Paper 9

PESTS OF MAIZE IN NEW ZEALAND

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INTRODUCTION

A wide range of insect species cause significant damage to maize crops in overseas countries (Dicke, 1977), but fortunately the number of species attacking maize in New Zealand (NZ) is much smaller. Similarly, soil nematodes (Johnson, 1979) and virus diseases, transmitted by aphids or leafhoppers (Gordon *et al.*, 1978), are not recognised as significant factors influencing maize production in this country.

Pests of maize crops in NZ are conveniently divided into those that primarily affect the seedling stage, up to six weeks from planting, and those which attack the leaves and fruiting bodies on established plants (Table 1).

Prior to 1972, damage by the cosmopolitan army worm, *Mythimna separata* (CAW), an insect which feeds mainly on established plants, was of major concern to maize growers. However, since that time CAW has been successfully controlled by the introduced parasitic wasp *Apanteles ruficrus* Haliday (Hill and Atkins, 1983). This pest and the tomato fruitworm (= corn earworm), *Helicoverpa armigera conferta* (TFW), are now largely of significance in sweetcorn crops, where the cosmetic appearance of ears is of paramount concern.

At this time, two pests which attack seedling plants, Argentine stem weevil, *Listronotus bonariensis* (ASW), and greasy cutworm, *Agrotis ipsilon aneituma*, are undoubtedly the most costly pest problems. These pests occur in all maize growing districts and occasionally cause such severe damage that crops require replanting. Two other pests of seedling maize, Australian soldier fly, *Inopus rubriceps*, and black beetle, *Heteronychus arator*, have declined in significance in recent years, for reasons which could be of long term effect (Robertson *et al.*, 1981; Watson and Wrenn, 1980).

This paper discusses the significance and prevention of pests that attack maize crops in NZ. Descriptions and colour illustrations of the more important pests can be found in publications of the DSIR Information Series No. 105.

AUSTRALIAN SOLDIER FLY

Australian soldier fly occur in pastures in South Auckland, Bay of Plenty, Waikato and more recently in Northland and coastal Taranaki (Robertson and Blank, 1982). The segmented, leathery soldier fly maggots move onto maize seedlings in the absence of their grass and legume hosts. Crop damage occurs at two levels — individual maggots can attack and destroy emerging seedlings, often by attack at the epicotyl (between the seed and plant base) (Hewitt, 1969; Given, 1973); growth of plants beyond the seedling stage may be stunted by many individuals sucking sap from the fibrous roots. Maize paddocks affected by large numbers of ASF therefore have both poor establishment and patchy, stunted growth. High populations of the pasture wireworm, *Conoderus exsul* are often associated with high soldier fly densities (Robertson *et al.*, 1981). This can further accentuate poor maize establishment.

Even though this pest has declined in importance in recent years, soldier fly numbers in pasture can reach several thousand/m^2 (Robertson *et al.*, 1981). Long fallows are required to reduce their numbers (Wilcocks and Hewitt, 1971). This period can be shortened using herbides to assist pasture breakdown (Cumberland *et al.*, 1973) and with insecticidal protection of seedlings (Davison *et al.*, 1979). Protection of maize can be obtained with carbofuran (Dixon and Grimmer, 1973; Mackay and Rowe, 1973), phorate (Saunders, 1975) and parathion (Hewitt, 1969; Fellowes, 1971). Because of the high numbers of ASF which can occur in pasture, even high density forage maize crops can be affected (Hutton, 1971). Insecticides at planting did not effectively protect high density direct drilled forage maize (Robertson *et al.*, 1980). ASF do not persist in significant numbers in arable ground.

WIREWORM

Several species of wireworm occur in pasture, with densities reaching 60/m^2 (Robertson *et al.*, 1981). Wireworm are elongate, six legged creatures up to 30 mm

Table 1: Invertebrate pests of maize.

Pest			Text symbol
Pests of seedling maize			
(i)	Mainly after pasture		
	Australian soldier fly	*Inopus rubriceps* (Macquart) Diptera: Stratiomyidae	ASF
	Pasture wireworm	*Conoderus exsul* Sharp	
	Variable wireworm	*Agrypnus variabilis* (Candeze) Coleoptera: Elateridae	
	Whitefringed weevil	*Graphognathus leucoloma* (Boheman) Coleoptera: Circulionidae	
	Black beetle	*Heteronychus arator* (Fabricius) Coleoptera: Scarabaeidae	
(ii)	After pasture and arable crops		
	Argentine stem weevil	*Listronotus bonariensis* (Kuschel) Coleoptera: Circulionidae	ASW
	Greasy cutworm	*Agrotis ipsilon aneituma* (Walker) Lepidoptera: Noctuidae	
Pests in established maize			
	Cosmopolitan armyworm	*Mythimna separata* (Walker) Lepidoptera: Noctuidae	CAW
	Southern armyworm	*Persectania aversa* (Walker) Lepidoptera: Noctuidae	
	Tomato fruitworm (= corn earworm)	*Helicoverpa armigera conferta* (Walker) *H. punctigera* Wallengren Lepidoptera: Noctuidae	TFW
	Green looper	*Chrysodeixis erisoma* (Doubleday) Lepidoptera: Noctuidae	
	Cereal aphid	*Rhopalosiphum padi* (L.)	
	Corn leaf aphid	*R. maidis* (Fitch) Aphididae: Hemiptera	
Minor pests			
	Maize seed beetle	*Clivina rugithorax* Putz. *C. basalis* Chaudoir Coleoptera: Carabidae	
	Brown field slug	*Deroceras panormitanum* (Pollonera and Lessona)	
	Grey field slug	*D. reticulatum* (Muller)	

long with yellowish to brown colouring. They are the larval stages of click beetles. They are omnivorous feeders which attack maize seedlings in the absence of alternative hosts. Some wireworm species are strongly attracted to germinating seeds (Doane *et al.*, 1975). The most common species in association with maize are the pasture wireworm and variable wireworm, *Agrypnus variabilis* (East and Watson, 1978). Granules of insecticides used at planting will prevent wireworm damage in maize. These include carbofuran, phorate and isazophos.

Wireworms, whitefringed weevil, *Graphognathus leucoloma*, and black beetle cause similar damage to maize seedlings. They tunnel at the base of the plant causing the centre leaves to wilt. Wireworm and whitefringed weevil usually leave a small circular hole, while black beetle feeding is characterized by a more mascerated appearance of damaged tissue. Damaged plants either die or tiller from the base of the plant and become stunted. All three insects may also feed on the seed and epicotyl although emergence of maize is seldom affected significantly.

WHITEFRINGED WEEVIL (see section on wireworm for effect on plant)

The white, legless grubs of whitefringed weevil occur at numbers which may exceed 200/m^2 in pasture, particularly in association with legumes (King and East, 1979). They are not strongly attracted to maize plants (East and Watson, 1978), but seedlings may be attacked in the absence of alternative hosts (Given, 1973). Numbers are reduced by intensive cultivation in spring (East and Parr, 1977a). Granular insecticides at planting afford some protection, but high rates may be required for effective reduction of larval numbers (East and Parr, 1977b). Any graminaceous crop will reduce numbers of whitefringed weevil by the second year as oviposition is greatly reduced in the absence of non-graminaceous host plants (East, 1977; East and Parr, 1977a).

BLACK BEETLE (see section on wireworm for effect on plant)

Black beetle grubs cause damage to the root system in pasture. The shiny, jet black, 10 mm long adults are the overwintering stage and also live in pasture, but feed at the base of grass tillers. It is the adult which attacks maize. Adult beetles commence post-winter feeding activity in early October. They continue feeding through the oviposition period until numbers in maize crops decline rapidly from mid November (Watson, 1978). Beetles usually die off by early December and may do so earlier, when surface soils become hot and dry.

Adult black beetle populations of up to 40/m² can occur in pasture in spring. Adult numbers are highest in pastures containing paspalum, *Paspalum dilatatum* Poir., or kikuyu, *Pennisetum clandestinum* Hochst. These pastures afford much higher overwintering survival than perennial ryegrass, *Lolium perenne* L., dominant pasture (Watson and Wrenn, 1980). Black beetle numbers are also greatly influenced by seasonal climatic conditions. They are favoured by warm dry seasons (King *et al.*, 1981). In some years, massed flights of black beetle occur in autumn. This can result in large numbers entering mature maize crops. The beetles feed at the base of brace roots, or bore into any maize stems or ears lying on the surface. The beetles are able to overwinter successfully on old maize roots and grass weeds and so affect new crops in spring (Watson, unpublished).

Early plantings are more severely attacked by black beetle than those planted after mid November (Watson, 1978). On average, each adult can kill one plant in October planted maize. Visible crop damage may not reach a peak until the four leaf stage. This differs from ASW and greasy cutworm attack where symptoms are usually most pronounced at or before the two leaf stage. Since low populations can affect maize establishment, ground inspection for the presence of black beetle should be conducted before planting in susceptible areas. This can be achieved by spade sampling (Watson *et al.*, 1980a) or from pitfall traps sunk into cultivated ground (Watson *et al.*, in prep.).

Black beetle adults are little affected by the mechanical effects of cultivations. Control can be obtained from granules of phorate (Saunders and MacDiarmid, 1976) or isazophos (Watson *et al.*, 1978). Heavy infestations above 10/m² are not adequately contained, however, and in such cases plantings should be delayed until mid November or until beetle numbers decline sufficiently (Watson *et al.*, 1978). Experimentally, baits of kibbled maize carrying isazophos have given effective black beetle control (Watson *et al.*, 1981). Baits were applied, at planting, at particle densities sufficient to be contacted by beetles before seedling emergence. Since severe damage to plants by black beetle is often delayed, post emergence "rescue" treatments, such as band sprays of isazophos (Watson *et al.*, 1978) or deltamethrin (Watson *et al.*, 1980b) have also shown promise. Registrations have not been sought for bait or spray treatments in NZ. In recent years, black beetle have rarely occurred above economic threshold levels in maize.

ARGENTINE STEM WEEVIL

ASW is a major problem in seedling maize sown after short cultivation periods from pasture, or in previously cropped ground where grass weeds, including *Poa annua* L. and couch, *Elytrigia repens* (L.) Beauv., are present (Kain and Barker, 1966; Watson *et al.*, in prep.). ASW is the greatest cause of seedling losses in maize in the Waikato (Watson *et al.*, in prep.) and this probably is true in other districts.

ASW larvae, small white legless grubs 1-3 mm in length, transfer from decaying grass tillers and enter the maize shoot before or soon after emergence. The larvae then bore towards the base of the plant where they sever the growing point. Visible damage includes emergence failure, wilting and collapse of plants up to the four leaf stage. Plants surviving attack, tiller prematurely and remain stunted. In worst cases practically every maize plant can become affected (Watson and Wrenn, 1978).

Control of ASW can be obtained by cultivation over a four-five week period to eliminate grass residues (Fig. 1). The cultivation period may be reduced to two weeks in late season plantings when hot dry soils hasten the death of ASW larvae (Barker *et al.*, 1982). Stem weevil cannot affect crops where grasses are absent in the seedbed before cultivations.

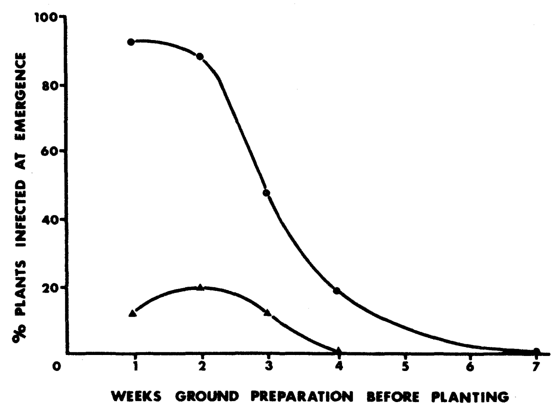

Figure 1. Stem weevil damage in seedling maize (weekly sowings after cultivation from pasture (after Watson and Wrenn, 1978)).

●No insecticide — recultivation before each planting.

▲Carbofuran 10 G (1.7 kg ai/ha) at each planting — direct drilled after initial turf desiccation.

In direct drilled maize and where short cultivations are unavoidable, protection of seedlings can be obtained from granules of carbofuran (Watson and Wrenn, 1978; Barker *et al.*, 1982), isazophos (Watson and Wrenn, 1978) or phorate (Watson *et al.*, in prep.). Insecticide should be applied in the furrow, or as a band, above the seed. Contact of either phorate or isazophos with the seed should be prevented to avoid phytotoxic failure or delay of seedling emergence. Preliminary experiments indicated that band sprays behind the drill are more effective than granules (Watson, unpublished). Spraying pasture to eliminate stem weevil larvae before pasture desiccation has also shown promise (Watson and Wrenn, 1978). Since much infestation of maize occurs before emergence of the seedlings, post emergence treatments for ASW control are not successful.

GREASY CUTWORM

Much recent research of relevance to greasy cutworm in maize has been conducted in the corn belt of the USA. Findings there appear to apply closely to NZ conditions. Young cutworm caterpillars are brown or greyish in colour. Larger caterpillars are darker grey with a waxy sheen. Cutworm caterpillars that damage emerging crops, are present before planting (Sherrod *et al.*, 1979; Levine *et al.*, 1981). Egg laying, which is associated with moth flights during the months prior to planting (Gaskin, 1970; Allan and Clare, in prep.), is strongly associated with weedy seedbed conditions and moist soils (Busching and Turpin, 1976).

In Waikato trials during 1981/82, cutworm moths were present before and after the commencement of planting, with a peak in late September/early October (Watson *et al.*, in prep.). Highest cutworm populations were associated with weedy paddocks dominated by docks, *Rumex* spp., chickweed, *Stelleria media* L., mouse eared chickweed, *Cerastium vulgatum* L. and *Poa annua*. High numbers were also present after potato crops and pasture. Short cultivations enhanced subsequent cutworm attack, particularly in late plantings. There was no clear relation between soil moisture conditions and cutworm attack, presumably because moisture levels in Waikato were uniformly high during spring. The season was characterised by frequent strong westerly winds, and highest infestations within some paddocks were found in the lee of shelter.

Cutworm damage in maize is determined by the numbers and stage of growth of the caterpillars, in relation to crop growth stage. Cutworm caterpillars proceed through 6-9 instars (usually 7) depending on temperature and humidity conditions (Archer *et al.*, 1980). The first three instars are spent on the soil surface, feeding on plant leaves. Cutworm start to sever maize plants at the third or fourth larval instar (Troester, 1982). Once cut, plants are usually consumed before caterpillars move to other plants. Plants are often taken into the burrows of the caterpillars. Small plants may thus disappear, making is easy to underestimate cutworm damage in early maize growth. Cutting stage caterpillars destroy about four plants each before the two leaf stage of maize seedling growth and about two plants at the 2-4 leaf stage (Archer and Musick, 1977a; Clement and McCartney, 1982). After the 4 leaf stage of maize growth, damage is more frequently caused by caterpillars tunnelling up into the maize stem from the base of the plant. A proportion of maize seedlings are chewed off well above ground level, particularly when soils are not dry. Plants attacked above the whorl at the 2 leaf stage are more likely to recover than similarly attacked older plants, and such plants may give 80% or more of the potential grain yield (Levine *et al.*, 1983). Greatest devastation of maize is, however, caused when the presence of cutting stage caterpillars coincides with crop emergence.

While flight activity can occur at temperatures as low as 3 °C (Broersma *et al.*, 1976) the threshold temperature for egg and larval development is about 10.5 °C (Luckmann *et al.*, 1976; Nasr and Moawad, 1982). This means that rapid development of the caterpillars does not commence in NZ until October/November, and the accumulated population in the ground resulting from an extended oviposition period tends to develop into late instars over a relatively short time interval (Table 2). The synchronization in development may be further enhanced by the rapid warming of soils as spring cultivation commences in preparation for planting. The result is that a large reservoir of cutting stage caterpillars can coincide with crop emergence, particularly in crops emerging during November and early December.

Table 2: Approximate date of appearance of greasy cutworm stages after different egg laying dates in Waikato, 1981.

Egg laying date	Date of appearance of larval instars[1] 1 (52° days)	4 (170° days)	6 (261° days)
1:8	4:10	12:11	30:11
15:8	5:10	13:11	30:11
1:9	7:10	14:11	1:12
15:9	16:10	15:11	5:12
1:10	23:10	20:11	9:12
15:10	2:11	26:11	17:12

Centigrade degree days for development based on Luckmann *et al.* (1976). Temperatures based on Ruakura Meteorological Station data August-December 1981.

Cutworm attack is sporadic and has been notably unpredictable in its occurrence. Methods of sampling for the presence of caterpillars before crop emergence (Archer and Musick 1977b; Story and Keaster, 1983) tend to be insufficiently accurate or practical for widespread use by growers. Accurate forecasting of the time of initiation of cutworm damage in maize, although not the level of attack, has recently been developed. It is based on moth catches in pheromone baited traps and local temperature data (Troester *et al.*, 1983). This method could be adopted in

NZ, although topographical differences may mean that predictions have localised rather than extensive application.

Differences in the extent of damage caused by the combination of different growth stages of both the caterpillars and the maize crop mean that accurate determination of economic threshold levels is complicated (Matthew and Edwards, 1979; Troester, 1982). Use of granular insecticides at planting to control cutworm is both expensive and inefficient. Of the granular insecticides commonly used in NZ, only isazophos has satisfactory activity against cutworm (Watson, 1981; Watson *et al.*, in prep.). Cutworm are effectively and most economically controlled by spray applications after emergence. Since larger plant numbers are destroyed at early crop growth stages, early detection and treatment is very important to gain maximum benefit from treatments (e.g. Watson, 1981). Generally, prevention of plant losses of 5000-10 000 plants/ha are required to give significant yield responses in normal maize crops of 80 000 plants/ha at emergence. This is because of the ability of surviving plants to compensate for plant losses at these high densities (Douglas *et al.*, 1982). Approximately 3 cutworms (evidenced as freshly damaged plants) per 100 plants before the two leaf stage, or 6 caterpillars/100 plants at the 2-4 leaf stage can equate to losses of 10 000 plants/ha. Since few further plants will be damaged after the 4 leaf stage treatments are not warranted at this stage, unless large numbers of small (instars 1-4) caterpillars are present.

A wide range of spray insecticides have registrations for cutworm or general caterpillar control (Watson, 1978). Of these, the most widely used have been methomyl and chlorpyrifos. More recently, synthetic pyrethroids have proven successful (Harris *et al.*, 1978; Hill *et al.*, 1983), and permethrin, cypermethrin and deltamethrin have become increasingly popular. Baits of carbaryl on bran or kibbled grain are also effective if correctly formulated and applied, but do not presently hold any cost effective advantages over pyrethroid sprays (Hill *et al.*, 1983).

Failures of insecticide control of cutworm have resulted from applications made too late, or under conditions unfavourable for insecticide activity. Caterpillars may feed underground on a severed plant for several days before emerging to damage further plants. Insecticides used for cutworm control have a short residual activity. Application on hot dry soils increases the loss of insecticide activity from sunlight, volatilization and direct soil/chemical inactivation. Baits are also ineffective unless they are moistened to attract cutworms (Martin, 1980; 1983). Preferably, and especially when hot dry conditions prevail, treatments should be applied in the evening when caterpillars are most active. Sprays should be banded along plant rows to maximise insecticide concentration in the zone of the caterpillars.

Cutworm caterpillars are secondary hosts to the wasp parasite, *Apanteles ruficrus*, although a recent survey showed only a 5% level of parasitism. Other parasites affected a further 1.4% of caterpillars (Hill, unpublished data). Attempts have recently been made to release a tachinid fly parasite, *Bonnetia compta* (Fallen) for improving biological control of cutworm (Allan and Hill, 1984).

COSMOPOLITAN ARMYWORM

Cosmopolitan armyworm is a pest of pasture and grain crops throughout Asia, Oceania and Australasia (Sharma and Davies, 1983). In New Zealand, it is a sporadic, though sometimes devastating, pest of pasture and grain crops. CAW is present throughout the North Island and northern part of the South Island. It has 3 or 4 generations per year over most of its range. Generation time in summer is 6-8 weeks. The small caterpillars are green, but in later stages turn to a pale greenish brown with parallel light and dark lines down the body length (up to 40 mm long). Adult wings vary in colour from pale straw to dark reddish brown, and the overall wing span is 30-40 mm.

Eggs are laid under leaf sheaths and other similar protected parts of grasses and grain crops. The caterpillars pass through 6 or 7 instars, feeding mainly on the leaf blades (Valentine, 1975a). Caterpillars undergo a so called phase-change, dependant upon rearing density, leading to changes in a number of morphological and physiological characters. Caterpillars from high density "outbreak" infestations are typically dark compared with those reared singly. These dark, gregariously reared caterpillars are also more active and may move en mass through paddocks of grass or grain crops, completely destroying the crop. The insect derives its name from this destructive habit.

Caterpillars are usually found in maize at or shortly before silking, and there is only one generation of larvae in the crop. CAW caterpillars graze on the leaf laminae of maize plants and leave only the midribs in severe infestations. Eighty five percent of total larval consumption occurs during the last two instars (Iwao, 1962) and the lower half of the maize plants are consumed before the caterpillar moves to the upper parts (Hill and Atkins, 1982). Severe defoliation usually occurs after silking. Defoliation causes grain yield reduction, though the effects of defoliation decline linearly with time following silking (Douglas *et al.*, 1981). Thus severe defoliation occuring 4 weeks after silking causes only about 30% reduction in yield. Also, the insect's habit of eating the lower leaves first is advantageous to the maize plant, since these contribute least to seed production (Douglas *et al.*, 1981).

Silks and seeds are also consumed, though there is no evidence to suggest that silk eating reduces fertilisation (unless attacks occur usually early in the season), or that ear chewing contributes significantly to yield reduction. However, it is likely that CAW larval activity in the top of the ear may attract birds and open up the husk cover for more serious seed predation of the grain by birds and rodents.

In 1971-72 the gregarious larval parasite, *Apanteles ruficrus*, was introduced from Pakistan in an effort to control CAW (Cumber *et al.*, 1977). It has become established as a highly effective parasite, with levels of parasitism commonly between 70% and 95% (Burgess, 1982; Hill, 1977; Hill and Atkins, 1983). Since its introduction, insecticide spraying of maize to control CAW has reduced from 2-3 times per year (Kain *et al.*, 1968) to single sprays on an estimated 5% of crops (Hill and Atkins, 1983). The parasite usually kills the armyworm larvae when they are still small and before they have consumed much food.

In spite of the success of the parasite, very high densities of up to 60 caterpillars per plant still occasionally defoliate maize crops. (Hill and Allan, unpublished data). These high numbers presumably result from exceptionally high levels of oviposition from dense aggregations of moths, coupled with favourable climatic conditions for egg and early caterpillar survival. There is some evidence to suggest that high levels of grass weeds in a crop favour outbreak populations (Anon, 1971; Hill and Allan, personal observations).

It is impossible to predict the occurrence of exceptionally high densities of moths, and crops should be checked for armyworm infestation at intervals for several weeks following silking. If high numbers of caterpillars are found, then a decision to spray will depend upon the age of the crop, size and number of caterpillars and level of parasitism. Work is in progress to provide spray threshold levels of larval density dependant upon these other factors. Current knowledge suggests, that for armyworm defoliation in grain maize crops occurring post-silking, with usual parasitism levels of 70-95%, caterpillar densities of up to 10 per plant will not cause severe defoliation or warrant a spray treatment. Should spraying be considered necessary, fenitrothion, methomyl, (Kain *et al.*, 1968; Scott, 1984), chlorpyrifos (MacDiarmid *et al.*, 1976) and synthetic pyrethroids (permethrin and fenvalerate) are all effective.

SOUTHERN ARMYWORM

Southern armyworm, *Persectania aversa*, is endemic to New Zealand. Like CAW, it is a defoliator of grain crops and grasses (Kelsey, 1956; Agnew, 1974). It is present throughout the country, and probably has two to three generations per year (Dick, 1940; Agnew, 1974). Adults have reddish-brown forewings irregularly streaked with white, and uniform brown hindwings. The biology and habits of southern armyworm are very similar to CAW though it is capable of surviving in colder, more southerly climates (Agnew, 1974; Goodwin, 1971).

Southern armyworm is a sporadic pest in southern parts of the North Island and in the South Island, and may occasionally attack maize (Agnew, 1974). There is no available information on parasitisation by the introduced *Apanteles ruficrus*, however, Valentine (1967) lists four known parasites. Presumably, the same chemicals effective for CAW control will also kill southern armyworm.

TOMATO FRUITWORM

Tomato fruitworm is also known as the corn earworm, emphasising its polyphagous habits. It is a common pest on many types of field and vegetable crops, and is a serious pest throughout Australasia, Asia and Africa. A closely related species, *H. punctigera* Wallengren, migrates to NZ from Australia in most years (Fox, 1978). Its larvae are superficially indistinguishable from TFW, and from time to time it may form a significant proportion of the so-called TFW infestation in some areas. Fortunately, *H. punctigera* does not survive the winter in NZ.

TFW adults have variable brown to orange-brown forewings and pale brown hindwings with a broad dark band along the trailing edge. Eggs are laid singly on the underside of leaves or on maize silks, and fecundity is usually 500-1000 eggs. Caterpillars are variable in colour, ranging from pink to green or brown, with prominent, often black, wart-like protuberances ending in strong bristles (Valentine 1975b).

Caterpillars feed preferentially on the fruiting parts of their host plants. On maize, silks and developing ears are eaten. If silks are eaten prior to tassling, fertilisation may be impaired, though TFW populations usually appear after tassling and silking. Extensive damage may be caused to the ear by the burrowing activity of TFW. It burrows down through the silks or enters from the side, by chewing through the husk leaves. The ear can be severely damaged by extensive browsing of TFW and by fungi growing on damaged seeds. Because TFW is cannibalistic and aggressive, there is rarely more than one caterpillar per ear at the penultimate instar.

Population levels at which insecticide spraying is economic have not been determined. Current evidence suggests that populations are rarely present in sufficient numbers to warrant chemical control. Chlorpyrifos (MacDiarmid *et al.*, 1976) permethrin (Jackson and Graham, 1979) and fenvalerate may all be used if chemical control is considered necessary.

In 1978/79, a parasite, *Apanteles kazak* Telenga, was introduced to New Zealand from Europe. It is well established in the North Island and is achieving levels of parasitism averaging 50%. It is a solitary parasite, which kills its host when it is still very small, thereby drastically reducing feeding damage (E.W. Valentine, pers. comm.).

When assessing maize plants for the presence of TFW, it is necessary to determine whether silk feeding damage has been caused by armyworms or TFW. If post-silking, the former may graze harmlessly on the silks without damaging the ear while the latter will transfer to the ear causing more severe damage. Once TFW have penetrated the ear, they are difficult to control and sprays should be applied while caterpillars are still small and feeding in the silks. Unfortunately, this may be before *A. kazak* parasitism has taken effect.

GREEN LOOPER CATERPILLAR

Like CAW and TFW, the green looper, *Chrysodeixis eriosoma* (Doubleday), is another noctuid moth species and basically has a similar life history (Dugdale, 1976; Roberts, 1979). However, its caterpillars are easily distinguished from other noctuid pests by their bright green colour and habit of looping instead of walking. It is a pest on a wide range of horticultural and field crops attacking both foliage and fruit, and also feeds on many weed species (Roberts, 1979). It is found in small numbers in maize, where it eats silks, but is not considered to be a serious pest. It may be chemically controlled using the same treatments as for CAW, and also suffers heavily from parasitism by the introduced hymenopterous parasite, *Litomastix maculata* Ishii (Roberts, 1983).

APHIDS

Cereal aphid, *Rhopalosiphum padi* (L.), and corn leaf aphid, *R. maidis* (Fitch), are recorded from maize in New Zealand. The former is a vector of barley yellow dwarf virus and a serious pest of small grain crops in New Zealand and many other parts of the world (Burnett, 1984; Lowe, 1964). Both species are found on many different types of grasses and grain crops. There are approximately 15-20 generations per year. The populations consist exclusively of parthenogenetic, viviparous females, which give birth to live young. Adults may be winged (alatae) or not winged (apterous). The former, produced in response to crowding and declining host plant quality, fly in search of new feeding sites.

Cereal aphid is an important vector of barley yellow dwarf virus, but neither it nor corn leaf aphid are known to be vectors of maize diseases in New Zealand. Corn leaf aphid is an important vector of maize dwarf mozaic virus in other parts of the world (Ortega *et al.*, 1980). Both species feed by sucking phloem sap from the host plant and infest the ear sheath and surrounding leaves. Infestations tend to build up late in the season and are often aggregated within the crop, building up from single immigrating apterous females. Feeding aphids produce a sticky exudate which may reduce pollination when large numbers occur at flowering (Graham, 1967). No studies have been undertaken to determine the economic importance of these aphids on maize in New Zealand. It is unlikely that the level of infestation reached under normal circumstances will lead to grain yield reductions. This may not be true for late planted crops where large aphid numbers coincide with maize flowering (Foott, 1976).

Infestations of both species are attacked by several beneficial insect species. The Tasmanian lacewing, *Micromus tasmaniae* Walker, larvae and two species of hoverfly, *Melanogyna novaezelandiae* (Macquart) and *Melanostoma fasciatum* (Macquart), larvae are often common amongst aphid colonies. In addition, aphids are often heavily parasitised by wasp (Aphidiid) parasites, eg. *Aphidius similis* Stary and Carver on cereal aphid (Stary and Carver, 1979; Cameron *et al.*, 1981) and *Aphidius* sp. on corn leaf aphid (Cameron, pers. comm.). While detailed population studies are lacking, it is likely that these insects contribute to population control of the aphids.

Chemical control may be effected by chlorpyrifos or demeton-S-methyl (MacDiarmid *et al.*, 1976).

MINOR PESTS

Maize seed beetles

Ground beetles, Carabidae of the genus *Clivina*, are normally predatory insects, but are known to attack maize seeds, usually in cold wet conditions which delay seedling emergence (Pausch and Pausch, 1980). The endemic *C. rugithorax* has caused damage to maize in Hawkes Bay (Muggeridge, 1939). In a survey of maize establishment in Waikato, high numbers of *C. rugithorax* and lesser numbers of *C. basalis* were caught in pitfall traps (Watson *et al.*, in prep.). Numbers were highest on heavier soils and after previous maize crops, but no significant effects of the beetles on emergence of maize were established. The insect is not regarded as a significant pest of maize in normal growing conditions.

Slugs

Slugs, usually the grey field slug, *Deroceras reticulatum*, and brown field slug, *D. panormitanum* occasionally damage emerging maize crops. Cavities are gouged in the seed, sometimes affecting the growing point, and early leaves often appear shredded as a result of slug feeding (Barker *et al.*, 1984). Damage is usually restricted to heavy, moist soils, which have a cloddy structure, and to direct drilled maize. Problems are minimised in a well worked seedbed following adequate cultivation. Standard molluscicide treatments of methaldehyde and methiocarb failed to give satisfactory control of slugs in direct drilled maize trials (Barker *et al.*, 1984).

VERTEBRATE PESTS

Species of game birds, including ducks, *Anas platyrhynca* L., pigeons, *Columba livia* L., pheasants, *Phasianus colchicus* L., and pukeko, *Porphyrio porphyrio melanotus* Pemminck, can be attracted to establishing maize, especially where seed is left lying on the ground. The birds may become attracted to rows where seeds are exposed, and soon learn to dig under plants for further seeds or insects. Localized damage can be severe. Dilks (1975) found that pigeons fed in maize stubble during autumn and winter but had little effect in spring. The solution is not to leave seed exposed on the ground. Some growers advocate deeper planting of seed to avoid seed excavation and theft. Once present, the birds can be fed grain until plants are no longer attractive by about the second week after emergence. Maize treated with methiocarb can be laid as a repellant, non lethal bait. Ultimately, a permit can be obtained to shoot protected species. Rats, *Rattus* spp., can also cause similar damage by digging up germinating seed.

Smaller bird species such as minahs, *Acridotheres tristis* (L.), starlings, *Sturnus vulgaris* L., and skylarks, *Alauda arvensis* L., damage maize seedlings by nipping off the shoot. Damage usually occurs before the two leaf stage. Earliest plantings are the worst affected in Waikato, particularly those near large nesting trees of the birds (Watson *et al.*, in prep.). Planting crops with granular insecticides appeared to have some deterrant effects. Explosive bird scarers could also be effective over the limited period that the birds are attracted to the maize seedlings.

Rabbits, *Oryctolagus cuniculus* (L.), and hares, *Lepus europaeus* Pallas, may forage on maize seedlings. Feeding is generally above the whorl, so plant production is little affected unless high numbers of the pests are present.

In standing maize, ears can be damaged during the seed filling stage by flocks of sparrows, *Passer domesticus* (L.), or by mice, *Mus musculus* L. This type of feeding is particularly encouraged after the silks have been eaten or minor ear damage has been caused by CAW and TFW. Pukeko sometimes learn to knock ears from mature standing maize as they fly into the crop. The grain is then removed on the ground.

SOIL NEMATODES

Nematodes can limit maize yields overseas (FMC Corporation, 1978; Johnson, 1979). In New Zealand, yield responses to insecticides at planting, in the absence of the pest damage, have also been attributed to nematode control (ICI Tasman, undated), but quantifying evidence is lacking. At least 17 nematode genera are implicated or confirmed as causing damage in maize, *viz Pratylenchus, Meloidogyne, Helicotylenchus, Trichodorus, Ditylenchus, Heterodera, Tylenchus, Tylenchorhynchus, Macroposthonia, Criconomoides, Xiphenema, Scutellonema, Hoplolaimus, Belonolaimus, Dolichodorus, Longidorus, Paratrichodorus* (FMC Corporation, 1978; Willmott *et al.*, 1972). The first 11 of these genera (up to *Xiphenema*) have all been recorded from New Zealand soils, many occuring under pasture, although species particularly destructive in maize, eg. *Pratylenchus zeae* Graham, have not been identified.

Yeates and Watson (in prep.), in a limited survey in the Waikato, found no evidence of a buildup of nematodes to potentially pathological levels in successively cropped maize. Highest numbers of potentially damaging genera were found under pasture, so that crops direct drilled, or with short cultivations after pasture might be expected to be most susceptible. Weed growth in maize ground provides overwintering hosts, and therefore also encourages nematodes.

Band applications of carbofuran, isazophos and phorate provide some protection to maize seedlings against nematodes. Treatments of these insecticides were not generally economic in Waikato maize unless significant plant losses occurred from other pests (Watson *et al.*, in prep.). A wider survey is needed to confirm this trend under specific growing conditions (eg. maize after pasture) and in other maize growing districts.

PESTS OF STORED MAIZE

Most of the cosmopolitan pests of stored maize are present in New Zealand. They are the maize weevil, *Sitophilus zeamais* Motschulsky, rice weevil, *Sitophilus oryzae* L., granary weevil, *Sitophilus granarius* L., Indian meal moth, *Plodia interpunctella* (Hubner), Mediterranean flour moth, *Ephestia kuehniella* Zeller, Angoumois grain moth, *Sitotroga cerelella* (Oliver), and the cereal mite, *Acarus siro* L. (Helson, 1971; Somerfield, 1971; Waller, 1984).

Though most of these are serious pests of field and stored grain in tropical countries (Ortega *et al.*,1980), they appear not to be important pests in New Zealand, presumably because of the temperate climate and efficient and hygienic maize storage practices. Fumigation and spraying practices are discussed by Helson (1971). Angoumois moth can affect crib dried maize, and may limit the time that maize can be safely left in the crib (Graham, 1967).

MINIMUM OR ZERO TILLAGE MAIZE

Any trend towards short cultivation reduces both the mechanical effects on, and the denial of food sources to the pests. Consequently, most pest problems are either enhanced, as with greasy cutworm (Harrison *et al.*, 1980), and slugs (Barker *et al.*, 1984), or at least not effectively reduced compared with the equivalent preplant period in cultivation eg. ASW or soldier fly (Watson and Wrenn, 1978; Carpenter *et al.*, 1978; Carpenter, 1981; Davison *et al.*, 1979). Costings for maize establishment using reduced cultivation methods should therefore include the necessity for adequate plant protection using pesticides. In some cases, particularly when establishing maize in former pasture, pest populations may be too high for adequate insecticidal control without cultivation (Davison *et al.*, 1979; Watson *et al.*, 1978). In general, the rapid agronomic developments in reduced tillage technology have not been matched by advances in pest control. The possibility of alternative insecticidal control of pests, such as preplant cover sprays for ASW (Watson *et al.*, 1978) or greasy cutworm (Harrison *et al.*, 1980), have not been adequately investigated.

HIGH DENSITY FORAGE MAIZE

Under standard conditions of seedbed preparation, high density forage maize crops should not require insecticides at planting (eg. Hutton and Douglas, 1975). There is sufficient flexibility in sowing time to enable an effective cultivation period of at least four weeks. In some cases granular insecticides which are effective for standard row widths are not effective in high density rows or as broadcast treatments (Davison *et al.*, 1979).

High density stands (Thom, 1977; Byford, 1980) have a greater ability to compensate for and hence tolerate populations of most pests. Pests such as soldier fly and ASW, which occur at extremely high densities in pasture, can nevertheless significantly reduce stand population and subsequent yields. The lower crop value of forage maize should not mean that farmers can minimise ground preparation before planting in susceptible situations.

PLANT BREEDING FOR PEST RESISTANCE

Maize genotypes with levels of resistance to various insect pests have been developed overseas. There has been little evaluation of such pest resistance material in NZ. This would imply that effective managerial or insecticidal controls are available to meet most pest situations.

Maize genotypes with resistance to first instar European corn borer, *Ostrinia nubilalis* (Hubner), were found to be ineffective against greasy cutworm as damage is caused by later instars (Guthrie, 1981). Such material could, however, be worthy of evaluation against ASW in NZ.

Large scale plant breeding programmes have been undertaken for pests of established maize, and resistance to both leaf and silk feeding insects has been achieved (Ortega *et al.*, 1980; Russell, 1978). One armyworm species, however, responded to reduced digestibility in "resistant" cultivars by eating more, rather than less, plant material (Manuwoto and Scriber, 1982).

CONCLUSION

Maize crops are attacked by a limited range of pests in NZ.

Damage at the seedling stage is largely predictable and preventable. This is achieved by having an adequate knowledge of the pests involved, inspection of the ground for pests before cultivation or planting and using appropriate cultural or insecticidal controls where necessary.

Successful management of sporadic pests such as greasy cutworm, cosmopolitan armyworm and tomato fruitworm requires vigilance at appropriate stages of crop growth, and early treatment with insecticides where necessary.

Many pest problems are lessened by good crop agronomy. This particularly applies to standards of cultivation and weed control. High standards generally achieved in this regard undoubtedly contribute to the low status of pest problems in maize in NZ.

While present pest control measures are adequate for most problems in conventionally grown maize, further development of specific controls are required for direct drilled and minimum tillage crops.

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