Paper 11

THE POTATO MOTH *PHTHORIMAEA OPERCULELLA* (ZELLER) — ITS HABITS, DAMAGE POTENTIAL AND MANAGEMENT

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INTRODUCTION

The potato moth, *Phthorimaea operculella* (Zeller) (Lepidoptera:Gelechiidae), is not new to Australasia; the first reference made to this cosmopolitan pest commented on the damage it had caused to the 1854 Tasmanian potato crop (Berthon, 1855). It was also suggested that the moth had been noticed in New Zealand a year earlier (Berthon, 1855). The pest was also observed in California at about the same time (Graf, 1917). In spite of these widespread observations, it is generally felt that the potato moth originated in South America (Picard, 1912) — the home of the potato plant (Correll, 1962). The potato moth is now globally distributed and is present in tropical or subtropical regions practically wherever potatoes are grown (Anon, 1951). Detailed reports on the pest's biology and damage potential, therefore emanate from many countries, including India, U.S.A., Egypt, Iraq, Japan, South Africa and Australia. Potato moth is not restricted only to potatoes; many studies discuss the pest's host range which extends to numerous species of Solanacae including tobacco (*Nicotiana tabacum* L.), tomatoes. (*Lycospersicon esculentum* Mill.) and egg-plants (*Solanum melongena* var.).

Two features that have rendered potato moth an important pest, are its high reproductive potential and the inability of insecticides to directly prevent tuber infestation (Foot, 1979). Once inside the tubers larvae are screened from contact insecticides. Consequently, considerable research effort has been directed towards the biology of potato moth with a view to developing non-chemical control methods.

This contribution attempts to review some of the research conducted on potato moth and to put the pest into New Zealand perspective. In order to do this we have drawn heavily on the comprehensive work of Marion Foot, formerly of the Plant Diseases Division, DSIR, Auckland.

POTATO MOTH LIFE STAGES, DAMAGE AND POPULATION DEVELOPMENT

Eggs

When laid, potato moth eggs are initially pearly-white; as development proceeds they turn orange and darken eventually becoming black just before hatching (Fenemore, 1982). They are about 0.5 mm long (Graf, 1917) and tend to be laid in groups stuck onto rough surfaces (Hofmaster, 1949) such as the undersides of host plant leaves, stems, eyes of tubers, rough sacking etc. It has also been suggested that potato moths oviposit preferentially on plants with a poor water balance (Yathom, 1968).

Duration of incubation varies with temperature; under Pukekohe 'summer' conditions Foot (1979) has found that eggs take about 5 days to hatch; this concurs with the findings of other workers (e.g. Broodryk, 1971).

Larvae

It is the larval stages that do the damage to potato crops. A newly emerged larva is about 1 mm long, transparent or pale coloured with a dark head capsule (Hofmaster, 1949). The last and fourth instar is 8.6-11.6 mm long, creamy white in colour and often has green or pink tinges (Hofmaster, 1949). The larvae have 3 pairs of black thoracic legs and 5 pairs of prolegs. They are fairly typical lepidopterous larvae. Development through the larval stages can be rapid — at 25 °C Broodryk (1971) found the time required for development was only 12 days.

Foliar attack by larvae is characterised by mines which leave the epidermal layers intact and blistered. Reed (1971) has pointed out that mine development typically occurs along the mid-rib of older, larger leaves which are attacked preferentially. Poos and Peters (1927) reported that when food is insufficient, larvae may abandon their mines and tie adjacent leaflets with silken thread, feeding generally on the leaf tissue.

There is uncertainty in the literature as to whether potato moth larvae mine in the stems and cause whole terminal sections of leaf to die off, as contended by Hofmaster (1949). Concensus is with Poos and Peters (1927) who rarely found larvae in the petioles or stems. Reed (1971) manipulated various larval densities per leaf and, at high levels, found that while larvae did not usually tunnel into the stems they made coverings of webbing under which they fed on the green outer tissue. Larvae never gain access to tubers by mining through the plant stems (Foot, 1979). Larval mining of foliage by potato moth has not been shown to have a direct effect on tuber quality and, in general, growth conditions over-ride the effects of absolute numbers of larvae (Bald and Helson, 1944). It was found however, that yield within a season was proportional to the area of leaves left undamaged (Bald and Helson, 1944). Generally, yield loss arises directly from larval mining in the tubers. Such damage occurs either as a consequence of oviposition on the tubers or through larvae moving from senescent or overpopulated tops (Broodryk and Zimmermann, 1967). Any tubers covered with less than 10 mm of intact soil are susceptible to such attack (Foot, 1979), and consequently cracked or lumpy soil can lead to serious damage.

Larval mining is usually made apparent by patches of dark-coloured, sawdust-like excreta pushed out of the tunnels onto the surface of the tuber often around the eyes (Fenemore, 1982). The mycelial clogged sinusoidal mines are often in the peripheral parts of the tuber, but can riddle the entire tuber in severe cases (Hofmaster, 1949). Either way, the tuber is unacceptable for consumption.

Prepupal and Pupal Stages

When fully grown, the larvae abandon their food source and spin a cocoon in which they enter the quiesient prepupal stage. During this time they become contracted and take on a bluish-green hue (Hofmaster, 1949).

The pupae themselves are a chestnut brown colour, encased within the silken cocoon (Fenemore, 1982). Broodryk (1971) reported pupal duration at 25 °C to be 6.4 days. Typically pupae and prepupae are found in the soil around the bases of the plants or other sheltered places (Hofmaster, 1949).

Adult Moths

Potato moths are rather nondescript, with grey-brown, darkly flecked wings which span some 10-12 mm and assume a narrow profile when at rest (Fenemore, 1982). The moths are usually inactive during the day, but when disturbed (e.g. by shaking the haulms of an infested potato plant) they undergo a short burst of characteristically flitting flight. Their peak flight activity is at dusk (Goldson and Emberson, 1977).

Foot (1979) found that fecundity varies with the prevailing conditions. About 140-170 eggs per female are laid in spring or autumn temperatures, compared to 50-80 eggs in summer. The moths only live for about 2 weeks (Fenemore, 1979) and they do not appear in the field as a discrete generation.

POTATO MOTH SEASONALITY, POPULATION DEVELOPMENT AND CROP DAMAGE

The potato moth overwinters, in a state of cold-induced torpor, on volunteer plants and culled tubers, usually in the prepupal stage and possibly in a state of reduced metabolic activity — a sort of precursor to adaptive diapause (Foot, 1979). It is from these beginnings that the infesting population develops. There are contradictions in the literature about the ability of potato moth to fly. An understanding of this aspect is important as it bears on the potential of the pest to infest crops in the spring. Graf (1917), Hofmaster (1949) and Fenemore (1982) have submitted that they are poor fliers, whereas others have contended that this may not be so (e.g. Attia and Mattar (1939); Yathom (1968); Goldson and Emberson (1977)). Goldson and Emberson (1977) suggested that leaf volatiles from spring crops attract the moths from their overwintering sites through an anemotaxic response. Reed (1971) noted higher numbers of larvae along the edge of a new crop planted 100 m to windward of an infested potato crop; this indicates a possible upwind migration of moths. Foot (1979) found highest densities of larvae in headlands and zones of wind dump — an effect she suggested may be related to areas of high volatile intensity.

The high fecundity and short development time of potato moth is a recipe for damaging population explosions. Foot (1979) calculated the potential potato moth population multiplication rate for spring/autumn conditions to be 36.6 per generation and has noted 6-8 generations a year in the North Island (Foot, 1975). Vagaries of weather have been shown to have an important influence on these explosions. In her analysis, Foot (1979) showed that seasonal variation in population at Pukekohe was strongly and positively correlated with temperature. Moisture also has a profound effect on the population development of potato moth — so much so that Graf (1917) was under the impression that rain killed the larvae in the leaves. Subsequent workers however, (e.g. Poos and Peters, 1927; Langford and Cory, 1932) have shown this to be incorrect.

Foot (1974a) observed that moist soil was less cracked, but even where larval or adult access to tubers was available, they were repelled by dampness. She also found that while sprinkler irrigation reduced the mines per leaf, the actual density per square metre increased; because there was more foliage available for infestation (Foot, 1974a).

Unchecked, potato moth can be most damaging; estimates of loss vary widely, but levels of up to 58% have been recorded in New Zealand (Anon, 1974).

THE CONTROL AND MANAGEMENT OF POTATO MOTH

There are a number of approaches aimed at reducing crop loss through potato moth, and good results can best be obtained by careful integration of all these methods.

Cultural Control

As early as the middle of last century, it was recognized that prompt harvesting and good storage hygiene could reduce levels of tuber infestation (Berthon, 1855). Graf (1917) emphasised the importance of substantial planting depths, and wide ridges. Poos and Peters (1927) found rotation valueless when numerous culled potatoes were left lying around throughout the winter. Hofmaster (1949) summarized all the main tenets of cultural control and, in doing so, advised growers to practice 'hilling', thereby keeping the tubers covered with at least 50 mm of soil. He, too, emphasised the value of early harvest — he advised against leaving dug potatoes in the field overnight and pointed out the importance of crop hygiene — i.e. the elimination of culled tubers that provide ideal overwintering sites for the following season's moths.

Foot (1974a, 1976a) conducted detailed research aimed at quantifying these recommendations and has put them into the New Zealand context. She found tuber damage was halved by planting seed potatoes 250 mm below the ridge apex, rather than at the standard 180 mm depth. To some extent further protection was also afforded by remoulding at flowering (Foot, 1976a).

Foot (1976a) investigated the effects of destruction of infested foliage 1 week before harvest. It was found that mowing the haulms can cause considerably increased damage to tubers because the wilting foliage lying near to the ground attracts egg-laying moths to the vicinity of the tubers. A proportion of newly emerged larvae also probably transfer straight to the tubers. This process had become apparent 12 days after harvest at regrading. Chemical defoliation (paraquat) did not lead to the same problem (Foot, 1976a). Foot (1976a) was also able to demonstrate that delaying harvest for 2 and 4 weeks after defoliation led to a proportional increase in tuber damage, thereby confirming that the moths will lay on potatoes in the absence of foliage.

Drought conditions have long been recognised as capable of making the problem of potato moth worse (Langford and Cory, 1932; Langford, 1933; Lall, 1949). Foot (1974a) investigated the effects of irrigation in New Zealand and found that in a dry season at Pukekohe, infestation of Ilam Hardy tubers was reduced from 86% to 10% by watering. She concluded that timely and consistent maintenance of soil moisture above 30% oven dry weight throughout the latter 6-8 weeks of the crop growth was important for Pukekohe summer crops. Consistent with Foot's (1974a) work, Shelton and Wyman (1979) showed that sprinkler irrigation was more effective at reducing damage than furrow irrigation, with 4% compared to 25% tuber damage respectively. They also showed a rapid rise in infestation levels after ending the irrigation. Further to her irrigation work, Foot (1976a) found that by increasing row spacing from 760 mm to 910 mm, yield losses could be reduced even more. This was presumably because the wider rows allowed more tuber 'bulking-up' before cracking the soil. The more gentle slopes of the wider rows were also less prone to erosion. Both of these processes would serve to reduce the susceptibility of the tubers to attack. Foot (1976a) was able to maintain plant density by planting seed potatoes at 250 mm rather than 300 mm intervals with no adverse effect on yield.

As elsewhere, crop hygiene in New Zealand is essential. In Canterbury, Goldson (1976) recorded an increase in infestation of culled tubers left in the field from 0% to 90% in 6 weeks — in a season where potato moth was not even a problem. This emphasises the need for culled tubers and volunteer plants to be collected and destroyed as quickly as possible. Similarly, Poos and Peters (1927) observed that after harvest the crop should be removed from the field promptly. If not, intervening oviposition and resultant larval attack can subsequently cause severe damage to the tubers when in storage. To minimise such damage, Fenemore (1982) has cautioned against positioning infected tubers in the vicinity of clean tubers, and recommends the maintenance of temperature below 10 °C in order to slow potato moth development.

Another approach to the problem of potato moth has been to search for resistent cultivars. Foot (1976b) field-tested 20 different varieties, but unfortunately found a high incidence of leaf and tuber damage in all. Any differences that did emerge were largely explainable in terms of the differential growth habits of the plants — some of which set and bulked up tubers higher in the soil profile than others (Foot, 1976b).

Biological Control

There are numerous parasitic enemies of potato moth. These have been described and listed by such workers as Graf (1917), Poos and Peters (1927), Hofmaster (1949) and Shepherd (1965).

In New Zealand, the braconid parasite *Apanteles subandinus* (Zeller) was released in the 1960's and has become widely established in both islands. Foot (1979) has since recorded levels of parasitism of 45.5%. However, she found that the relative population dynamics of the moth and this parasite were such that there is likely to be little reduction in damage levels to potatoes resulting from summertime explosions of moth populations (Foot, 1979).

Under laboratory conditions, Steinhaus (1945) found potato moth larvae infected with the bacteria *Serratia mercescens* Bizio and *Aerobacter cloacae* Jordan. Picard (1912) found a protozoan *Nosema bombycis* Nag. Although recorded, none of these pathogens have appeared subsequently in the literature as important population regulators. Neither apparently, have any predators.

Of substantially more interest was the discovery of a granulosis virus attacking Sri Lankan potato moth (Steinhaus and Marsh, 1967). It has since been found in Australia (Reed, 1969) and South Africa (Broodryk and Pretorius, 1974). Reed and Springett (1971) were able to drastically reduce potato moth populations with this virus in south-west Western Australia. Since then, the potential of the pathogen as a control agent has been explored further and Briese and Mende (1981) have shown that field-sampled potato moths can vary in susceptibility by a factor of up to 11.6 times. These workers have suggested that degrees of genetic resistance may operate periodically against this endemic virus which probably flares up occasionally under natural conditions. In view of this potential for resistance, they have cautioned that the development of this virus as a biological pesticide would be fraught with difficulties (Briese and Mende, 1981).

Excitants and sex attractants for male potato moths have been known for some time (Hughes, 1967; Adeesan *et al.*, 1969; Persoons *et al.*, 1976). However, on account of the very high reproductive potential of potato moth, it is unlikely that such attractants could usefully reduce populations. A major use for these materials may well be population monitoring, and researchers such as Shelton and Wyman (1979) have explored their potential for such work. Sex attractants could also be used to monitor population growth, so that spray programmes may be density-based and not just conducted as calender schedules.

Chemical Control

Prior to the advent of DDT , control had been attempted with an array of materials including mercuric chloride, lead arsenate, sodium flouride and magnesium carbonate (Hofmaster, 1949). None of these chemicals had any real economic value. Caldwell (1946) made the first tentative suggestion that DDT might be useful for the control of potato moth in the field. Much of the pioneer work with DDT was summarized by Helson (1949). He described how 0.1% DDT was superior to all other treatments irrespective of how it was applied. Hofmaster (1949) pursued the DDT work further and May (1952) in Queensland, Australia, showed how DDT applied at fortnightly intervals on 2 or 3 consecutive occasions could adequately protect a crop from potato moth, and lead to a 43% increase in weight of table grade tubers. It was the lack of degradability of DDT — the very thing that made it an environmental pollutant — that contributed to this material's success as a control agent, as it was able to continue to kill larvae after emergence from the protection of leaves and tubers and thereby suppress population explosions. By the mid-60's, potato moth was showing resistance to DDT (Champ and Shepherd, 1965; Richardson and Rose, 1967) and this, combined with environmental reasons, led to the abandonment of DDT.

The more transient organo-phosphate and carbamate insecticides have been less effective at controlling potato moth than DDT. For example, Ispray Ltd (1974) in their 1973-74 report, described how 11 fortnightly applications of azinphos-ethyl were only able to reduce the percentage weight of infected tubers from 29.8% (control) to 21.4%. Foot (1974b) systematically assessed several insecticides applied at 10 day intervals against potato moth at Pukekohe. Generally, she found none could control damage to the tubers although there were varying degrees of success in limiting foliar infestation. She found azinphos-ethyl at 0.46 kg ai/ha in 842 litres of water was the most effective material. This was later substantiated by laboratory tests (Foot, 1976c). She further noted that acephate (0.83 kg ai/ha), methamidaphos (0.67 kg ai/ha) and chlorpyrifos (0.56 kg ai/ha) in 1000 litres of water gave reasonable control of foliar attack under moderate infestation pressure (Foot, 1974b). As with azinphos-ethyl, the final effect of acephate was reduced tuber infestation.

As a result of the work on chemical control, the following materials have been registered with the New Zealand Pesticides Board as control agents for potato moth: acephate 0.75 kg ai/ha, azinphos-ethyl 0.5 kg ai/ha, azinphos-methyl 0.4-0.5 kg ai/ha, endosulfan 0.7 kg ai/ha, methamidophos 0.7 kg ai/ha.

In general, Foot (1974b) has pointed out that chemical suppression of population increases in foliage during the growing season results in fewer moths and larvae to infest tubers when the crop matures. In view of this, there is no point in chemically protecting a stand if there is a severely infested stand nearby (Foot, 1974b).

Foot (1974b, 1976a) has warned of the problems of virtually invisible potato moth eggs and neonate larvae being overlooked at harvest grading and subsequently becoming a problem during storage. This can be particularly damaging to a grower's reputation with commercial produce marketers; to offset this, she has strongly recommended regrading of tubers after 2 weeks (Foot, 1974b, 1976a).

Du Toit and Rowe (1980) have tested a number of insecticides applied to sacking as a possible means of reducing in storage infestation of tubers. They found that fenvalerate (30 g in 5 litres water/m^2 of sack) decamethrin (1.25 g in 5 litres water/m^2 of sack) and maldison (150 g in 5 litres water/m^2 of sack) all prevented oviposition through sacking for at least 6 months. While this may be of value to small producers, many larger operators maintain tonnes of tubers in bulk storage, rather than in sacks.

In the North Island, ambient storage temperatures are frequently well above the recommended 10°C minimum (Fenemore, 1982). In view of this, there is considerable interest in the possible use of insecticidal dusts or sprays applied to tubers just prior to storage to prevent further spread of infestation. Trought (unpublished) experimented with maldison dusts at or below the 8 p.p.m maximum permissible limit set by the Food and Drug Regulations 1973. He found this rapidly killed adults in storage for over 13 weeks, but there were serious problems associated with the lack of adhesion of dust during the application process. This also led to patchy distribution of insecticide, and a possible health hazard through inhalation. In summary, Trought (unpublished) was of the opinion that spray application would be more satisfactory, although this would require a more complex technology. Similar to maldison, carbaryl residues are permissible to levels of up to 10 p.p.m and, on request, a 5% dust is available which may be used at 2 kg/tonne of tubers. However, there are no rigorous experimental data yet available to demonstrate this product's efficacy or otherwise (Fuller, pers. comm., The N.Z. Farmers' Fertilizer Company Limited).

Chemical protection of tubers in storage presents its self as a useful area for further work, particularly as on

11th March 1983, the Pesticide Act 1979 replaced the Agricultural Chemicals Act 1959. Under the provisions of the old Act, 'crops' became 'food' after harvest, and only Food and Drug regulations applied. However, under the auspices of the Pesticides Act of 1979, chemicals that are supposed to protect crops in storage have to be demonstrated to be efficient control agents as well as conforming to Food and Drug Regulations residue limits; companies had a year to demonstrate this.

CONCLUSIONS AND RECOMMENDATIONS

There is general concensus in the literature that potato moth is particularly troublesome during hot dry seasons. These conditions facilitate a rapid build up of population and allow ready access to the tubers by adults and larvae through cracks in the soil; the latter may sometimes transfer from foliage. Because of the protected habitat of potato moth it is generally agreed that insecticides alone are inadequate and cognizance of cultural control and crop hygiene must be taken.

In New Zealand, tuber damage can be halved by planting at depths of 250 mm, instead of the standard 150-180 mm. Likewise, it has been shown that sprinkler irrigation to maintain soil moisture at levels above 30% oven-dry weight during the latter 6-8 weeks crop development can reduce damage by over 75%. It is suggested that remoulding at flowering may reduce damage further and it has been noted that mechanical defoliation produces higher levels of attack than chemical methods. Delayed harvest after defoliation may also induce further damage. Moreover, 910 mm ridge spacing rather than the standard 760 mm spacing reduces damage by allowing more room for the tubers to set without soil cracking. This wider ridging also reduces erosion through irrigation. At harvest, it is important to remove all culled tubers and volunteer plants as promptly as possible as these provide ideal overwintering sites for the moth.

Of the insecticides available, azinphos-ethyl at 0.5 kg ai/ha in 1000 litres of water applied regularly once infestation has started is recommended. This tends to keep larval populations reduced, thereby minimising subsequent transfer to the tubers.

Regrading of tubers is recommended within 2 weeks of harvest, where severe infestation has occurred. This helps to prevent the moth spreading through the crop in storage. To further reduce storage damage it is strongly recommended that tubers are removed from the field as quickly as possible after harvest. It is also important not to store infested tubers in the vicinity of clean ones and, if possible, to maintain store temperatures below 10°C to slow down potato moth development. Where temperature control is impossible, maldison treatments at 8 p.p.m or carbaryl at 10 p.p.m applied to the potato skins may further reduce the spread of damage to tubers in storage. Similarly, when storage is in bags, fenvalerate, decamethrin, maldison and cypermethrin can be used to treat sacking and reduce damage.

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