., when there was considerable daylight and it was continued until 06·00 hours, a period of 10 hours covering the whole period of darkness.

Black and white film failed to differentiate leather-jackets clearly against the similarly coloured soil. To get

better contrast the background was changed by sprinkling a thin layer of white sand over half the box leaving half the box normal soil as a control. The film records showed that the larvae seemed to avoid the white background and were more active on the brown soil. So, the idea of changing the background was dropped. Instead a colour film (Ektachrome commercial) was tried. This colour differentiation provided good records contrasting the larvae from the soil and was used for the remainder of the observations.

After processing, the film was analysed frame by frame on a Lytax 16 mm. analyser. The number of frames exposed per night was 484. For convenience of analysis, the screen was divided into 4 rectangles, and the activities in each rectangle were recorded separately. This procedure simplified viewing the film and ensured adequate concentration on each quadrant of the total so that no activities of the larvae were missed, a disadvantage of this procedure was that it necessitated viewing each record four times. Each observation period was ten hours, so in the final analysis the total activity was expressed in hourly periods.

The film was examined for the number of larvae on the surface and their mode of behaviour. The numbers of the frames were known and, therefore, the time at which each larva came to the surface, its movements and the duration of stay on the surface could be determined. The maximum number in any frame gave the percentage of a known population occurring on the surface. The distance between the tunnels from which a larva emerged and

the plant which it attacked was also determined. Some sub-surface activity was determined by movement of soil whenever traced. In addition to examination frame by frame the movement of larvae and of plants was more readily observed by running the film through the analyser at a low speed (8 frames per second).

Records were kept of:-

(i) The time of first appearance of larvae and when last seen on the surface.

(ii) Duration of presence of individual larvae on the surface.

(iii) Peak period of surface activity.

(iv) Number of larvae occurring on the surface at one time.

(v) Crawling and distance covered in time.

(vi) Occurrence and duration of surface feeding.

(vii) Distance of plants from tunnels and onset of feeding.

(viii) Mode of feeding

(ix) Sub-surface activity (traced by the movement of soil or plants)

(x) Sub-surface feeding.

Some of the nocturnal behaviour on the surface is summarised in Table 49.

All the numbers shown in Figs. 34 and 35 and Tables 48 and 50-53 are the number of occasions larvae were observed in the film in each hourly period against their respective types of behaviour. This represents the degree of activity by a known population of leatherjackets in a small area.

Surface and sub-surface feeding is summarised in Fig. 35

and Tables 50 and 53. Tables were analysed to show whether there was any variation in their hourly activities.

The distances between the points of exit from the soil and the nearest plants were observed and correlated with whether or not the larvae fed. The results are shown in Fig. 36 and Table 51.

The number of observations taken was 9 (9 nights), 3 in heavy-loam and 6 in sandy soil. The box with sandy soil was initially prepared for this experiment, the observations taken with the field soil were to show whether there was any variation between the two. Greater importance in statistical analysis was given to the hourly observations and the value of "F" between the two boxes shows the variation.

6.3 Results

Leatherjackets move sufficiently slowly that the time between frames of 75 seconds was not too long to enable the activities of a single larva to be followed. The electronic flash (about 1/1000 second duration) did not appear to affect the activities of the larvae.

6.31 Activity at or above the soil surface

The number of larvae at or above the soil surface was determined in hourly periods irrespective of their behaviour, and the results are shown in Fig. 34(a) and Table 48, from which it

is obvious that larval activity was well spread throughout the night, beginning at 20·00 - 21·00 hours G.M.T. and rising to a peak soon after at 21·00 - 22·00 followed by a gradual decline in activity which ceased at about 06·00 hours by which time it was daylight.

There was a slightly greater activity in box I than box II, significant at the 5 per cent level, but this might not mean anything as the two trials ran consecutively and not concurrently, and there was also one larva more in box I.

(i) Time of appearance and last seen on surface.

The time of appearance on the surface was observed earlier than in the laboratory experiment (see 4.63). The earliest arrival time was 20·10 hours, but on most of the nights larvae were not noticed until after 20·36 hours. I cannot suggest any reason for the short periods of activity on the 4th and 9th nights (Table 49).

On one night only a larva was on the surface as late as 05·08 hours, otherwise activity had ceased before 05·00 hours. 7·6 hours was the average period during which activity was observed over the 9 nights, quite a long period.

(ii) Duration of presence of a larva on surface.

Usually larvae remained on the surface for a short time. But occasionally they remained for a considerable period and this stay was associated with feeding. The maximum record of individual larvae on the surface varied from 28 to 120 minutes on different nights. This recorded presence does not mean that

TABLE 48

Number of larvae active on surface

Serial Nos. of the frames on the film	Time	Heavy loam				Sandy soil							Total of all	Mean	L.S.D. between two means
		1 Night	2 Night	3 Night	Total	4 Night	5 Night	6 Night	7 Night	8 Night	9 Night	Total			
1-48	20-21	7	2	1	10	6	0	3	3	4	0	10	20	2·22	
49-97	21-22	4	6	4	14	0	5	5	4	1	2	17	31	3·44	
98-145	22-23	3	3	5	11	1	3	1	5	1	4	15	26	2·88	a, 1·33
146-194	23-24	4	3	6	13	1	4	2	4	1	2	14	27	3·0	b, 1·85
195-242	24-1	4	1	2	7	3	2	6	4	3	2	20	27	3·0	
243-·90	1-2	4	1	2	7	4	1	7	2	1	0	15	22	2·44	
291-339	2-3	0	2	4	6	2	1	3	2	0	0	8	14	1·55	
340-387	3-4	1	1	3	5	0	1	4	1	2	0	8	13	1·44	
388-436	4-5	1	1	3	5	0	0	2	1	0	0	3	8	0·88	
437-484	5-6	1	0	0	1	0	0	0	0	6	0	0	1	0·11	
	TOTAL	29	20	30	79	11	17	33	26	13	10	110	189		

The value of "F" between the two boxes is 4·44, significant ($p < 0·05$)

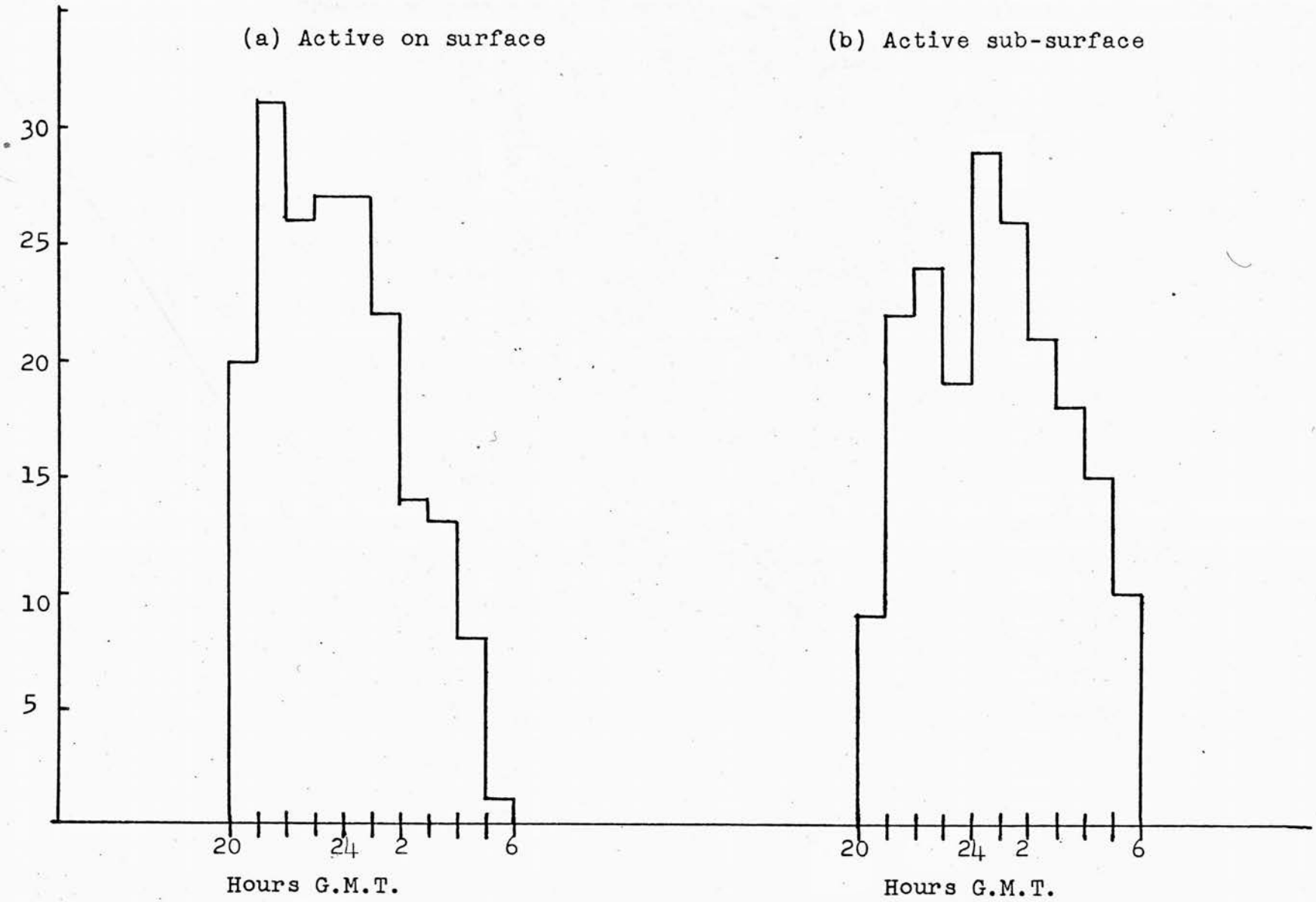


Fig. 34. No. of larvae active in different hours.

the whole body of the larva was exposed, but if even partly seen it was recorded.

(iii) Number of larvae occurring on the surface at one time.

The maximum number was 4 from a population of 14 and occurred at 03·04 hours. Finding up to 20 per cent of the population at a time on the surface was more common. This occurrence varied at different times each night, but was not found earlier than 21·00 hours or later than 03·42 hours.

(iv) Crawling and distance covered in time

Usually larvae were seen in the openings of their tunnels, the head end emerging and then retracting. Sometimes the whole body was out of the tunnel and the larvae moved around and then went in. The number of larvae crawling over the surface was very few. The maximum distance travelled by a larva was 11 in. in 11 minutes. In general the movement was sluggish and it varied from $\frac{1}{3}$ to $1\frac{1}{2}$ in. per minute.

(v) Occurrence and duration of surface feeding

It is obvious from the figures 34(a) and 35(a) that less than half of the total active larvae on the surface were feeding. Statistically there is no significant difference between two consecutive one hourly periods of feeding (Table 50), but Fig. 35(a) shows that feeding was certainly more from 21·00 to 02·00 hours. There was also no variation between the total larvae feeding in the two boxes.

TABLE 49

Showing some of the nocturnal behaviour of leatherjackets on the surface

Nights of filming	First seen on the surface	Last seen on the surface	Maximum time stayed on surface by any one larva in minutes	Maximum number of larvae at a time on surface		Distance travelled in time		Min. temp. in °F	Max. temp. in °F
				No. of larvae	Time observed	Distance in inches	Time in minutes	during the 10 hours	
1	21.18	05.08	50	3	00.27 to 00.46	5	11	50	53
2	20.37	05.01	63	2	more than once			51	52
3	20.10	04.46	76	3	22.30 and 03.42			51	53
4	00.09	02.09	28	2	00.09 to 00.14	9 3	28 2	55	56
5	21.16	03.30	39	2	21.46 to 21.56			56	59
6	21.47	04.32	51	4	03.04	4	6	54	60
7	20.36	04.37	120	3	21.55 to 22.08 and 01.07 to 01.17			53	59
8	20.15	03.57	60	1	many times			54	60
9	21.40	03.22	32	3	22.25 to 22.30 and 00.28 to 00.33	11	11	53	60

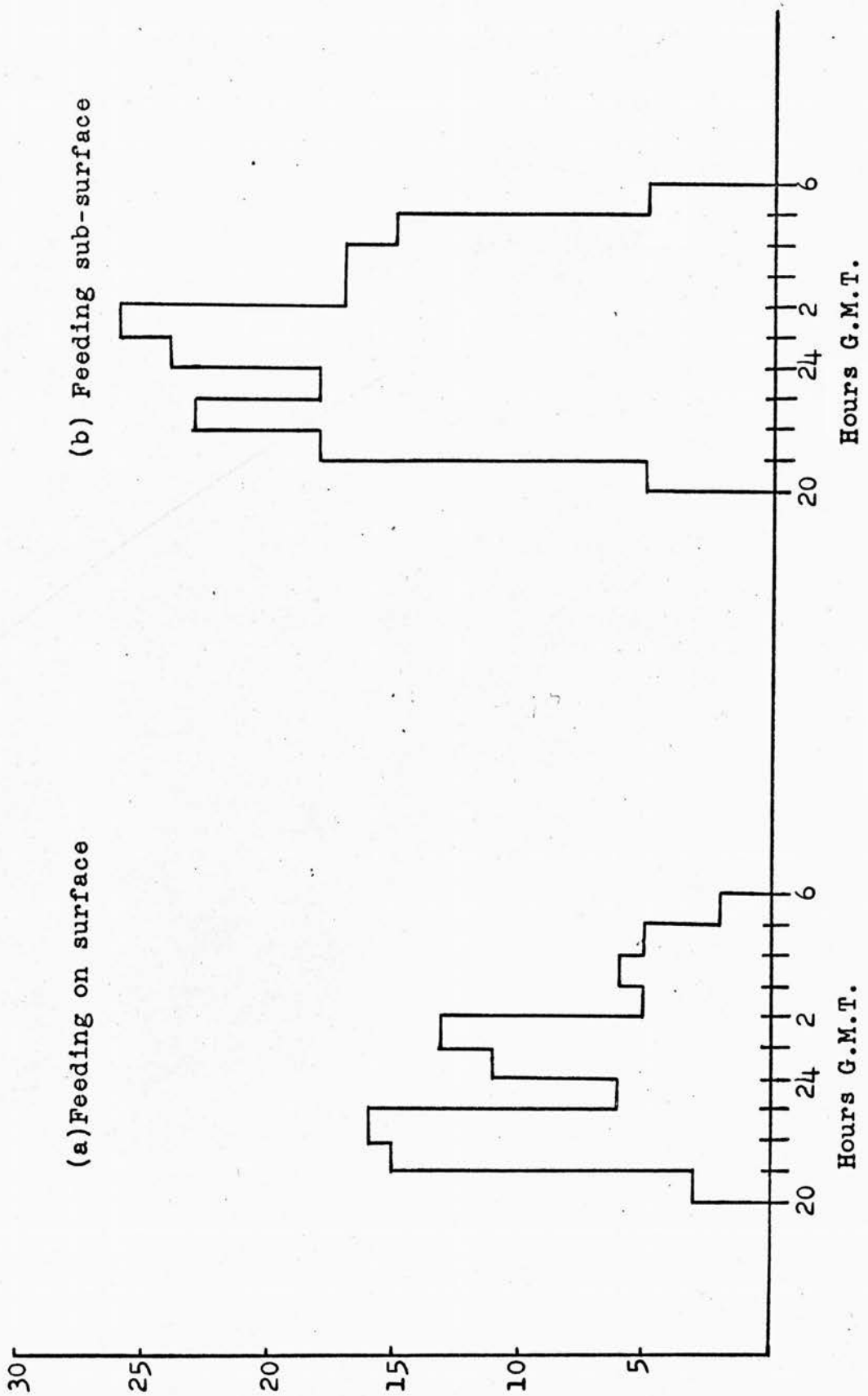


Fig. 35. No. of larvae feeding in different hours.

(vi) Distance of plants from the tunnel and onset of feeding.

From Fig. 36 and Table 51 it is evident that the feeding of a larva is dependent on the distance of the nearest plant from its tunnel. The nearer a plant was to the tunnel the more the feeding observed. All the larvae started feeding which came out at the base of a plant (0· mm.). The value of "F" is significant and also the number of larvae feeding at 0· mm is significantly more ($p < 0·01$; see the value of 'a' and 'b' in Table 51) than at any other distance. No feeding was noticed on a plant 30 mm. away from the tunnel, except in one case where a larva moved a distance of 110 mm. and attacked a plant, though the nearest plant was at a distance of 35 mm. This result also indicates that most of the larvae live below the plants and near to their food. This was also noticed in the field observations where the maximum number of larvae occurred in samples containing plant material.

(vii) Mode of feeding

In surface feeding, each larva appeared, attacked the nearest leaf or stem and went on feeding. In the case of a leaf, it often cut off the tip or pulled the leaf into its burrow, as a result of which the distal part of the leaf was half burried in soil and was eaten in the burrow. Sometimes a larva gnawed the leaf bit by bit and the ultimate injury was shredding or cutting. In the course of feeding a larva would often disappear into the burrow and reappear again at the same spot and gnaw the same leaf or stem in the same part previously attacked. Whether it was the

TABLE 50

Number of larvae feeding on the surface

Serial Nos. of the frames on the film	TIME	Heavy loam				Sandy soil							Total of all
		Night 1	Night 2	Night 3	Total	Night 4	Night 5	Night 6	Night 7	Night 8	Night 9	Total	
1-48	20-21	0	0	1	1	0	0	0	1	1	0	2	3
49-97	21-22	1	8	1	10	1	1	1	1	1	0	5	15
98-145	22-23	2	3	2	7	0	2	1	4	1	1	9	16
146-194	23-24	0	0	1	1	0	0	1	2	0	2	5	6
195-242	24-1	4	0	2	6	0	1	1	1	1	1	5	11
243-290	1-2	4	0	0	4	0	1	5	2	1	0	9	13
291-339	2-3	0	0	2	2	0	2	1	0	0	0	3	5
340-387	3-4	0	0	2	2	0	1	3	0	0	0	4	6
388-436	4-5	0	0	2	2	0	0	2	1	0	0	3	5
437-484	5-6	0	0	0	0	0	0	0	2	0	0	2	2
	TOTAL	11	11	13	35	1	8	15	14	5	4	47	82

Value of "F" is 1·77 which is not significant

Difference between two hours is also not significant.

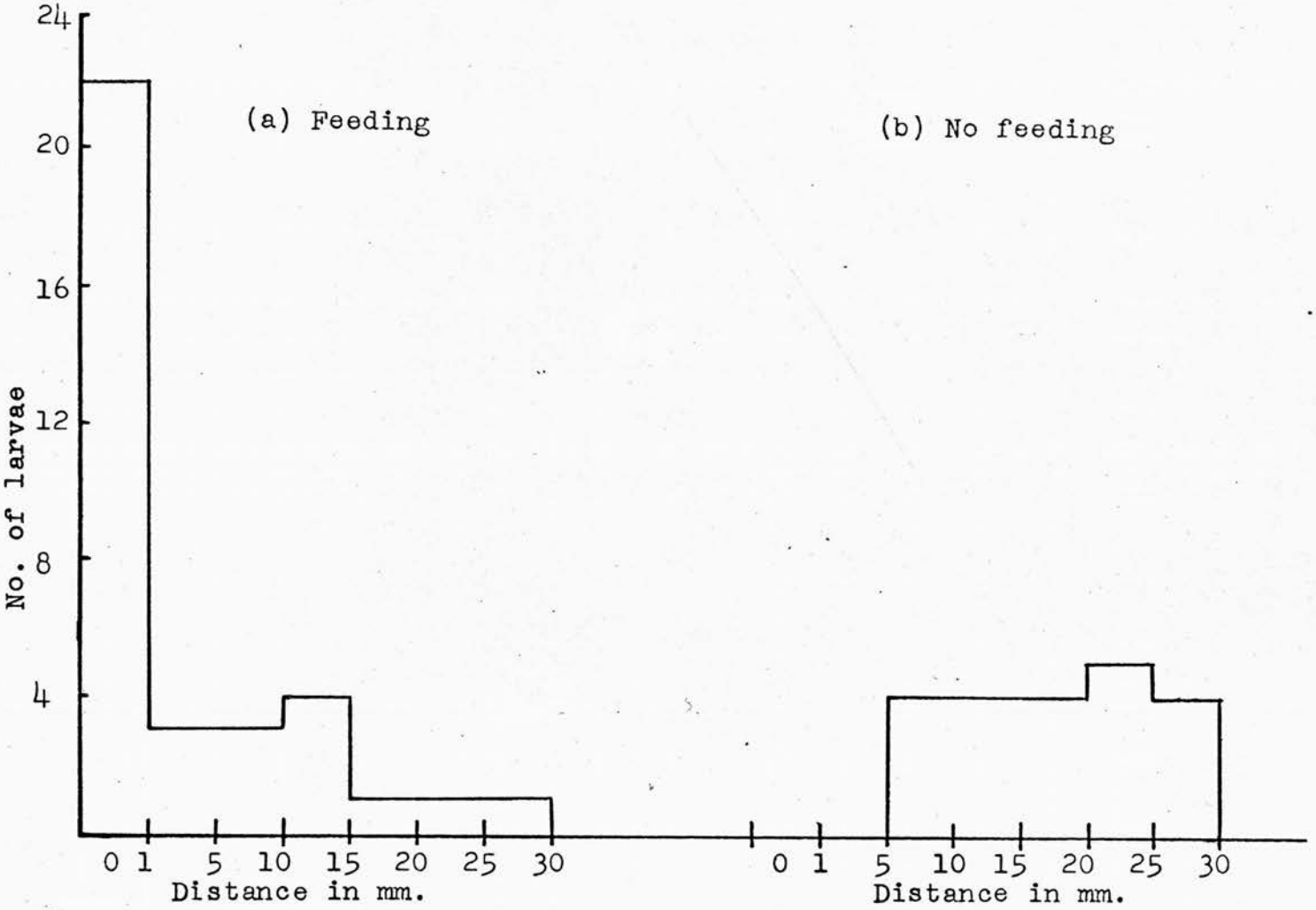


Fig. 36. Showing number of larvae which appeared and the distance to the nearest plant in mm.; whether larvae started feeding or not.

TABLE 51

Distance to nearest plant from the tunnel from which larvae appeared

No. Nights	No. larvae started feeding at distances mm.							No. larvae did not feed, distance in mm.								L.S.D. between two distance means
	0	1-5	6-10	11-15	16-20	21-25	26-30	1-5	6-10	11-15	16-20	21-25	26-30	31-40	45-over	
1	2	1	1						1	1						
2	9									1						
3	3	2	1	2						1					2	
4	0			1							1				0	a, 0·80 b, 1·05
5	1								1	1		1			1	
6	2			1	1	1					2	2	1	1	1	
7	3								1			2	3		0	
8	0		1				1								1	
9	2								1		1			1	2	
	22	3	3	4	1	1	1	0	4	4	4	5	4	2	7	

The value of "F" between feeding and not feeding is not significant.

same larva could easily be ascertained from the film by tracing the underground movement till reappearance. Frames 49 to 112 of the film of night 2 demonstrated well the way a larva feeds.

6.32 Sub-surface activity

It was difficult to determine definitely all the sub-surface activity of larvae. There were two indications: (a) movement of a plant (b) movement of the soil.

When the larvae were moving just below the soil, the movement was clearly noticed, but if they had gone too far below, it was very difficult to locate them. So the total sub-surface activity as shown in Fig. 34(b) and Table 52 is likely to be far below that which actually occurred.

A comparison of Fig. 34(a) and (b) indicates that the activity that could be observed underground agrees with that on the surface, in that it increases to a maximum a little after midnight (00·12 G.M.T.) and then decreases to cease about dawn.

There was no significant difference between activity in boxes I and II.

Sub-surface feeding

The boxes for filming were placed on the floor of the insectary surrounded by brick walls. There was no possibility of wind causing movement of the individual plants. It was therefore assumed that movement of a plant was caused by the underground activity of a larva. When a continuous movement was noticed, it was presumed that a larva was feeding. Plants moved sideways as the larvae pushed and pulled them. Eventually

TABLE 52

Number of larvae active sub-surface

Serial Nos. of the frames on the film	Time	Heavy loam				Sandy soil							Total of all	Mean	L.S.D.
		Night 1	Night 2	Night 3	Total	Night 4	Night 5	Night 6	Night 7	Night 8	Night 9	Total			
1-48	20-21	0	0	0	0	1	2	2	3	1	0	9	9	1	
49-97	21-22	1	1	1	3	4	4	4	4	3	0	19	22	2·44	
98-145	22-23	3	2	3	8	1	5	2	4	3	1	16	24	2·66	
146-194	23-24	1	0	4	5	1	3	3	4	3	0	14	19	2·11	a, 1·15
145-242·0	24-1	2	3	6	11	1	6	5	4	2	0	18	29	3·22	b, 1·52
243-290	1-2	3	1	5	9	4	5	2	4	2	0	17	26	2·88	
291-339	2-3	3	0	3	6	2	6	1	3	3	0	15	21	2·33	
340-387	3-4	0	0	5	5	3	3	3	2	2	0	13	18	2·0	
388-436	4-5	0	1	2	3	2	4	5	1	0	0	12	15	1·66	
437-484	5-6	4	0	1	5	1	0	2	2	0	0	5	10	1·11	
	TOTAL	17	8	30	55	20	38	29	31	19	1	138	193		

The value of "F" between boxes is 2·72, non significant.

TABLE 53

Number of larvae feeding sub-surface

Serial Nos. of the frames on the film	Time	Heavy loam				Sandy soil							Total of all	Mean	L.S.D.
		Night 1	Night 2	Night 3	Total	Night 4	Night 5	Night 6	Night 7	Night 8	Night 9	Total			
1-48	20-21	0	0	0	0	1	1	1	2	0	0	5	5	0·55	
49-97	21-22	1	1	2	4	2	5	1	4	2	0	14	18	2·0	
98-145	22-23	3	0	3	6	1	6	3	4	2	1	17	23	2·55	
146-194	23-24	1	2	3	6	1	4	2	3	2	0	12	18	2·0	a, 1·01 b, 1·34
195-242	24-1	2	3	7	12	1	4	3	3	1	0	12	24	2·66	
143-290	1-2	3	1	6	10	4	4	2	5	1	0	16	26	2·88	
291-339	2-3	3	0	3	6	3	4	3	1	0	0	11	17	1·88	
340-387	3-4	0	1	5	6	3	2	3	2	1	0	11	17	1·88	
388-436	4-5	0	0	3	3	3	3	4	2	0	0	12	15	1·66	
437-484	5-6	0	0	1	1	1	0	1	2	0	0	4	5	0·55	
	TOTAL	13	8	33	54	20	33	23	28	9	1	114	168		

The value of "F" between two boxes is <1, non significant.

after cutting a stem, a larva would pull the plant into the burrow. In previous insectary experiments it had been observed that plenty of plants were so pulled into the soil. Many times cut leaves completely disappeared from the surface as the larvae pulled them into the tunnels.

Fig. 35(b) shows that feeding activity under the surface follows the same pattern as general sub-surface activity, increasing until about 01·00 hours and then gradually decreasing until it ceased about dawn. In fact most of the observations under general activity were actually evidence of feeding as indicated by disturbance of the plants, hence graphs 35(b) and 35(b) are very similar. Again there was no difference between sub-surface feeding in boxes I and II.

6.4 Discussion and conclusions

The results give information on the activity of larvae in a population sufficient to cause damage to a cereal crop.

Compared with similar work by Newell (1966) on slugs, there was not found to be any definite sequence of activities by the leatherjackets.

Activity and feeding both above and below ground commenced shortly after dark and continued to near dawn. Owing to the walls and roof of the insectary, however, it would become dark slightly earlier and remain so slightly longer than outside and so the total period of observed activity might have exceeded

slightly that in the field. The maximum activity was reached shortly after midnight (times are in G.M.T. and so midnight at Edinburgh is at 00·12 hours) and remained fairly high for 3 to 4 hours in all, falling off quickly by about dawn. Most larvae remained only a short time on the surface, those remaining longer up to 2 hours were engaged in feeding. The maximum proportion of the population on the surface at one time was about 20-25 per cent. This is correlated with the fact that more activity was recorded below the surface, even though the technique used may not have detected activity which was not very near the surface.

Most larvae seemed to live in the neighbourhood of the plants and most came to the surface close to them. The distance to the nearest plant from the point of exit from the soil determined the onset of feeding, larvae emerging near plants starting to feed and those further from them often failing to feed. The movement of larvae was slow; and, as most seemed to live close to the plants, there was no necessity for much movement. The greatest distance moved was recorded as 11 in. and the speed was up to 1½ in. per minute. The larvae did not show any evidence of disturbance by the electronic flash.

SECTION 7. SOIL PREFERENCE OF T. PALUDOSA IN OVIPOSITION

7.1 Introduction

Leatherjackets are more abundant in the wetter parts of the country. The rainfall is of considerable importance, especially when they are in the first and second instars. Desiccation causes high mortality to eggs (Laughlin, 1958; Milne et al. 1965). Soil types have different water holding capacity. It might be a factor that females lay eggs more in lighter soil, but as the mortality is high due to less water holding capacity, this fact remains unnoticed. So, it was decided to provide the females with four different types of soil to see whether there is any preference in egg-laying.

7.2 Material and method

Three wooden frames (measuring 20 x 19 x 24 in.) were covered with polythene bags (Plate 10). Numerous holes were made for free ventilation. Each frame was put over a set of 4 tins (9 x 8½ x 4½ in. deep). Each tin was fitted with a turf from a field with clay, loam, sand or peat soil, the soil surface being level with the edges of the tins, so that they provided no barrier between the turves. The vegetation was cut to a uniform height of 5 in., and a note was made of the species of plants present. The weight of each tin as prepared was noted.

PLATE 10. One of the frames which housed the 4 different types of soil for the experiment in oviposition.

Randomization:- The randomization came out as shown in Figure 37.

Frame I		Frame II		Frame III	
Peat (P_3)	Loam (L_1)	Sand (S_3)	Clay (C_1)	Loam (L_3)	Sand (S_1)
Sand (S_2)	Clay (C_2)	Peat (P_1)	Loam (L_2)	Clay (C_3)	Peat (P_2)

Fig. 37. The randomization of tins in each frame.

All these frames with tins were put on a cemented table in the centre of an insectary exposed to outside air temperatures.

Release of adults:- Five females and 5 males 2 to 3 days old were put in each cage in the afternoon. Adults were reared in the laboratory from collected larvae. Mating was noticed just after the release of the adults (1 pair in F_I, and 1 pair in F_{II}). They were left for 5 days. Afterwards tins were taken away from the frames for soil examination for eggs.

Washing of soil:- The soil was broken down by hand and the vegetation was separated. The vegetation was washed in two buckets of water in succession. The eggs are heavier than water and were recovered by sieving with sieves of 8, 30, 50 and 100 mesh per linear inch. The sieves with contents were immersed in

magnesium sulphate solution so that the eggs floated up for collection. Eggs however were found only in the 50 and 100 mesh sieves.

7.3. Results

The number of eggs laid in the different soils are shown in Table 54. The result of the experiment is not significant. But numerically sandy soil had the maximum number of eggs. There is just a significant difference as indicated by the " t " test ($p < 0{\cdot}05$) between sandy soil and peat, and the difference between sandy soil and clay is very near to significance.

TABLE 54

The number of eggs recovered from each type of soil after washing.

Frame No.	Sand	Loam	Clay	Peat
1	176	201	134	170
2	388	176	127	70
3	148	36	30	50
TOTAL	712	413	291	290
Mean	237·33	137·66	97·0	96·6

The value of "F" = 2·66 between two treatments (not significant). Least significant difference between treatment means = 140·65 when $p = 0{\cdot}05$.

The experiment was repeated and the results are shown in Table 55.

TABLE 55

The number of eggs recovered from each type of soil after washing

Frame No.	Sand	Loam	Clay	Peat
1	617	225	397	112
2	701	153	341	60
3	741	76	120	197
Total	2059	454	858	369
Mean	686·33	151·33	286·33	123·0

The value of "F" = 18·30 between two treatments, significant ($p < 0·01$). The least significant difference between treatment means = 209·27 when $p = 0·05$ and 316·90 when $p = 0·01$ respectively.

The result shows that the number of eggs laid in the sandy soil was aignificantly greater ($p < 0·01$) than in any of the other soils, but that there were no significant differences between the numbers laid in the peat, loam or clay soils.

7.4 Discussion and conclusions

There were many more eggs in the 2nd experiment. This was because in frame 3 of the first, one female died without laying eggs, so in the repeated experiment the number of males was doubled (10). A female can mate with more than one male and lay eggs the same night and can mate and lay again on a subsequent night (Rennie, 1916; Laughlin, 1967). This may account for the greater number of eggs in the second experiment.

There could be two possible reasons why females lay more eggs on sandy soils:-

(i) The soil surface has less dense vegetation which facilitates the oviposition of the fly in the soil.

(ii) Sandy soil must be easier in which to insert the ovipositor, as females deposit eggs in the soil (Rennie, J. 1916).

SECTION 8. VIRUS DISEASES OF LEATHERJACKETS

8.1 Introduction and review of literature

8.11 Nuclear polyhedrosis virus.

Rennie (1923) reported for the first time a virus disease in T. paludosa. The disease is recognizable in the advanced stage of infection. As the disease progresses the normal earthy colour of the larva becomes pallid, finally chalky white. When the skin of an infected larva is pricked, an immediate flow of milky white fluid exudes. On microscopical examination, the fluid is found to be thickly charged with innumerable irregularly shaped colourless highly refractile bodies. Besides blood cells are also seen numerous detached fat-cells within many of which may be seen similar refractile, crystal-like particles.

(i) Development of virus:

Rennie (1923) gives in detail the following developmental stages of polyhedra as the size of the infected cell becomes enormous. (1) The nuclear chromatin is gathered in granules that form grape-like clusters surrounded by a clear ring. These granules are later found on the periphery of the nucleus. The cytoplasm consists of but a thin layer. (2) A chromatin mass or masses, sometimes 2 or more in number and rounded in form, appear in the body of the nucleus. The remainder of the nucleus is granular in appearance, and the cytoplasm has almost disappeared. (3) The polyhedra appear symmetrically in a ring-like form on the surface of the central mass. They are usually triangular in shape and

are sharply angled, sometimes they appear regularly crescentic, resembling the segment of an orange. (4) The polyhedra then become massed in one hemisphere of the nucleus. At this stage their shape is more or less ovoid, but they never become symmetrical. (5) Finally the hypertrophied nucleus bursts, liberating the polyhedra into the blood. The common size of polyhedra is 5-10 μ, in Tipula rather smaller. They are heavier than water.

Smith et al. (1954) rediscovered this disease in England. They compared this disease with the nuclear polyhedrosis of lepidopterous larvae (more particularly Phlogophora meticulosa).

(ii) Chemical composition.

The polyhedra do not contain any fat (Rennie, 1923). They are primarily protein crystals (Smith and Williams, 1958) within which several hundred virus particles are included. The released polyhedral bodies are readily obtained in pure form by gentle sedimentation and decantation of a water suspension of the contents of the bodies of infected insects. The pure virus particles are highly infective.

8.12 Tipula iridescent virus (TIV)

TIV was first reported by Xeros (1954). This cytoplasmic disease is primarily of the larval fat-body. No multiplication of the cells of the fat body is involved and inclusions in fat cells are formed as a result of the disease. The fat body appears purple in strong sun-light, through wetted skin. In the course

of the disease the lobules of the body distend enormously and the tissue becomes nodular. The nodules are orange in transmitted light and iridescent, purple, blue, green etc. in reflected light. The animal when moribund becomes purplish-white in colour with the disruption of diseased fat cells and the liberation of their contents into the blood. Death occurs at 2-4 weeks or more after the disease becomes detectable. As many as 15 per cent of a low density natural population of Tipula larvae were found to have the disease, which appears to be less virulent than polyhedrosis of lepidopterous larvae.

(i) Structure of TIV.

Xeros (1954) says the virus particles measure 100 mμ. Virus bodies are not simple spheres, but are somewhat irregular in shape and composite, many smaller particles being embedded in each. They look like cytoplasmic polyhedrosis of the mid-gut of lepidopterous larvae rather than rod-shaped nuclear polyhedrosis viruses. Williams and Smith (1958) investigating the structure of TIV concluded that the virus particles are of uniform 130 mμ in size, the shape is not polyhedral but icosahedral.

The virus particles occur in enormous quantities in the fat-body of the infected insect, and no less than 25 per cent of dry weight of the larva is converted into virus (Williams and Smith, 1957).

(ii) Chemical composition of TIV

The extraction and purification of the elementary particles from the diseased insects are fairly easy, (Smith and Williams, 1958).

Immediately after death has ensued, the cadavers are simply placed in water, and they are left for a few days there when the virus particles leach out. A brief low speed centrifuging removes the gross-material, and repetition of low and high speed centrifuging will form the virus particles into a pellet of fairly pure material which is highly infective to healthy larvae.

From the preliminary chemical analysis by Smith and Williams (1958) it appears that virus particles consist of nucleoprotein. The nucleic acid portion is all of the deoxy type and constitutes about 15 per cent of the mass of the virus. Thomas (1961) has shown that TIV contains 12·4 per cent DNA and 5·2 per cent lipid. The remainder of the virus material appears to consist mostly, or perhaps entirely of protein including some phosphoprotein. Thomas and Williams (1961) did further investigation on DNA and protein in TIV.

(iii) Development of virus in T. paludosa

In the study of this virus with the electron microscope using ultra-thin sections, Smith (1956) showed that each virus particle is surrounded by a membrane and is often hexagonal in section. Moreover, numerous apparently empty membranes of approximately the same size as the virus particle frequently occur. These empty membranes are most numerous in the early stages of infection. Later on an apparent primary body, which may be thread-like in its initial stages, develops in the centre of the membrane. This primary body increases in size until the membrane is filled, and the various steps in this process can easily be

seen. Smith (1958) and Smith and Hill (1959) suggested that the formation of the empty membranes and the apparent gradual development of their contents are the means by which the virus multiplies. It has been confirmed by Xeros (1964) that empty viral membranes take part in the development of normal virus particles. Though the initial site of virus multiplication is the fat body, as the disease progresses, and the amount of virus increases, invasion of other tissues and organs takes place (Smith et al. 1961). In addition to the fat body Xeros (1964) showed that virus development may occur in the muscles of infected larvae. Anderson et al. (1959) even showed the presence of TIV in the "skin" of T. paludosa.

(iv) Cross-inoculation of TIV

TIV is unique in the sense that from an infected larva it could be isolated in a pure form as a brilliantly iridescent pellet (Smith and Williams, 1958). This facilitates cross-inoculation studies. Smith and Rivers (1959) made cross-transmissions with a number of species of Tipula other than original host species i.e. T. oleracea, T. livida and several other unidentified species of Tipula. Two infection methods were used, by ingestion of a drop of purified virus and by injection. All insects treated became infected. Other species infected were Pieris brassicae, Bibio marci and Tenebrio molitor. The injection method is the more successful of the two. In further cross-inoculation studies Smith et al. (1961) have shown that a total of seven species of Diptera, eleven species of Lepidoptera and three species of Coleoptera can be infected. The fat body is the initial

site for virus multiplication but the virus also multiplied in the skin, muscles, wing buds, legs and head.

From the previous literature, it is evident that a large amount of information has already been obtained about both the nuclear polyhedrosis and TIV diseases of Tipula larvae. Most of these studies are on the structure, chemical composition, and development of the viruses in the infected host. Very little work has been done so far on the transmission of these viruses from infected to healthy larvae though it is known that they are highly infective by ingestion and injection (Smith et al. 1961). Smith and Williams (1958) point out that viruses are mostly if not wholly spread from diseased to healthy larvae by the ingestion of contaminated food. The efficiency of spreading is greatly increased by the way viruses are contained in granules and polyhedral bodies which may retain their infectivity for several years. On the other hand, the nuclear polyhedral viruses are quite labile after removal from their protein matrix. The manner of the development of nuclear polyhedrosis is also favourable to the spread of disease; the skin of the diseased insect ruptures on death and the liquefied contents of the body get splashed by rain upon plants used for food by healthy larvae. TIV can leach out of a dead larva and can contaminate the soil. In addition in some cases the healthy larvae are strongly attracted by the liquefying cadavers, on which they feed with devastating results.

The way in which cytoplasmic polyhedroses are developed, however, is not so favourable to the spread of disease. But

presumably they are ingested with the food (Smith and Williams, 1958). There is some evidence that cytoplasmic polyhedral virus from Arctia caja (garden tiger moth) (Smith, 1951) and granulosis virus affecting the caterpillars of Pieris brassicae (Large white butterly) (Smith and Rivers, 1956) are transmitted through eggs. There is no evidence yet to say that any of the two viruses can be transmitted through eggs with which we are concerned here.

8.2 Occurrence of diseased larvae in the field

The field study of leatherjackets from 1964-5 to 1966-7 shows that the incidence of both the virus diseases is widespread in South East Scotland. It has already been reported that a number of diseased larvae occurred in Mavis Hall (see 2.32) and also in earlier experiments (see 4.615) both in larvae collected from the field and laboratory reared ones later put into field soil.

Two 3rd instar larvae, suffering from TIV were recorded in the Balerno field (Table 1) out of 42 larvae collected by the St. Ives method in the last week of February (1966). This is the highest percentage (4·7) so far recorded in a field here. In a group of 35 larvae, reared in the laboratory to obtain adults, the incidence of TIV was recorded in late 4th instar larvae (Plate 12) and some in pupae with deformed wing buds and showing clearly the iridescent colour of virus infection (Plate 15). The larvae were collected from Crofthead Farm (Table 1) and reared in two perspex cages (20 and 15 per cage). No infected pupae

PLATE 11. Normal larva.

PLATE 12. Larvae suffering from Tipula iridescent virus, showing the blue iridescence.

PLATE 13. Larva suffering from nuclear polyhedrosis virus, showing the whitish colour.

PLATE 14. Normal pupa.

PLATE 15. Deformed pupae with obvious signs of Tipula iridescent virus infection.

or larvae reached the adult stage. Only nine adults (4 + 5) emerged from both the groups and 15 (9 + 6) showed clear signs of infection with TIV. The rest of them must have died due to cannibalism. From the experimental field in Crofthead Farm, 2 larvae were found suffering from polyhedrosis and 1 from TIV in the same plot (C_6). One larva was sent to Mr. Rivers who confirmed the presence of some TIV in the polyhedrosis diseased one.

In 1967, in the experimental field on South Mains Farm, five larvae, collected throughout the whole season, were suffering from polyhedrosis disease. One larva (15.6.67) was found on the surface, almost moribund, and obviously unable to burrow into the soil. The body was completely chalky white. Apart from the above, while studying beetle population (see 9.1) two larvae were found in the traps suffering from nuclear polyhedrosis.

Some larvae reared in the Golf course (adjacent to the laboratory) in 1965 also showed the presence of TIV and nuclear polyhedrosis in the later 4th instar.

This record of nuclear polyhedrosis disease is the second in Scotland (after Rennie, 1923) and third in Great Britain, and the incidence of TIV the first in Scotland and second in this country (after Xeros, 1954). The report was confirmed by Longworth.

It would not be out of place to mention that no larva was found to harbour the parasitic fly Bucentes geniculata (Rennie and Sutherland, 1920; Lovibond, 1937) nor the Mermithid parasite Mermis albicans (Rennie, 1926) which have been reported in the North of Scotland.

8.3 Experiments on virus transmission

Attempts have been made to investigate the way a virus is transmitted from a diseased to a healthy larva. There are two possibilities (1) ovarian transmission as in the case of Arctia caja (Smith, 1951), or (2) ingestion of virus particles with food material.

8.31 Ovarian transmission

8.311 Material and method

A. (a) The first trials (6.8.65) were made with pupae (3 males and 2 females) washed well in distilled water and dipped in a suspension of virus for 3 minutes, and a control treatment was also kept, where the pupae were dipped in sterilized water.

(b) The same number of pupae, male and female, were pricked with a very fine entomological pin (No. 0056 x 10) just behind the wing buds on the ventral side. Pins were sterilized before use. A camel hair brush was dipped in TIV suspension and the wet brush rubbed against the wounds. A control treatment was also kept, but the wound was rubbed with sterilized water.

In these trials TIV only was used.

(c) In this and the following treatments both the viruses were used. Both the virus suspensions were obtained in a purified state from the Insect Pathology Laboratory, Oxford. The nuclear polyhedrosis contained 542 million polyhedra per ml. In the injection process, to check the death rate caused by extraneous

bacteria, 200 i.u. of penicillin and 200 i.u. of streptomycin per ml. (Smith et al. 1961) were added to the inoculum.

Two doses (i) 0·01 ml. per pupa, (ii) 0·002 ml. per pupa, were injected into two groups of pupae with 5 (3 male + 2 female) in each group, the same treatments being applied to both the virus groups. Another group of 5 was kept as a control. Injection was made just below the integument in the ventral thoracic region.

All the pupae, used for these treatments and the pupae of the TIV only treatments were put in sterilized sponge, a hole being made in each piece to accommodate a pupa. The sponge was kept moist. All of them were put in rearing jars, each treatment separately. All pupae used were 1-2 days old.

B. The same doses for injection were used against 3 male and 3 female adults. Both the viruses were used in this case too, and adults were also 1-2 days old, and laboratory reared. They were also put in rearing jars.

8.312 Results

A. (a) One female, with a swollen abdomen and obvious signs of virus infection, emerged 12 days after injection and was found lying near the pupal case. Three males emerged after 11 days, one with deformed wings, last abdominal segments swollen and very passive; other two were also less active. They were put with healthy females but no mating was noticed, they died in 3-5 days. One female pupa died with virus without emerging.

All pupae in the control emerged.

(b) Pricked pupae showed more signs of virus infection. One male emerged after 10 days and died after another 5 days without mating. Only one female emerged after 12 days with very swollen abdomen and died soon after. All other pupae failed to emerge.

One female in the control died.

(c) Of the pupae inoculated on 27.7.66 with 0·01 ml. of the TIV suspensions, one female died on 28.7.66 the other two on 31.7.66; the two males died on 5.8.66. Virus infection was usually noticeable on the 4th day after injection. The same results were obtained with 0·002 ml. group, no adults emerging.

All the pupae injected with polyhedra also died.

B. The injected adults were put in pairs two days later, but all died of virus infection, the bodies being swollen.

These results were very disappointing in that no fertile eggs were obtained to test for the occurrence of germinal transmission, but clearly showed the effectiveness of the virus by immersion and injection methods in pupae, as had been observed by Smith et al. (1961).

8.32 Transmission through ingestion of food

8.321 Material and method

A. Five polypots with sterilized sand were used in each of the following treatments which were applied with both the viruses.

(a) Soil infected with virus (later named SIT in case of TIV, and SIP in case of polyhedrosis)

One fifth ml. of purified virus suspension was mixed with the surface sand in each polypot and in each five second stage larvae (1-2 days old) were released. The larvae were fed on sterilized dried grass scattered over the surface.

(b) Grass infected with virus (later named GIT, in case of TIV, and GIP in case of polyhedrosis)

One ml. of virus suspension was mixed with 500 mg. of dried grass and then equally divided and scattered over the sand surface of 5 polypots and five second stage larvae were released in each. The larvae were allowed to feed on the contaminated grass for one week and then the sand was changed.

(c) Dead infected larvae fed to healthy ones (later named DFT in case of TIV, and DFP in polyhedrosis)

In the case of TIV, two dried dead bodies of infected larvae were broken up and scattered on the surface of the sand, the healthy second instar larvae were allowed to feed for a week and then the sand was changed, and normal dried grass was provided.

In the case of polyhedrosis, a diseased larva still just alive was chopped and, along with the milky fluid which exuded, was put on the surface of the sand, and five larvae were allowed to feed.

(d) Control

Larvae in this group were put into polypots and were allowed to feed on dried grass.

Thereafter the sand in all the polypots was washed once per week, and twice per week dried grass was added as necessary throughout the experimental period.

The groups of experiments with the two viruses were kept completely separated from each other and from the controls.

8.322 Testing field soil

In this set of experiments 10 porcelain pots (4½ in. diam. 5¾ in. high) were used for each of the following two treatments.

(a) Sterilized soil from the field which was used for the 1966 field experiment was used to rear 10 second stage larvae in each pot.

(b) As in (a) except that the soil was not sterilized.

8.323 Results

8.3231 Polypot experiments with sand - TIV

Weekly observations were made throughout the larval stages. The experiment was started on 29.8.66, and at the first observation infection had already occurred with the iridescent virus. There were five infected larvae in treatment SIT and 8 in the DFT treatments. Diagnosis was always made by observing the change in colour of the larvae as there is no other way available.

It is obvious from the Figs. 37 and 38 that the rates of virus infection and mortality were higher in the SIT and DFT

TABLE 56

Mean number of larvae which died and adults which emerged in each treatment, and values of "F" between treatments (TIV)

Treatments	Death from virus in instars			Value of "F"	Death due to cannibalism in instars			Value of "F"	Adults emerged	Value of "F"
	2	3	4		2	3	4			
SIT	1·2	0·2	0·2		1·6	0·6	0·4		0·6	
GIT	0	0·4	0·4	18·51**	1·2	1·2	0·2	1·9	1·6	10·76**
DFT	2·4	1·4	0·2		1·0	0	0		0	
Control	0	0	0		0·4	1·2	1·4		2·0	
Variation between instars within treatments		₱ 7·4				* 2·46				

₱ Value of "F" Highly significant (p = 0·01)

* Value of "F" Significant at 5 per cent level (p = 0·05)

** Highly significant (p = 0·01).

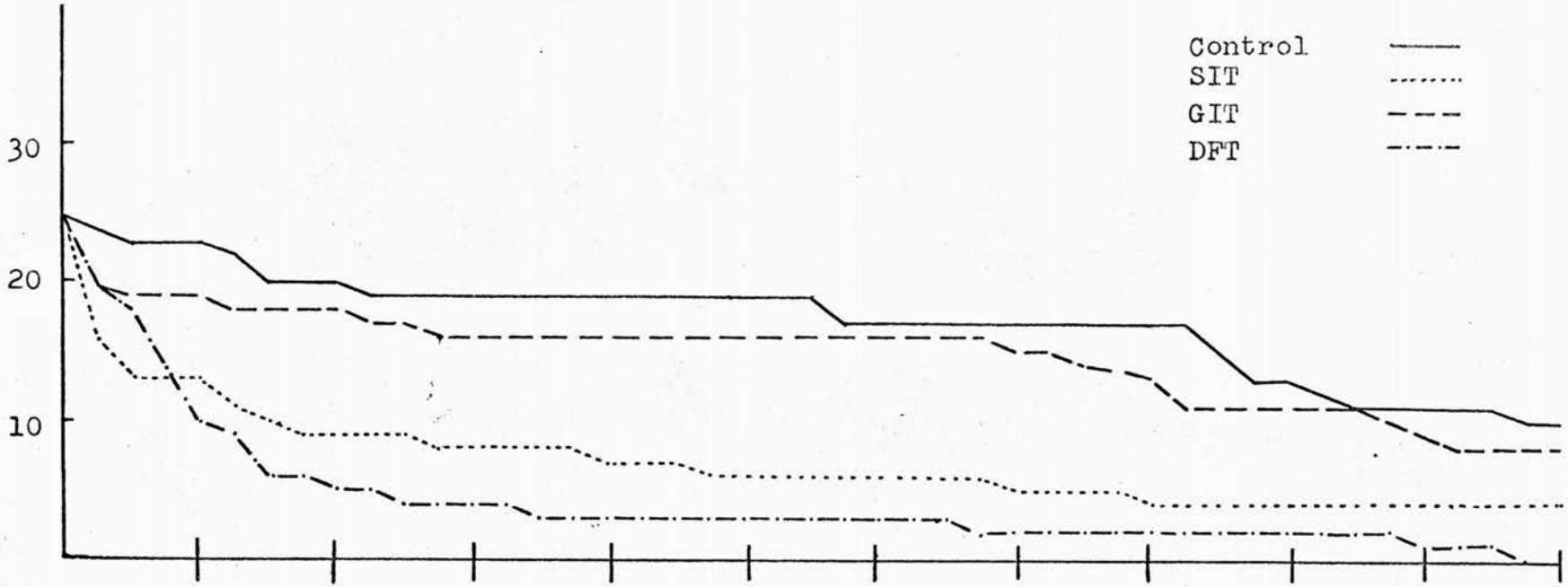


Fig. 37. No. of larvae alive in TIV treatments.

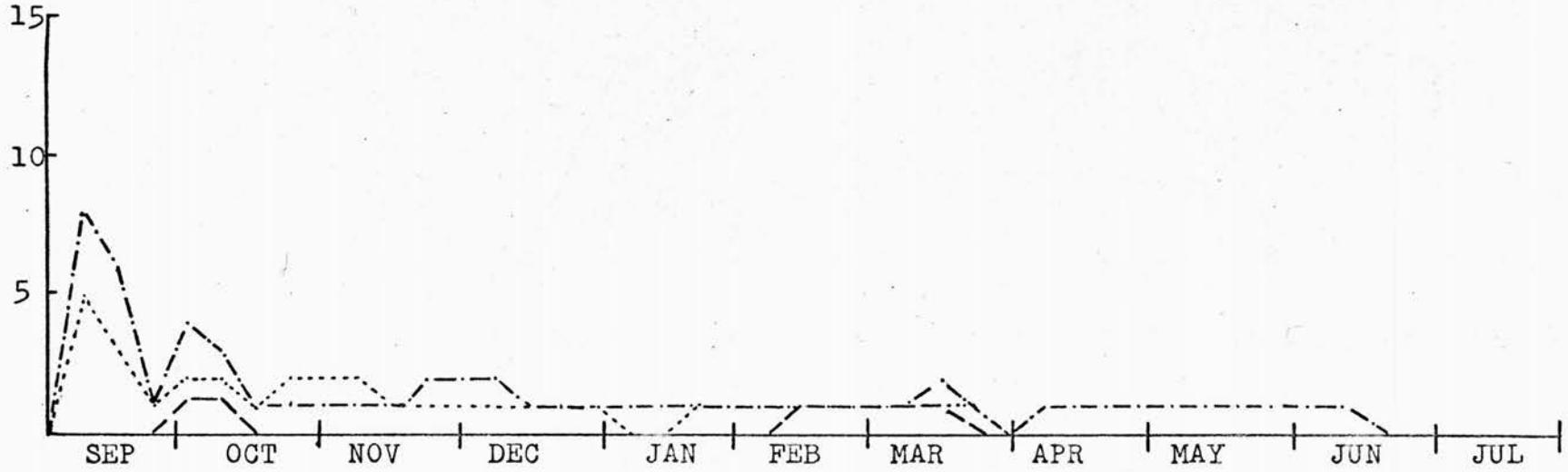


Fig. 38. No. of infected larvae with TIV in each treatment. None in control

treatments, and were most marked near the beginning of the experiment. The incidence of death due to cannibalism was higher in all treatments in early stages. Table 56 summarizes the figures shown in detail in Appendix III, Table 44. The incidence of virus infection between treatments were significantly ($p < 0.01$) different. There was no infection in the control. DFT is significantly different ($p < 0.01$) from all other treatments. SIT is significantly different from control ($p < 0.01$) and from grass infected with TIV ($p < 0.05$). Among the three treatments DFT is most virulent as suggested by Smith et al. (1961). All the larvae except three had died by December in this treatment, two others had died by March and the remaining one died in July, all from TIV infection. The virus infection was also higher in SIT (Table 56). There was a low incidence of virus infection in GIT. This treatment was expected to give a high infection rate (Smith et al. 1961), but no infection showed in the 2nd instar, there was infection in the 3rd and 4th instars but significantly low compared with the other treatments.

The same table also shows that the mortality was greater in second instar larvae than in the later instars ($p < 0.01$) in both SIT and DFT treatments. The mortality was greater in the 3rd than in the 4th instars ($p < 0.01$) in the DFT treatment only. It is also obvious from the Fig. 37 that very few larvae in SIT and DFT could reach the 4th instars, especially in DFT.

Cannibalism is an important factor for the drop of population where a number of larvae is confined in a small polypot or in a

confined space (Laughlin, 1960). Here the number of larvae eaten by others was determined by finding larvae partly eaten or completely eaten except for the hard mandibles (in the sand). There is no significant difference of death due to cannibalism between any of the treatments; but there is significant difference ($p < 0{\cdot}05$) between the instars within the treatments. There is significant difference ($p < 0{\cdot}05$) between 2nd instar and the 3rd instar or 4th instar larvae in SIT, and between the 2nd or 3rd or 4th in GIT. Cannibalism in 3rd or 4th instar larvae in DFT is significantly different from 2nd instar ($p < 0{\cdot}05$).

Infected larvae survived with virus from 1-13 weeks (Appendix III). The larva which survived longest with virus was in the 3rd instar.

The larvae had their second moult between 8-13 September and 3rd moult 8-16 March. There was no variation in moulting between treatments and controls. After a larva was seen to be infected, it did not moult.

The number of adults which emerged in the control was highly significantly greater than in SIT and DFT ($p < 0{\cdot}01$) treatments, but not from GIT. The number of adults emerging in the GIT treatment was significantly greater ($p < 0{\cdot}05$) than those in the SIT treatment and highly significantly greater ($p < 0{\cdot}01$) in the DFT treatment.

8.3232 Nuclear polyhedrosis

Compared to TIV, the infectivity of nuclear polyhedrosis was very low. This result, as shown in Table 57, is contrary to field

findings where more larvae were found to have polyhedra in them than TIV. Only DFP treatments were found to be highly virulent. None of the larvae in the 2nd stage (Appendix III, Table 45) were found to suffer from this virus disease. It was the 3rd instar which suffered most. Only one larva in GIP was infected with virus. The mortality in the DFP treatment was greater than in the other treatments and the control ($p < 0{\cdot}01$). Of the 8 larvae which died in this treatment one was in the 4th instar and 7 in the 3rd. The infection rate was obviously too low to permit discrimination between instars. The virus infection was first noticed in 10th week after virus contamination in GFP (7.11.66) when all the larvae were in the 3rd instar. The single infection in the GIP treatment showed up in the 4th instar (24.4.67).

The times of moulting were the same as already recorded in TIV experiments. None of the larvae observed to be infected in the third instar moulted, the one already in the 4th instar died on 7.9.67 after all the adults had emerged. A third instar larva in one polypot of DFP treatment ate part of an infected larva on 13.4.67, showed signs of infection on 30.4.67 and died on 29.7.67 without moulting. This larva almost stopped feeding on 19.5.67 and remained moribund on the surface 8 weeks before it died. The minimum and maximum numbers of weeks larvae survived after infection was observed and is given in Table 45 Appendix III.

Regarding cannibalism in this experiment the summary in the Table 57 shows no significant difference between treatment and the only significant difference ($p < 0{\cdot}01$) between instars within the

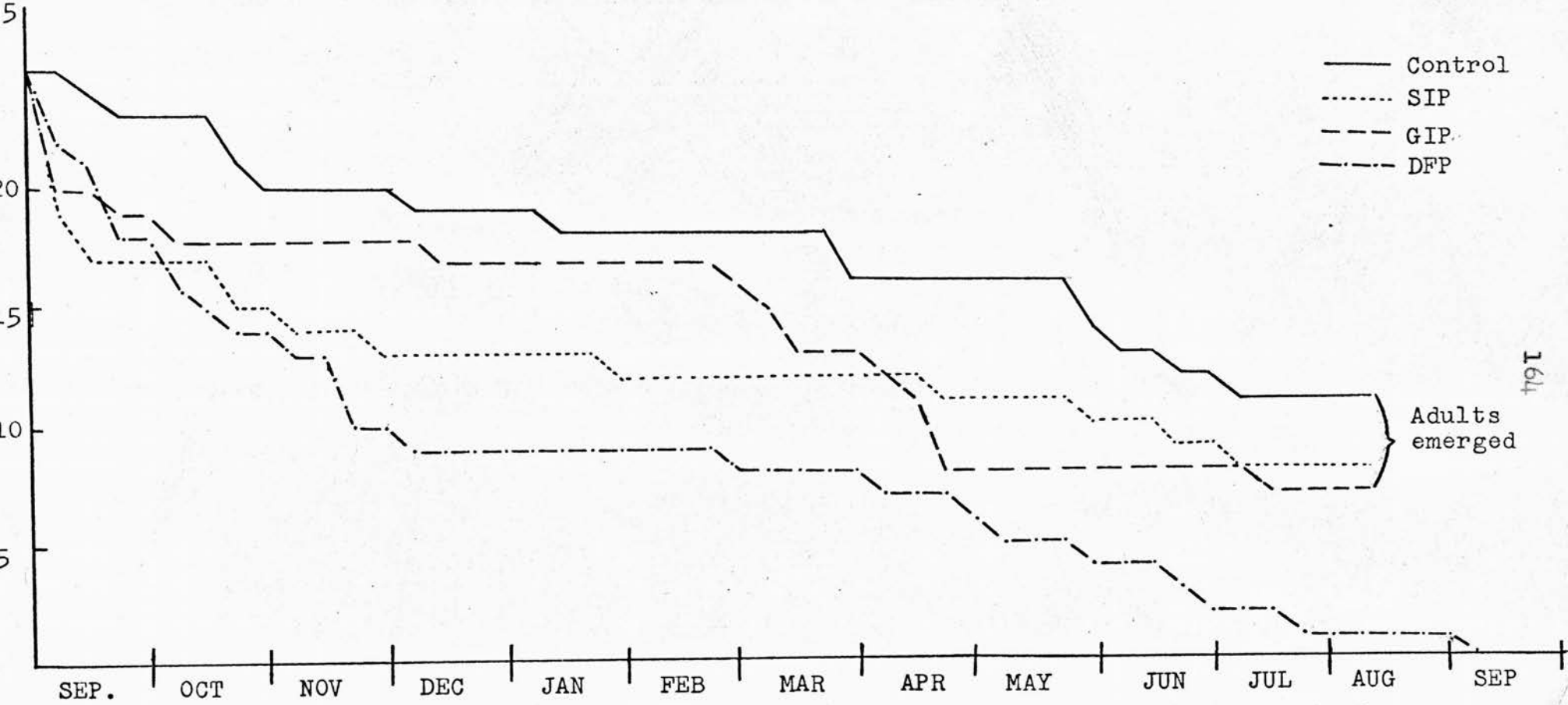


Fig. 39. No. of larvae alive in different treatments of nuclear polyhedrosis transmission experiment.

TABLE 57

Mean number of larvae in each treatment and values of "F" (variance ratio) between treatments

Treatments	Death with virus	Value of "F"	Death due to cannibalism in instars			Value of "F"	Adults emerged	Value of "F"
			2	3	4			
SIP	0		1·4	1·0	0·8		1·6	
GIP	0·2		1·2	1·0	1·2		1·4	
DFP	1·6	Ŧ 13·0	0·6	2·6	0	0·01	0	Ŧ 21·65
Control	0		0·8	1·2	0·8		2·2	
Value of "F" between instars within treatment			** 3·01					

Ŧ Highly significant (p = 0·01)

** Highly significant (p = 0·01)

treatments is that between the 3rd instars and the others in DFP.

Fig. 39 shows the number of larvae alive in weekly observations. The above Table 57 in "adults emerged" column shows the mean number of adults emerged. All larvae died in DFP. There is no variation between SIP and GIP, but control differs significantly ($p < 0{\cdot}01$) from others. Of course SIP and GIP vary significantly from DFP ($p < 0{\cdot}01$). So, like TIV treatments, the polyhedrosis experiments also show the mortality is considerably less in controls than in treated ones.

8.3233 Field soil

The experiment was started at the same time as other virus ones. Soil was sorted out from each pot in a tray on 4.7.67 before pupation begun in other groups. The mean number of larvae found in each treatment has been shown in Table 58 and the details in Appendix II, Table 46.

TABLE 58.

The mean number of larvae alive in each treatment

Sterilized field soil	Normal field soil	Variance ratio (F)
3·2	2·7	1·95

The value of "F" is non significant.

It is obvious from Table 58 that there is no variation between the numbers of larvae which survived in the two treatments.

None of the larvae showed virus infection.

8.4 Discussion and conclusions

Infection by eating diseased larval material has been shown in my experiments to be the most virulent means. Smith et al. (1961) suggested that this might be a virulent means of infection. It is not known, however, to what extent cannibalism occurs in the field. Any method by which virus is taken in through the mouth has been shown to produce infection, although ingestion with the dried grass diet was less effective in this way. Whenever larvae were dissected during the work, small soil particles were always found in the gut and their presence may indicate how larvae become infected from contaminated soil. The greater incidence of TIV infection in SIT could be due to the fact that the contaminated sand in this treatment was not changed so as to keep the medium always contaminated with virus, although later in the experiment the sand was washed for cleaning and to prevent fungus growth. But this washing could not possibly free the soil from virus. Ingestion with food was also successful but the results do not show as much as with soil. This might be due to the fact that they did not take enough infested food during the short time it was available to show great infectivity. As the virus is rapidly fatal in 2nd instar larvae and as the second stadium is very short (not exceeding 11 days) the chance of finding infected 2nd instar larvae in the field is very small. On the other hand, larvae showing infection in the later instars do not

usually die rapidly and so can carry on infection through the winter. Also diseased larvae were never seen to moult and died in the same instar. This is because of the fact that always by the time disease becomes recognizable, the larvae have an enormous quantity of virus in them and soon become too sick to move. Highly infected larvae are normally found on the surface. The 3rd and 4th instar larvae in the early stages of infection with TIV feed normally, later the intake of food is reduced and the majority continue to feed a little right up to becoming moribund. On the other hand 3rd and 4th instar larvae infected with polyhedrosis viruses stop feeding early and may remain alive (up to 8 weeks) without further feeding. As 5 larvae were put in each polypot, cannibalism was an obvious cause of drop of population. There was cannibalism on diseased ones and vice versa; but as no virus infected larva ever recovered, those which were killed by others were treated as though they had died from virus. Cannibalism of infected larvae obviously increased infection in the cannibals. On the contrary, due to cannibalism a very few diseased larvae might even have been missed, as observations were made weekly. However, these studies were carried out to determine the infectivity of this virus, and the degree of mortality it could cause. As the viruses are widely spread in S.E. Scotland, they could be considered as a factor in year to year drop in population in addition to climatic factors as elucidated by Milne et al. (1965). Table 57 also shows quite interesting results in different treatments. Strangely enough no pupa was found to have virus in it.

Polyhedrosis is more likely to be widespread due to the fact that the virus is enclosed in a protein matrix and can remain in it many years (Smith and Williams, 1958). This suggestion was confirmed by my finding more polyhedrosis infected larvae in the field. But in laboratory trials TIV had more infectivity than nuclear polyhedrosis disease. Particularly as there was rather more cannibalism in polyhedrosis experiments and so greater opportunity of infection by this process.

Polyhedrosis was found to have a longer developmental period than TIV. No infection showed up in 2nd instar larvae and most infected larvae died in later 3rd instar. Infected larvae become passive and may remain so without feeding for many weeks. This fact was noticed in field populations and the larvae remaining alive such a long time (up to September) with virus can enhance the field infection of leatherjackets, because the next generation of leatherjackets have already appeared in the field. The mode of development of this virus is also helpful to the spread of the disease as the highly infected larvae die, burst and release the polyhedra into the soil. This bursting of infected larvae was also noticed in the laboratory.

All the larvae found with polyhedrosis in the field were 4th instars, but TIV infected larvae in 3rd instar were found too. Both these diseases play an important part in controlling the numbers of larvae in the field in S.E. Scotland.

~~As no diseased larvae were found in the controls where sterile sand was used, there was no indication of hereditary~~

~~transmission of these viruses~~

Although no infection was found in the laboratory experiments using field soil, it cannot be concluded that the field as a whole was free from viruses, as only a very small quantity of soil was used. In fact a few larvae infected with the viruses were found in the previous year in the area from which the soil had been taken for experimental purposes.

SECTION 9. BEETLES FEEDING ON LEATHERJACKETS

9.1 Introduction

It has already been mentioned that in 1965 many beetles were observed at Crofthead Farm (see 2.3411). The maximum number were seen in June. A number of species of Carabus, Calosoma, Harpalus, Pterostichus etc. have been found to feed on insect larvae (Clausen, 1940). Webster (1893) has found Harpalus pennsylvanicus, Harpalus caliginosus and Platynus sp. feeding on both adults and larvae of the injurious crane fly Tipula bicornis. No report has been obtained that the beetles feed on the larvae of the oleracea group.

9.2 Beetle population in the field

The population of beetles was estimated for 2 weeks (31 May to 13 June) in 1966 and 3 weeks (7 June to 28 June) in 1967 to give an idea about the species of ground beetle and their numbers.

9.21 Material and method

Pitfall traps (jamjars) were laid out in the field. One trap was used per plot in the 1966 experiment and put in the centre. In the 1967 field experiment the number of traps was two per plot; one of them had the bottom replaced by 18 mesh wire gauze to facilitate drainage. Observations were made twice a week.

9.22 Results

The mean number of beetles trapped per plot in 1966 is shown in Table 59, which indicates that Pterostichus niger was

TABLE 59

Mean number of beetle in the field (1966)

P.madidus	P.niger	N.brevicollis	Euryporus	L.S.D.	Value of "F"
2·66	42·33**	2·22	41·22**	a, 7·63 b,10·24	69·58

** Significant at p < 0·01

the most common species, followed closely by Euryporus spp. (which were not separated). Pterostichus madidus and Nebria brevicollis were much less abundant. A few Agonum mulleri were also found.

TABLE 60

Mean number of beetles collected in each treatment (1966)

Name of beetle	Control	Aldrin	DDT	Value of "F"
P. madidus	1·6	4·8	1·5	1·28
P. niger	44·2	38·0	44·8	<1
N. brevicollis	1·3	4·8	0·5	1·93
Euryporus spp.	38·6	44·5	40·5	<1

When one examines the mean numbers trapped in the plots of the different treatments (Table 60) it is found that there was no significant difference between the treatments.

The proportions of species trapped in the 1967 experimental plots (Table 61) differed from the 1966 results, as Euryporus spp.

TABLE 61

Mean number of beetle in the field (1967)

P. niger	P. vulgaris	A. mulleri	Euryporus	L.S.D.	Value of "F"
7·33	7·88	9·50	19·11**	a,4·24 b,5·61	13·35

** Significant at $p < 0·01$

(taken as a whole) were most abundant followed by A. mulleri, P. vulgaris, P. niger which occurred in approximately equal numbers. P. madidus and N. brevicollis were present but scarce. Again there was no significant difference between

TABLE 62

Mean number of beetles collected in each treatment (1967)

	Control	DDT	Folithion	Value of "F"
P. niger	6·16	7·16	8·66	1·79
P. vulgaris	8·00	8·16	7·50	<1
A. mulleri	7·66	6·33	14·50	2·14
Euryporus spp.	17·00	21·83	18·50	1·10

the treatments (Table 62).

9.3 Laboratory experiments on predation by beetles

Experiments were set up in the laboratory to investigate if the beetles which had occurred in the field, would feed on leatherjackets.

9.31 Material and method

(a) Tins (as in 4.2) were prepared each with ten 4th instar leatherjackets. Six beetles were released in each tin, one tin was left as a control. There were six replications. The experiment continued for 2 weeks in June 1966 after which the remaining larvae were counted. P. niger, P. madidus and Euryporus spp. were used.

(b) In this experiment perspex boxes (9 in. x 4½ in. x 2 in. deep) containing 1½ in. soil and with lids ventilated by gauze inserts, each with three 4th instar leatherjackets were used. Three P. niger were put in each, except for the control, and there were 4 replications. The experiment lasted 3 weeks in June 1967, after which the larvae remaining were counted.

(c) In this experiment polypots with 1½ in. of soil were used, one larva and one beetle in each. The object was to find out the number of larvae eaten by each beetle. The polypots were examined every third day and, when a larva was found to have been wholly or partly eaten a fresh one was added. Partly eaten larvae were not removed. The experiment was done in two sections (1) in 1966 and (2) in 1967. In (1) P. niger, P. madidus and

N. brevicollis and a control were used, replicated 4 times and in (2) P. niger, P. vulgaris, A. mulleri with a control were replicated 6 times. This experiment (c) continued for 2 weeks.

The beetles were not released until the larvae had burrowed into the soil as it had been noticed in the laboratory that beetles encountering larvae on the surface attacked and killed them at once.

9.32 Results

(a) Table 63. All the larvae in the control and Euryporus tins

TABLE 63

Mean number of larvae in each tin at the end of the experiment

Name of beetle			Control	L.S.D.	Value of "F"
P. niger	P. madidus	Euryporus			
7·00**	5·33	10·00**	10·00**	a,1·19 b,1·65	34·40

** Significant at $p < 0{\cdot}01$

survived. P. madidus ate significantly ($p < 0{\cdot}01$) more than P. niger.

(b) All larvae except one in this experiment were eaten by the beetles (P.niger). There was also high cannibalism among the beetles in 2 boxes, in which only one beetle remained, the others being found on the surface partly eaten. This cannibalism was probably due to the lack of food after the larvae had been eaten.

There was no death or cannibalism among the larvae in the control.

(c) Tables 64 and 65 show the mean number of larvae eaten by each beetle.

(1) It is obvious from Table 64 that the number of larvae eaten by

TABLE 64

Mean number of larvae eaten by each beetle

Name of beetle			Control	L.S.D.	Value of "F"
P. niger	P. madidus	N. brevicollis			
1·75*	1·75*	0·50	0	a, 1·15 b, 2·11	3·97

* Significant at $p < 0·05$

P. niger and P. madidus was significantly more ($p < 0·05$) than by N. brevicollis. There was no mortality in the control.

(2) Table 65 shows that the number of larvae eaten by P. niger was significantly more ($p < 0·01$) than in any other treatment. No

TABLE 65

Mean number of larvae eaten by each beetle

Name of beetle			Control	L.S.D.	Value of "F"
P. niger	P. vulgaris	A. mulleri			
3·00**	0·50	0	0	a,0·78 b,1·10	34·36

** Significant at $p < 0·01$

feeding on larvae [was observed] by A. mulleri, and there was no mortality in the control.

9.4 Discussion and conclusions

The beetle population of the 1966 experimental field was greater than in the 1967 field. P. niger and Euryporus spp. were common dominant species in both years. P. madidus and N. brevicollis were more abundant in the 1966 field but few in the 1967 field; instead P. vulgaris and A. mulleri were dominant species in the latter year.

In predation experiments, the maximum number of leatherjackets was eaten by P. madidus and P. niger both in groups and in individual feeding. The two species could be possible control factors of leatherjackets in a field where the larval population is very high. N. brevicollis showed that it could feed on leatherjackets, but A. mulleri and Euryporus spp. failed to do so.

From these laboratory experiments, it might be concluded that carabid beetles could play some part in the reduction of the population of leatherjackets in the field; but it should be noticed that, in the experiments, the beetles had no choice of food. To try to shed more light on this subject 85 individuals of P. niger, collected in the field, were dissected, but no material from their alimentary canals could be definitely identified as from leatherjackets.

SUMMARY

1. Survey of leatherjacket population and damage.

A survey of leatherjacket populations in autumn and winter showed that populations varied from 32,000 to 756,000 per acre in 1964-65, and 30,000 to 144,000 per acre in 1965-66 in different counties in S.E. Scotland. More infestation was recorded in the western part of the region which is wetter.

Damage to cereals was more observed in spring barley by shredding and cutting leaves and also cutting the stems both on or below the surface. Damage was mostly in the month of May. In a field of winter wheat 30 per cent of the plant population was damaged by a population of over ½ million. Damage to oats showed that it suffered less than barley.

A decline in larval population occurred in the later half of May and at the beginning of June associated with a dry spell at that time of the year. DDT (25 per cent) 4 pint and aldrin (30 percent) 3 pint miscible liquid per acre with 20 gallons of water controlled larval population but γ-BHC (80 per cent w/v) ½ pint, and diazinon (20 per cent) 3, 4, or 6 pint per acre failed to do so.

2. Investigation of the population of leatherjackets in a grass field.

An estimation of leatherjacket population from November to June showed that there were two distinct declines in population

(i) in January and February and (ii) over the month of May and June. The former may be called "winter mortality" which accounted for 50 per cent of population reduction. The latter decline was mainly due to drought, other factors which partly contributed to it being disease and parasites; and accounted for 60 per cent of the rest of the larval population.

The maximum efficiency of St. Ives method of sampling was 60 per cent compared with 100 per cent by 4 in. diam. cores; and it gradually declined to about 8 per cent at the end of June.

3. Experiment in the insectary to study leatherjacket damage to barley.

Experiment A. Heavy damage to barley was recorded both on the surface and below in this experiment in the insectary. There were more shredded leaves than cut leaves. The number of stems cut on the surface was also more than below the surface. The plant population was reduced to 50 per cent in the controls compared with the insecticidal treatments. The damage was significantly less ($p < 0{\cdot}01$) in insecticidal treatments compared with the controls. The weights of shoots and roots in control treatments were significantly less ($p < 0{\cdot}01$) than in insecticidal treatments.

The mortality of larvae was 17, 9, 92 and 100 per cent in CA, CB, IS and IM treatments respectively at the end of the experiment. The 10 per cent of live larvae in CA and 4 per cent in CB showed virus infection.

Experiment B. The damage both surface and below surface was far less outside the insectary (B) than inside (A) and the same pattern of damage was observed except that there were more cut leaves than shredded leaves. The population of barley was reduced to 9·6 per cent in controls compared to insecticidal treatments. There was no variation of weights in shoots and roots in any of the treatments.

The mortality of larvae was 50, 28, 97 and 100 per cent in CA, CB, IS and IM respectively. The greater mortality in controls was due to drought.

The number of larvae seen on the surface in controls in experiment A was 2, 3, 9, 10 and 11 at 22·00, 23·45, 01·15, 01·30 and 02·30 hours G.M.T. respectively, but none in experiment B.

4. The field experiments.

(a) The field experiment in 1966.

The population of larvae was 235,000 per acre. There were two declines in control, (i) in the first week of June, mainly due to drought, and also to disease, parasites and predators; amounting to 50 per cent of population reduction; (ii) in July due to emergence of adults. Pupation began between 4 to 11 July and adults were seen flying on 18 July. The larval populations in plots treated with aldrin (30 per cent) 4 pint and DDT (25 per cent) 4 pint miscible liquid per acre, declined sharply and 3 weeks after spraying about 85 per cent control was achieved.

The maximum surface damage by shredding and cutting of leaves was 23 per cent on 17 May; cut stems both surface and sub-surface were 18 per cent at the same date. Very little damage was observed in treated plots showing that both insecticides were very efficient. The yield of barley was 22·8, 23·9 and 27·7 cwt/acre in the control, aldrin and DDT treatments respectively. The difference was not significant between any of the treatments.

(b) The field experiment in 1967.

The population of larvae was 247,000 per acre. The natural decline in control was first observed at the beginning of June and amounted to a population reduction of 60 per cent due to the same factors as in 1966. The second decline, was due again to adult emergence. Pupation started between 5 to 14 July and adults were seen flying by 20 July. The reduction of larval population in plots treated with DDT (25 per cent) 3 pint and folithion 1 lb. of A.I. per acre was 50 per cent 2 weeks after spraying, and the subsequent reductions were enough to check the damage.

The damage to barley was more compared to 1966. The heaviest damage by shredding and cutting leaves in control was 33·5 per cent of total plant population on 25 May, and 21·4 per cent was the damage by cutting stems on surface and sub-surface on 18 May. The damage had completely ceased by 30 June. Damage to both the insecticidal treatments was very little which showed the efficiency of the insecticides used. The number of undamaged plants in the

control was significantly less ($p < 0.01$) than in the treated plots; but this difference was compensated by damaged plants in the control producing more ($p < 0.01$) tillers.

There was delayed ripening in the control plots. The yield of barley was 35·8, 34·7 and 31·3 cwt. per acre in the control, DDT and folithion treatments respectively. The difference was not significant. The quality of grain was also not affected in any of the treatments.

5. Nocturnal behaviour of leatherjackets recorded by time-lapse cinematography.

Usually leatherjackets appeared on surface by 20·36 hours and stayed as late as 05·08 hours and the average period of activity observed was 7·6 hours. The surface activity was well spread reaching a peak at 21·00 to 22;00 hours and gradually declining to nil by 06·00 hours. An individual larva stayed up to 2 hours on surface, which was associated with feeding. Four larvae out of 14 was the maximum found on the surface at one time (at 03·04 hour).

Very few larvae were found to crawl, and the speed varied from $\frac{1}{3}$ to $1\frac{1}{2}$ ins. per minute; and a maximum distance up to 11 in. was recorded. Most of the larvae appeared from below the plants and started feeding; the further the plants were away from the tunnel the less was the feeding. Usually larvae fed on a leaf by pulling it into the burrow. In the course of feeding larvae often went into the soil and then came out again and attacked the plant at the same part as previously.

The sub-surface activity was also well spread over the night, but most of the larvae active sub-surface were feeding. There was no real difference obtained between the activity in ~~the~~ box I with heavy loam and box II with sandy soil.

6. Soil preference of Tipula paludosa Meigen in oviposition.

Males and females were released in cages containing a choice of sandy, loam, clay and peat soils. In repeated experiments it was found that females laid more eggs in sandy soil.

7. Virus diseases of leatherjackets

The virus diseases, i.e. Tipula iridescent virus and nuclear polyhedrosis, were found in S.E. Scotland. Larvae in 4th instar were commonly found to suffer from diseases in the field; but in one case, where 4·7% of the larval population in a grass field were found infected with TIV, infection was seen in 3rd instar larvae. In the 1966 experimental field, 2 larvae were collected with nuclear polyhedrosis and 1 with TIV. In the 1967 experimental field, 5 diseased larvae were found all suffering from nuclear polyhedrosis.

The laboratory experiments for the ovarian transmission of viruses failed, but great infectivity was achieved by injecting 0·01 ml. and 0·002 ml. of inocula of each of the viruses into pupae and adults. All 2nd instar larvae got virus infections by feeding on the dead bodies of diseased larvae and died. The larvae reared in soil contaminated with TIV, showed high virus

incidence, but the same treatment with nucelar polyhedrosis failed. Little incidence of virus transmission was achieved in larvae feeding on contaminated powdered dried grass. No larvae with obvious signs of virus infection moulted, and no diseased larvae collected from the field reached the adult stage. Cannibalism was common in larvae reared in groups of 5 in each polypot.

8. Beetles feeding on leatherjackets

In the 1966 experimental field, Pterostichus niger was the most common species, followed closely by Euryporus spp., and Pterostichus madidus and Nebria brevicollis were much less abundant. A few Agonum mulleri were also found. In the 1967 experimental field, Euryporus spp. were most abundant followed by A. mulleri, P. vulgaris and P. niger., and also very few P. madidus and N. brevicollis.

In laboratory experiments it was observed that both P. madidus and P. niger fed readily on leatherjackets, N. brevicollis very little, but A. mulleri and Euryporus spp. failed to do so.

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APPENDIX I

Tables 1 to 8, showing the data of section 2.

Tables 9 and 10, showing the data of section 3.

TABLE 1

Total number of damaged plants in 30 cores at Mavis Hall Farm in 1965.

Type of damage	Date	Control	Treated Area A	Area B
Leaves	19.4	15	5	5
Shredded and/or cut	10.5	37	11	4
	9.6	10	1	3
	14.6	7	7	2
Stems cut	10.5	29	1	1

TABLE 2

Total number of undamaged plants in 30 cores at Mavis Hall Farm in 1965.

Date	Control	Treated Area A	Area B
19.4	160	162	164
10.5	120	162	184
9.6	117	137	129
14.6	114	125	118

TABLE 3

The total number of larvae collected in 30 cores at Mavis Hall Farm in 1965.

Date	Control	Treated Area A	Area B
19.4	38	30	33
10.5	42	31	26
9.6	13	4	6
14.6	12	7	6

TABLE 4

Total number of damaged plants in 30 cores at Crofthead Farm in 1965

Type of damage	Date	Control	BHC	DDT	Diazinon
Leaves shredded and/or cut	29.4	52	20	5	28
	24.5	23	8	0	7
	22.6	0	0	0	0
Stems cut on surface or sub-surface	29.4	21	19	2	12
	24.5	16	9	0	15
	22.6	1	2	0	0

TABLE 5

Total number of undamaged plants in 30 cores at Crofthead Farm in 1965

Date	Control	B.H.C.	D.D.T.	Diazinon
29.4	127	117	152	116
24.5	87	93	145	95
22.6	92	111	135	95

TABLE 6

The total number of leatherjackets in 30 cores at Crofthead Farm in 1965

Date	Control	B.H.C.	D.D.T.	Diazinon
29.4	34	29	2	21
24.5	20	15	0	13
22.6	12	8	0	8

TABLE 7

The rate of mortality in weekly laboratory observations of larvae collected from Mavis Hall Farm in 1965.

Date	Cage No.	No. of larvae alive	
		Control	Treated
21.5	1	30	30
	2	30	30
	3	30	30
27.5	1	30	29
	2	30	30
	3	29	29
3.6	1	30	24
	2	29	18
	3	25	27
10.6	1	28	18
	2	28	14
	3	20	21
18.6	1	26	16
	2	25	12
	3	16	18
25.6	1	23	16
	2	25	12
	3	16	17
27.6	1	23	16
	2	25	11
	3	15	16

TABLE 8

The rate of mortality of larvae collected from Crofthead Farm (Exptl. plots) shown in weekly observations in the laboratory in 1965.

Date of Observation	Polypot No.	No. of larvae alive Control	Diazinon	B.H.C.
20.5	1	6	6	6
	2	6	6	6
	3	6	6	6
	4	6	6	6
	5	6	6	6
	6	6	6	6
26.5	1	6	6	6
	2	6	6	5
	3	6	6	6
	4	6	6	6
	5	6	6	6
	6	6	6	6
3.6	1	6	6	6
	2	6	6	5
	3	5	6	6
	4	6	5	6
	5	6	6	6
	6	6	6	6
11.6	1	6	6	6
	2	6	6	5
	3	5	6	5
	4	6	5	6
	5	6	6	6
	6	6	6	6

[Contd. on next page

TABLE 8 (Contd.)

Date of Observation	Polypot No.	No. of larvae alive		
		Control	Diazinon	B.H.C.
18.6	1	6	6	6
	2	6	6	5
	3	5	6	5
	4	6	5	6
	5	5	6	4
	6	6	6	6
25.6	1	6	6	6
	2	6	6	5
	3	5	6	5
	4	6	5	6
	5	5	6	4
	6	6	5	5
2.7	1	6	6	6
	2	6	5	5
	3	5	6	5
	4	6	5	6
	5	4	6	4
	6	5	5	3
9.7	1	6	6	6
	2	6	5	5
	3	5	5	5
	4	6	5	6
	5	4	6	4
	6	5	5	3

TABLE 9

Estimation of the population of leatherjackets in a grassfield at Crofthead Farm in 1965-66.

Date of sampling	Estimation by 4" diam. core				Estimation by St. Ives Method			
	Plot No.	No. of Cores	No. of Larvae	Estimated population per acre (A)	No. of $ft.^2$	No. of Larvae	Estimated population per acre (B)	B as % of A
15.11.65	1	8	8	499016	4	28	304920	61·11
	2	8	7	434140	4	32	348480	80·27
	3	8	10	623770	4	25	272250	43·65
	4	8	11	683651	4	37	402930	58·94
	5	8	7	434140	4	18	196020	45·16
5.12.65	1	8	7	434140	4	23	250470	57·70
	2	8	8	499016	4	28	304920	61·11
	3	8	6	374262	4	19	206910	55·29
	4	8	9	558897	4	22	239580	42·87
	5	8	8	499016	4	20	217800	43·65
3.2.66	1	8	5	309389	4	15	163350	52·80
	2	8	6	374262	4	11	119790	32·01
	3	8	3	187131	4	14	152460	81·48
	4	8	7	434140	4	18	196020	45·16
	5	8	3	187131	4	15	163350	87·3

(Contd.

TABLE 9 (Contd.)

Date of sampling	Estimation by 4" diam. core				Estimation by St. Ives Method			
	Plot No.	No. of Cores	No. of Larvae	Estimated population per acre (A)	No. of $ft.^2$	No. of Larvae	Estimated population per acre (B)	B as % of A
15.4.66	1	8	2	124754	4	9	98010	78·56
	2	8	3	187131	4	12	13068	6·98
	3	8	4	249508	4	17	185130	74·2
	4	8	6	374262	4	13	141570	37·83
	5	8	5	309389	4	15	163350	52·80
10.6.65	1	8	1	10890	4	1	59881	18·18
	2	8	0	0	4	0	0	
	3	8	2	21780	4	2	124754	17·45
	4	8	1	10890	4	0	0	
	5	8	2	21780	4	1	59881	36·37

TABLE 10

Estimation of the population of leatherjackets in a grassfield at Crofthead farm 1966 - 1967

Date of sampling	Estimation by 4" diam. core				Estimation by St. Ives Method			
	Plot No.	No. of Cores	No. of Larvae	Estimated population per acre (A)	No. of $ft.^2$	No. of Larvae	Estimated population per acre (B)	B as % of A
24.11.66	1	8	8	499016	4	23	250470	50·13
	2	8	12	748525	4	29	315810	42·20
	3	8	11	683652	4	45	490053	71·69
	4	8	10	623770	4	36	392040	62·86
	5	8	10	623770	4	35	381150	61·11
9.12.66	1	8	7	434140	4	22	239580	55·19
	2	8	8	499016	4	30	326700	65·47
	3	8	10	623770	4	33	359370	57·62
	4	8	9	683651	4	22	239580	35·05
	5	8	7	434140	4	32	348480	80·27
10.2.67	1	8	3	184636	4	15	163350	88·48
	2	8	6	374262	4	18	196020	52·38
	3	8	4	249508	4	13	141570	56·74
	4	8	7	434144	4	14	152460	35·12
	5	8	9	558898	4	20	217800	38·97

(Contd.)

TABLE 10 (Contd.)

Date of sampling	Estimation by 4" diam. core				Estimation by St. Ives Method			
	Plot No.	No. of Cores	No. of Larvae	Estimated population per acre (A)	No. of $ft.^2$	No. of Larvae	Estimated population per acre (B)	B as % of A
10.4.67	1	8	7	439134	4	9	98010	22·31
	2	8	2	124754	4	5	54450	43·64
	3	8	6	374262	4	8	87120	23·27
	4	8	3	184636	4	3	32670	17·69
	5	8	9	558898	4	13	140570	25·16
17.5.67	1	8	3	187131	4	10	98010	52·37
	2	8	4	249508	4	4	43560	17·45
	3	8	6	374262	4	8	87120	23·27
	4	8	5	309389	4	5	54450	17·59
	5	8	5	309389	4	4	43560	14·08
30.6.67	1	8	1	59881	4	1	10890	18·18
	2	8	1	59881	4	0	0	
	3	8	2	124754	4	1	10890	8·73
	4	8	2	124754	4	0	0	
	5	8	0	0	4	1	10890	

APPENDIX II

Tables 11 to 19, showing the data of Section 4

Tables 20 to 27, showing the data of the field experiment in 1966 (Section 5.1)

Tables 28 to 42, showing the data of the field experiment in 1967 (Section 5.2)

TABLE 11

Total number of stems cut on the surface in each treatment in 1966. (Expt.A)

Date	CA*	CB*	IS*	IM*
19/4 - 4/5	38	29	6	12
4/5 - 22/5	82	92	5	3
22/5 - 7/6	70	79	3	1
7/6 - 24/6	80	93	1	0
Total	270	293	15	16

TABLE 12

Total number of stems cut sub-surface in each treatment in 1966. (Expt. A)

Date	CA*	CB*	IS*	IM*
19/4 - 4/5	25	30	14	6
4/5 - 22/5	53	63	12	0
22/5 - 7/6	75	59	4	0
7/6 - 24/6	48	47	1	0
Total	201	199	31	6

* details on page 48

TABLE 13

Total number of leaves shredded in each treatment in 1966 (Expt. A)

Date	CA	CB	IS	IM
19/4 - 4/5	5	8	2	3
4/5 - 22/5	13	0	1	1
22/5 - 7/6	58	66	0	0
7/6 - 24/6	41	34	4	0
Total	167	108	7	4

TABLE 14

Total number of leaves cut in each treatment (Expt. A)

Date	CA	CB	IS	IM
19/4 - 4/5	12	12	3	5
4/5 - 22/5	8	8	3	1
22/5 - 7/6	23	18	2	0
7/6 - 24/6	9	26	2	0
Total	52	64	10	6

TABLE 15

Total number of undamaged plants in observations of treatments in 1966 (Expt. A)

Date	CA	CB	IS	IM
/19.4.66	960	960	960	960
25.4.66	947	948	956	957
1.5.66	912	917	949	948
7.5.66	877	876	937	941
13.5.66	823	813	927	939
22.5.66	763	743	920	939
28.5.66	716	687	915	939
4.6.66	659	645	915	971
11.6.66	595	583	913	943
18.6.66	525	517	912	943
24.6.66	485	479	912	944

/ The number of plants initially put in each treatment.

TABLE 16

The number of larvae alive in each treatment (Expt. A)

Tin No.	No. initially put in	No. of Larvae at the end of experiment			
		CA	CB	IS	IM
1	5	5	5	0	0
2	5	5	5	0	0
3	5	2	3	1	0
4	5	5	5	1	0
5	5	4	5	0	0
6	5	5	5	2	0
7	5	5	5	0	0
8	5	5	5	0	0
9	5	4	4	1	0
10	5	4	3	0	0
11	5	2	5	0	0
12	5	4	5	0	0
Total	60	50	55	5	0

TABLE 17

Total number of plants damaged in each treatment (Expt. B)

Type of damage		CA	CB	IS	IM
Leaves shredded		17	24	0	4
Leaves cut		20	42	5	3
Stems cut	On surface	42	32	3	9
	Sub-surface	19	31	5	9

TABLE 18

The number of undamaged plants in each treatment at the end of experiment (Expt. B)

Tin No.	No. plants at the beginning of expt.	CA	CB	IS	IM
1	80	74	77	80	80
2	80	77	75	79	80
3	80	77	76	80	78
4	80	78	76	80	78
5	80	80	70	78	79
6	80	79	78	80	80
7	80	76	77	80	79
8	80	80	79	80	80
9	80	78	75	79	80
10	80	69	79	80	80
11	80	74	79	79	79
12	80	76	72	79	79
Total	960	918	913	957	952

TABLE 19

The number of larvae in each treatment (Expt. B)

Tin No.	No. of larvae initially put in	No. of larvae at the end of experiment			
		CA	CB	IS	IM
1	5	5	3	0	0
2	5	2	3	0	0
3	5	2	4	1	0
4	5	3	2	0	0
5	5	2	5	0	0
6	5	3	3	0	0
7	5	1	5	0	0
8	5	3	3	0	0
9	5	2	3	1	0
10	5	3	4	0	0
11	5	2	5	0	0
12	5	2	3	0	0
Total	60	30	43	2	0

TABLE 20

The number of larvae per plot (1966)

Date	Control						Aldrin						DDT						
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	
29.4	2	6	5	3	4	4	4	4	2	3	5	5	4	4	6	3	2	5	
8.5	4	3	3	7	6	4	1	2	3	1	2	1	2	3	1	4	1	2	
17.5	4	7	4	5·5	4	4	1		1		1	1	2	3	1	3		4	
23.5	7	4	2	7	3	3							1	1	1				
30.5	5	4	6	5	3	3								1					
6.6	4	2	2	3	3				1			1		1	1		3		
15.6	5	1		1	3	2													
20.6	2		3	1		2													
27.6	2	1	2	5		1													
4.7	1	1	1	3	1	2													1♂ ≠
11.7	2	1		1		1													1♂ ≠
18.7	1	1		1	1														1♂ + 1♀ ≠
25.7	1	1	1	1															
1.8			1																1♂ ≠≠
8.8	1																		
15.8																			
25.8																			
Total	41	32	30	43·5	28	26	6	6	7	4	8	8	9	13	10	10	6	11	

≠ No. pupae in control ≠≠ Empty pupal case in control

TABLE 21

The number of plants with shredded leaves (1966)

Date	Control						Aldrin						DDT					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
29.4																		
8.5		2	1	3	1	3	1	1	1	1	3		2		1	1	1	1
17.5	4	6	3	3	2	1		1	1				2		2		1	
23.5	2	3	2	2	1	1									1			
30.5	2		4	2														
6.6	1		1	2	1			1	1			1					2	
15.6	1																	
20.6																		
27.6																		
4.7																		
11.7																		
18.7																		
25.7																		
1.8																		
8.8																		
15.8																		
25.8																		
Total	10	11	11	12	5	5	1	3	3	1	3	1	4		4	1	4	1

TABLE 22

The number of plants with cut leaves (1966)

Date	Control						Aldrin						DDT					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
29.4																		
8.5		2	3	1	4	1		1	1			2	1	1	1		1	1
17.5		5	4	6	2	2												
23.5	4	9	4	5	2		1			1			1					
30.5	1	2	1	6	1	4												
6.6				1	1											2		
15.6																		
20.6																		
27.6																		
4.7																		
11.7																		
18.7																		
25.7																		
1.8																		
8.8																		
15.8																		
25.8																		
Total	5	18	12	19	10	7	1	1	1	1		2	2	1	1	2	1	1

TABLE 23

The number of stems cut on surface (1966)

Date	Control						Aldrin						DDT					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
29.4																		
8.5			1															
17.5				2	2	2				1						1		
23.5		1																
30.5	1	2	1			1												
6.6	2		2	2								1						
15.6																		
20.6																		
27.6																		
4.7																		
11.7																		
18.7																		
25.7																		
1.8																		
8.8																		
15.8																		
25.8																		
Total	3	3	4	4	2	3				1		1				1		

TABLE 24

The number of stems cut sub-surface (1966)

Date	Control						Aldrin						DDT					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
89.4																		
8.5	1			2	3		1		1		1			1			2	1
17.5	3	4	2	5	5	2						2	1	1	1	1	2	
23.5	2	4		3	3	2		1	1	1	1	1	1					
30.5	3	2	3		3								1	1	1			
6.6	2				1							1	1			1	1	
15.6	1	1		1	1													
20.6																		
27.6																		
4.7				1														
11.7																		
18.7																		
25.7																		
1.8																		
8.8																		
15.8																		
25.8																		
Total	12	11	5	11	16	4	1	1	2	1	2	4	4	3	2	2	5	1

TABLE 25

The number of undamaged plants per plot (1966)

Date	Control						Aldrin						DDT					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
29.4	27	25	29	21	23	32	24	23	20	21	25	21	20	28	25	30	23	31
8.5	31	20	37	24	24	24	24	30	18	22	29	20	32	25	26	28	27	31
17.5	31	16	20	17	11	29	20	37	26	21	21	17	21	22	25	23	18	22
23.5	19	18	23	18	16	25	19	23	27	18	19	23	20	17	19	21	19	21
30.5	17	17	19	16	18	20	24	21	27	24	24	26	24	21	18	25	21	22
6.6	21	23	21	16	19	28	25	23	23	24	21	20	25	22	23	21	23	26
15.6	17	20	21	23	20	22	20	25	23	24	24	25	22	26	22	25	22	25
20.6	22	22	23	23	20	24	25	24	24	25	23	24	22	24	19	27	22	23
27.6	20	27	20	24	29	27	22	25	23	25	22	23	23	23	20	24	23	25
4.7	24	23	22	21	25	22	24	23	21	23	25	25	21	22	23	26	25	23
11.7	24	26	24	22	24	24	21	25	22	26	23	22	25	24	22	22	21	21
18.7	25	27	23	22	21	24	25	23	20	21	21	21	24	20	20	23	23	24
25.7	25	27	23	22	21	24	23	21	24	20	24	25	23	23	25	25	20	26
1.8	24	25	22	23	25	21	21	22	25	22	23	23	24	21	23	22	22	23
8.8	23	21	20	25	21	21	25	20	23	21	23	21	22	24	22	24	24	21
15.8	23	22	25	25	25	22	23	23	22	23	21	26	25	22	22	23	27	25
25.8	20	23	21	23	23	21	22	22	23	25	25	24	23	23	21	21	22	23
Total	393	382	373	365	365	410	387	410	391	385	393	386	396	387	375	410	378	412

TABLE 26

The percentage of plants not visibly damaged (1966)

	Date	Control	Aldrin	DDT
	29.4	100	100	100
	8.5	84·8	91·7	88·5
17	17.5	65·6	95·7	91·1
	23·5	72·3	94·7	97·7
	30.5	73·5	100·0	97·7
	6.6	88·0	96·4	95·6
	15.6	97·5	100·0	100·0
	20.6	100·0	100·0	100·0
	27·6	100·0	100·0	100·0
7.7	7.7	100·0	100·0	100·0
	11.7	100·0	100·0	99·3
	18.7	100·0	100·0	100·0
	25.7	100·0	100·0	100·0
	1.8	100·0	100·0	100·0
	8.8	100·0	100·0	100·0
	15.8	100·0	100·0	100·0
	25.8	100·0	100·0	100·0
	Mean	92·6	98·7	98·1

The L.S.D. at $P < 0{\cdot}05 = 1{\cdot}49$ and $P < 0{\cdot}01 = 1{\cdot}95$ between two treatment means

TABLE 27

The weights of grain (in lbs.) in an area of 49 sq. yds. of each plot.

Replicate No.	Control	Aldrin	DDT
1	30·18	27·34	31·50
2	26·45	34·82	27·34
3	27·50	27·50	32·97
4	25·50	31·83	30·93
5	22·73	20·50	34·50
6	22·86	20·70	31·11
Total	155·22	162·69	188·35

TABLE 28

The number of leatherjackets per plot (1967)

Date	Control						DDT						Folithion						
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	
28.4	3	4	4	6	3	5	4	3	6	7	2	3	3	2	7	4	2	5	
4.5	3	4	7	7	5	5	4	2	3	2	2	4	3	3	5	5	5	4	
11.5	4	7	4	4	3	3	1	4	3	2	2		2	2	2	3	3	2	
18.5	6	4·5	4	6	3	5			1	1		4	3	1			2	1	
25.5	4	3	5	4·5	4	3			1	1	1	1			1				
2.6	5	4	8	4	6	2	1	1				2	2	3		2	1		
8.6	4	10	3	2	3	3						1	4				1		
15.6	6	1	2	2	1	4	1			2		1	1			1	1		
22.6	1	4	2	1	1	2	1	1										1	
29.6	1	1	3	2	2	2			1			1	1	1				1	
5.7	1	3	4	1	2	1	2						1						
14.7	2	1	3			1						1		1		1			1♂ ≠
20.7	1	2	2	2	1				1						1			1	2♂ + ♀ ≠
27.7																		1	1♀, ≠1♂≠≠
3.8	1			1		1													2♀ + 1♂ ≠
10.8																			
17.8																			
24.8																			
Total	42	48·5	51	42·5	34	37	14	11	16	15	7	18	20	13	16	16	15	16	

≠ As in Appendix Table 20.

Table 29

The number of plants with leaves shredded per plot (1967)

Date	Control						DDT						Folithion					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
28.4																		
4.5			1				2											
18.5	1		1	1		1												
25.5	2		2	1	1	1						2					1	1
2.6	7	2	4		3	7	3	2										
8.6		8	8	5	3	1												
15.6	4	3	4	2	1	3							1				1	
22.6		2		2	1	5								1				
29.6	1	2	2	2	1	2	2								1			
5.7			1	1														
14.7																		
20.7																		
27.7																		
3.8																		
10.8																		
17.8																		
24.8																		
Total	15	17	23	14	10	20	7	2				2	1	1	1		2	1

TABLE 30

The number of plants with leaves cut per plot (1967)

Date	Control						DDT						Folithion					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
28.4																		
4.5																		
11.5	1	4	1		2				1					2				
18.5	3	1	6	5	2	6											3	
25.5	19	6	4	2	4	6						1						
2.6	1	2	3	2	7	2			1									
8.6	2	3		2	1	2									1			
15.6	1		1	1	1													
22.6																		
29.6																		
5.7																		
14.7																		
20.7																		
3.8																		
10.8																		
17.8																		
24.8																		
Total	27	16	15	12	17	16			1	1		1		2	1		3	

TABLE 31

The number of plants with cut stems per plot (1967)

Date	Control						DDT						Folithion					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
28.4																		
4.5				1														
11.5	1	2	1						1				1					
18.5	1	1	1	3	5	2				1				1			2	
25.5	3		1	2	2	1												
2.6	1			1														
8.6	3					1												
15.6																		
22.6																		
29.6																		
5.7																		
14.7																		
20.7																		
27.7																		
3.8																		
10.8																		
17.8																		
24.8																		
Total	9	3	3	7	7	4			1	1			1	1			2	

TABLE 32

The number of plants with cut stems sub-surface per plot (1967)

Date	Control						DDT						Folithion					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
28.4																		
4.5																		
11.5	1	5	1	1	1				2				2					
18.5	2	7	5	1	1	2			1								2	
25.5	4	2	4	3	7			1	1						1	2		
2.6	3	5	2	2	6	1	1			1								
8.6	1	4	1	1		2								1				
15.6	3				1				2									
22.6						1												
29.6																		
5.7																		
14.7																		
20.7																		
27.7																		
3.8																		
10.8																		
17.8																		
24.8																		
Total	14	23	13	8	16	6	1	1	4	1			2	1	1	2	2	

TABLE 33

Number of undamaged plants per plot (1967)

Date	Control						DDT						Folithion					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
28.4	28	21	22	33	30	21	34	31	27	22	31	23	25	36	31	24	22	33
4.5	31	27	32	36	32	30	29	27	30	34	29	31	33	25	33	33	34	34
11.5	29	23	23	35	25	36	24	37	31	26	35	33	35	38	27	27	23	24
18.5	22	12	16	18	28	18	29	30	23	31	28	21	24	26	23	29	16	30
25.5	14	12	17	15	13	20	25	22	23	24	18	19	17	22	19	22	29	19
2.6	13	7	12	16	7	12	20	22	20	22	16	18	17	16	20	16	21	27
8.6	12	7	14	18	18	11	20	17	17	16	22	17	18	17	15	23	26	20
15.6	14	9	21	18	15	19	18	19	19	15	22	18	17	20	24	20	19	24
22.6	15	17	11	16	15	15	19	19	20	17	21	18	19	22	23	21	26	15
29.6	12	11	12	13	14	10	18	20	24	20	14	18	23	14	14	12	16	18
5.7	19	9	21	17	15	18	18	11	22	18	23	11	14	32	23	20	12	16
14.7	16	12	12	15	14	11	28	15	17	13	19	18	27	18	15	11	16	17
20.7	11	19	18	13	14	16	20	20	17	16	15	16	21	20	19	14	13	24
27.7	15	13	15	15	15	21	25	22	14	25	22	24	20	15	19	18	23	23
3.8	15	13	13	14	20	20	17	21	21	21	17	20	19	18	14	18	17	20
10.8	17	10	12	16	16	15	13	25	22	24	14	17	13	20	17	22	19	16
17.8	14	28	13	16	16	13	21	20	20	12	19	23	18	24	19	23	26	20
24.8	12	15	14	15	17	19	23	20	18	17	25	15	15	14	22	20	18	19
Total	309	255	298	339	324	325	418	398	385	373	390	360	385	397	377	373	376	399

TABLE 34

Percentage of plants not visibly damaged (1967)

Date	Control	DDT	Folithion
28.4	100·0	100·0	100·0
4.5	99·0	98·0	99·0
11.5	87·0	98·1	97·9
18.5	64·3	97·3	93·8
25.5	50·3	96·0	97·8
2.6	53·2	97·8	100·0
8.6	63·1	100·0	97·5
15.6	83·9	98·4	99·2
22.6	89·0	98·4	98·3
29·6	97·5	100·0	100·0
5.7	100·0	100·0	100·0
14.7	100·0	100·0	100·0
20.7	100·0	100·0	100·0
27.7	100·0	100·0	100·0
3.8	100·0	99·2	100·0
10.8	100·0	90·6	92·8
17·8	100·0	100·0	100·0
24.8	100·0	100·0	100·0
Mean	88·2	98·6	98·7

The value of "F" between two treatment mean with 10 error degrees of freedom = 122·37 (significant at $P < 0·01$). The L.S.D. at $P < 0·05 = 1·57$ and $P < 0·01 = 2·06$.

TABLE 35

The number of tillers per plot (1967)

Date	Control						DDT						Aldrin					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
22.6	33	33	39	43	44	30	38	44	34	36	31	40	33	37	41	49	38	38
29.6	46	27	38	31	34	17	52	55	44	34	52	35	36	35	34	49	33	38
5.7	37	25	39	51	28	41	39	25	55	41	40	23	26	56	45	37	21	39
14.7	43	31	37	30	40	37	45	24	29	23	40	33	39	42	35	32	39	42
20.7	34	44	46	44	32	31	37	38	43	44	48	37	37	45	42	53	31	46
27.7	27	27	33	40	36	36	37	38	45	41	44	37	43	30	42	37	43	51
3.8	28	33	41	30	42	41	40	36	34	38	44	33	39	33	36	45	35	41
10.8	33	26	23	30	38	30	51	36	38	39	27	33	36	34	30	46	36	27
17.8	32	36	38	36	35	34	38	36	28	24	34	37	32	41	35	37	39	38
24.8	31	31	26	30	26	35	32	35	28	34	39	28	26	25	30	38	31	31
Total	344	313	360	365	355	332	409	367	388	354	399	336	347	378	370	423	346	391

TABLE 36

The mean number of tillers per plant
(1967)

Date	Control	DDT	Folithian	L.S.D. between two treatments
22.6	2.26	1·94	1·88	
29.6	5·59	2·47	2·45	
5.7	2·28	2·17	1·93	a, 0·49
14·7	2·76	1·77	2·32	b, 0·65
20.7	2·59	2·42	2·38	
27.7	2·14	1·93	2·08	
3.8	2·30	1·94	2·17	
10.8	2·11	1·72	1·78	
17.8	2·25	1·73	1·72	
24.8	1·98	1·68	1·78	
Total mean	2·33	1·98	2·04	

TABLE 37

Dry matter percentage of each 150 grams of grains (1967)

Replicate No.	Control	DDT	Folithion
1	65·2	66·3	65·9
2	65·0	66·9	66·1
3	64·4	65·4	66·4
4	62·9	66·4	64·8
5	65·1	62·8	66·4
6	65·1	65·2	64·7
Total	387·7	393·0	394·3
Mean	64·61	65·50	65·71

TABLE 38

Mean number of tillers per plant

Replicate No.	Control	DDT	Folithion
1	2·34	1·87	1·62
2	1·96	1·90	1·81
3	2·51	1·93	1·81
4	2·40	1·85	2·04
5	2·26	2·11	1·74
6	2·06	1·86	1·85
Total	13·53	11·52	10·87
Mean	2·25	1·92	1·98

TABLE 39

Total number of ears, ripe and unripe, in 8 samples each 1 ft. length of row

Replicate No.	No. of unripe ears			No. of ripe ears		
	Control	DDT	Folithion	Control	DDT	Folithion
1	47	15	18	161	232	228
2	44	3	12	149	222	195
3	26	7	7	251	240	305
4	32	47	39	193	284	281
5	25	17	12	220	256	187
6	21	3	12	197	230	237
Total	195	92	100	1171	1464	1433
Mean	32·5	15·33	16·66	195·16	244·00	238·83

TABLE 40

The weights of Barley (in lbs.) in an area of 58·8 sq. yds. of each plot in 1967 expt.

Replicate No.	Control	DDT	Folithion
1	55·0	41·0	37·0
2	44·0	37·0	39·0
3	54·0	54·0	29·0
4	40·5	54·0	59·0
5	55·0	58·0	49·0
6	39·0	34·5	41·0
Total	287·5	278·5	254·0
Mean	47·91	46·41	42·33

TABLE 41

No. of grains per 20 grams, in each plot

Replicate No.	Control	DDT	Folithion
1	374	421	371
2	398	435	415
3	354	352	421
4	360	400	422
5	394	427	405
6	420	384	382
Total	2300	2419	2416
Mean	383·33	403·16	402·66

TABLE 42

No. of unripe grains in each 20 grams. of grain per plot

Replicate No.	Control	DDT	Folithion
1	9	7	6
2	11	14	2
3	2	3	2
4	7	7	3
5	3	3	9
6	10	3	5
Total	42	37	27
Mean	7·0	6·16	4·5

APPENDIX III

Table 43, showing the plant species in different soils in the experiment of Section 7.

Tables 44 to 46, showing the data of Section 8.

Tables 47 to 51, showing the data of Section 9.

TABLE 43

The vegetation species in different soils

1. Sandy soil.	Dominant. Italian Rye Grass.
2. Loam.	Dominant. Perennial Rye Grass. Annual Meadow Grass.
3. Clay.	Dominant. Yorkshire Fox. White clover. Rough stalked Meadow Grass. Smooth stalked Meadow Grass. Agrostis. Perennial Rye Grass.
4. Peat.	Dominant. Agrostis. Perennial Rye Grass. Buttercup. White clover.

TABLE 44

The number of larvae dead, due to virus, cannibalism, etc..and number of adults emerged in different treatments.

Treatments	Poly Pot No.	No. of larvae	Death with virus in instars 2	3	4	Total death by virus	Death due to cannibalism in instars 2	3	4	Total death by cann.	cause of death unidentified	Total death	No. of adults emerged	No. of weeks infected larvae survived Min.	Max.
SIT*	1	5	2	1		3	2			2		5		8	9
	2	5	2			2	1		1	2	1	5			2
	3	5						3	1	4		4	1		
	4	5	1		1	2	2			2		4	1	2	3
	5	5	1			1	3			3		4	1		2
Total		25	6	1	1	8	8	3	2	13	1		3		
GIT*	1	5					3	1		4		4	1		
	2	5					1	1		2		2	3		
	3	5		1	2	3	0	2		2		5			3
	4	5		1		1	1	1		2		3	2		3
	5	5					1	1	1	3		3	2		
Total		25		2	2	4	6	6	1	13		17	8		
DET*	1	5	1	2	1	4	1			1		5		4	13
	2	5	3			3	2			2		5		1	3
	3	5	2	2		4	1			1		5		2	5
	4	5	1	3		4	1			1		5		1	6
	5	5	5			5						5			3
Total		25	12	7	1	20	5			5		25			
Control	1	5						4		4		4	1		
	2	5					1	1	1	3		3	2		
	3	5							2	2		2	3		
	4	5						1	2	3		3	2		
	5	5					1		2	3		3	2		
Total		25					2	6	7	15		15	10		

* Details on page 157.

TABLE 45

The number of larvae dead due to nuclear polyhedrosis virus, cannibalism etc., and number of adults emerged

Treatments	Poly Pot No.	No. of larvae	Death with virus in instars 2	3	4	Total death by virus	Death due to cannibalism in instars 2	3	4	Total death by cann.	cause of death unidentified	Total death	No. of adults emerged	No. of weeks infected larvae survived Min.	Max.
SIP	1	5					1	1		2	1	3	2		
	2	5					1		2	3		3	2		
	3	5					1	1	2	4		4	1		
	4	5					3	1		4		4	1		
	5	5					1	2		3		3	2		
Total		25					7	5	4	16	1	17	8		
GIP	1	5						2	2	4		4	1		
	2	5	1			1	1	1	1	3		4	1		3
	3	5					3			3		3	2		
	4	5					2	2		4		4	1		
	5	5							3	3		3	2		
Total		25	1			1	6	5	6	17		18	7		
DFP	1	5	1	1		2		3		3		5		5	12
	2	5	2			2	1	2		3		5		5	11
	3	5	2			2		3		3		5			14
	4	5					2	2		4	1	5			
	5	5	2			2		3		3		5			13
Total		25	7	1		8	3	13		16	1	25			
Control	1	5					1	2		3		3	2		
	2	5					1	1	1	3		3	2		
	3	5					1	1		2		2	3		
	4	5						1	2	3		3	2		
	5	5					1	1	1	3		3	2		
Total		25					4	6	4	14		14	11		

TABLE 46

Number of larvae reared in field soil and sterilized field soil, and number alive at the end of experiments

Pot No.	No. larvae in each	Alive in sterilized soil	Alive in unsterilized soil
1	10	2	1
2	10	3	3
3	10	2	4
4	10	2	3
5	10	5	1
6	10	4	4
7	10	4	2
8	10	3	3
9	10	3	2
10	10	4	1
Total	100	32	24

TABLE 47

Experimental Field, 1966 (31 May to 13 June).

A total of 5 observations in each treatment

Name of beetle	Control	DDT	Aldrin	Total each sp.
1. Pterostichus madidus	10	9	29	48
2. Pterostichus niger	265	269	228	762
3. Nebria brevicollis	8	3	29	40
4. Euryporus spp.	232	243	267	742

TABLE 48

Experimental Field 1967.

A total of 8 observations in each treatment
(7 June to 28 June)

Name of beetle	Control	DDT	Folithion	Total of beetle each sp.
1. Pterostichus niger	34	43	52	129
2. Pterostichus vulgaris	48	49	45	142
3. Agonum mulleri	46	38	87	171
4. Euryporus spp.	102	131	111	344

TABLE 49

Total number of larvae in each tin at the end of the experiment (initially there were 10 larvae in each tin)

Tin No.	Names of predators			
	P. niger	P. madidus	Euryporus spp.	Control
1	7	5	10	10
2	9	5	10	10
3	7	6	10	10
4	5	7	10	10
5	6	4	10	10
6	8	5	10	10
	42	32	60	60

TABLE 50

Total number of larvae eaten by each beetle within 2 weeks

Polypot No.	Names of predators			
	P. niger	P. madidus	N. brevicollis	Control
1	2	3	1	
2	2	1		
3	2	1		
4	1	2	1	
	7	7	2	

TABLE 51

Total number of larvae eaten by each beetle within 2 weeks

Polypot No.	Names of predators			
	P. niger	P. vulgaris	A. mulleri	Control
1	3	1		
2	4			
3	3			
4	4	1		
5	1	1		
6	3			
	18	3		

APPENDIX IV

Tables 52 to 56, showing the rainfall records

TABLE 52

The monthly rainfall in 1965

(a) Humbie represents the trial at Mavis Hall Farm,

(b) Armadale at Crofthead Farm.

Months	Humbie House	Armadale
March	2·58	2·71
April	1·99	3·24
May	2·46	2·65
June	2·05	3·51
July	5·12	4·25

Rainfall is recorded in inches.

TABLE 53

Rainfall record (Bush, Midlothian) 1965, in inches.

Days	April	May	June
1			
2		0·01	
3		0·35	
4			0·05
5	0·10		0·05
6	0·02	0·10	0·26
7	0·10	0·23	0·04
8		0·07	
9	0·42	0·01	
10	0·05		
11	0·51		0·04
12	0·01		0·11
13			
14	0·07	0·11	0·53
15			0·28
16	0·18	0·52	
17	0·13	0·57	0·17
18	0·10	0·13	0·06
19	0·10		
20			0·60
21		0·03	0·01
22	0·03		
23		0·14	0·08
24		0·11	0·23
25	0·06	0·25	0·34
26	0·23	0·12	
27	0·21	0·05	
28	0·19	0·03	
29			
30			0·02
31			
Total	2·51	2·83	2·87

This rainfall table covers the period of field experiments in Section 2, showing the dry days.

TABLE 54

Rainfall 1966 (Record of Blackford Hill, Edinburgh) in mm.

Days	April	May	June	July
1				
2				
3			1·3	
4		1·4	0·1	
5	5·9	4·1		5·5
6	0·1		10·1	0·2
7	1·4	4·7		
8	4·4	1·7	0·2	
9	12·2		0·1	
10	6·7		0·2	4·3
11	2·2	9·0	0·2	
12	0·2		3·6	0·3
13			0·5	5·1
14	2·1	1·5	3·6	0·6
15	0·1		11·3	5·0
16			12·2	0·1
17		0·6	8·4	
18	1·6	1·0	3·5	
19	2·0	1·2	0·8	
20	0·2	1·6		
21	1·3	3·3	10·3	
22	6·3	2·3	10·5	
23	0·6		17·3	
24	1·0	4·0	1·2	0·1
25		0·1	0·3	4·1
26	0·2		9·1	2·0
27			3·1	1·8
28				
29				3·6
30				7·2
TOTAL in mm.	48·5	36·5	107·9	39·9
" " in.	1·91	1·44	4·25	1·57

// This rainfall table covers the period of experiment B in section 4 showing the dry days.

TABLE 55

Rainfall, 1966 (record of Armadale#) in inches

Days	April	May	June	July	Aug
1					0·09
2					
3			0·14		0·65
4		0·05	0·20		0·52
5	0·12	0·38	0·01	0·09	
6	0·01	0·11	0·27	0·02	
7				0·01	
8		0·23			0·04
9	0·66		0·09		0·65
10	0·09			0·08	0·09
11	0·08	0·45			0·30
12			0·20	0·13	0·20
13		0·02		0·18	1·73
14	0·02	0·03	0·07		
15			0·66	0·05	
16		0·30	0·01	0·05	0·12
17		0·12	0·34		0·03
18	0·13	0·09	0·30		
19	0·14	0·18	0·25		
20		0·14	0·06		0·32
21	0·28	0·50	0·54		0·30
22	0·63	0·11	0·27		0·02
23			0·69		
24	0·20	0·23	1·29	0·06	
25		0·01		0·20	
26	0·12		0·04	0·04	
27	0·03		0·25	0·08	
28			0·17		
29				0·25	0·22
30				0·32	
31					
Total	2·51	2·95	5·85	1·56	5·10

This recording station is near the sites of the field experiments in 1966 and 1967.

TABLE 56

Rainfall, 1967 (Record of Armadale) in inches

Days	April	May	June	July	Aug
1	0·38	0·05		0·10	
2	0·27	0·50	0·08	0·13	
3	0·08	0·07	0·09	0·09	
4	0·03	0·04			
5			0·08		
6		0·36	0·20		
7		0·08	0·06	0·20	0·02
8	0·14	0·04		0·16	0·12
9					0·12
10		0·12			0·04
11		0·47			0·73
12					0·50
13		0·05		0·33	
14		0·04		0·30	1·17
15		0·71		0·20	0·02
16		0·36		0·21	0·12
17		0·25		0·46	
18		0·19		0·06	
19	0·15	0·01	0·28		
20	0·03		0·02		0·01
21		0·20	0·16		
22		0·12	0·29		
23		0·31		0·13	
24	0·17	0·10			
25		0·07	0·07	0·05	
26			0·02	0·06	
27		0·39	0·06	0·06	0·27
28		0·05	0·23		0·13
29	0·10			0·16	0·03
30				0·13	0·03
31				0·27	
Total	1·35	4·58	1·64	3·10	3·31