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RECENT ADVANCES IN PASTURE PEST MANAGEMENT IN THE NORTHERN NORTH ISLAND

Summary: Withdrawal of the use of cheap, persistent organochlorine insecticides in New Zealand pastures has shifted the emphasis of insect pest control to non-chemical methods during the last 10-15 years. The potential of plant resistance and biological control for achieving major advances in pasture pest management are illustrated by the resistance to Argentine stem weevil *(Listronotus bonariensis)* of ryegrasses infected by the endophytic fungus *Acremonium loliae,* the reduction of Australian soldier fly *(Inopus rubriceps)* populations to subeconomic levels by invertebrate predators, and the effects of pathogens on grass grub *(Costelytra zealandica)* populations.

Keywords: Acremonium endophyte; Argentine stem weevil; Australian soldier fly; biological control; Costelytra zealandica; grass grub; Inopus rubriceps; insect pests; Listronotus bonariensis; population dynamics; predation; resistance.

Introduction

Pasture pest control in New Zealand relied primarily on the use of cheap, persistent organochlorine insecticides during the 1950's and 1960's. The banning of DDT and most other organochlorines from farm use by 1970 focused attention on the development of alternative control measures. Over the last 10-15 years, pasture pest research has concentrated on the development of new and improved controls for each major pest (Pottinger, 1975; East, 1985). There has been a marked shift in emphasis from heavy reliance on insecticides to greater use of cultural and biological controls (East and Pottinger, 1982, 1983, 1984), with increasing interest in integrated pest management (Kain, 1979; Kain *et al.,* 1982a; Pottinger, 1985).

Recent advances in pest management research in the northern North Island (between Taupo and Auckland) are illustrated by the use of plant resistance to control Argentine stem weevil *(Listronotus bonariensis* (Kuschel), Coleoptera: Curculionidae), and the effects of naturally occurring predators on Australian soldier fly *(Inopus rubriceps* (Macquart), Diptera: Stratiomyidae), and pathogens on grass grub *(Costelytra zealandica* (White), Coleoptera: Scarabaeidae). Cheap, effective chemical controls are not available for these three pests.

Case Studies

Plant resistance: Argentine stem weevil

The stem-mining larva of Argentine stem weevil is a major introduced pest of grasses and cereals in New Zealand (e.g., Barker *et al.,* 1984a; Prestidge *et al.,* 1984). A major breakthrough in the control of this pest occurred with the discovery that perennial ryegrass *(Lolium perenne* L.) plants infected by the endophytic fungus *Acremonium loliae* Latch, Christensen and Samuels are resistant (Prestidge *et al.,* 1982); resistance to Argentine stem weevil in ryegrasses had been detected earlier by Kain *et al.* (1982b). Hyphae of *A. loliae* grow intercellularly within the host plant's tissues and the endophyte is transmitted only in seed to the next host generation. Plants growing from infected seed remain infected throughout their life. Endophyte-infected ryegrasses suppress adult stem weevil feeding activity and oviposition (Barker *et al.,* 1984c) and larval survival (Barker *et al.,* 1984b; Prestidge and Gallagher, 1985). The effect on adults is the major mechanism of resistance.

Endophyte-conferred resistance of grasses to other insects which feed on foliar tissues has also been recorded (e.g., Funk *et al.,* 1983). The mutualistic relationship between endophytes and their host grasses appears to provide a unique mode of resistance to herbivory. The interactions between Argentine stem weevil and the endophytic fungi of perennial ryegrass and tall fescue *(Festuca arundinacea* Schreb.) have been reviewed in detail by Pottinger *et al.* (1985).

The resistance to Argentine stem weevil of endophyte-infected plants has major consequences for ryegrass persistence and production (Prestidge *et al.,* 1982, 1984, 1985c; Barker *et al.,* 1984a, 1986). In areas such as the central North Island volcanic plateau, Argentine stem weevil appears to eliminate most endophyte-free ryegrass plants within 4-6 years of sowing pastures; stem weevil populations decline below damaging levels (about 100 per m^2) with the elimination of susceptible hosts (Fig. 1). Consequently, when low-endophyte seedlines of ryegrass are sown the ryegrass content of the sward declines to low levels within a few years, necessitating

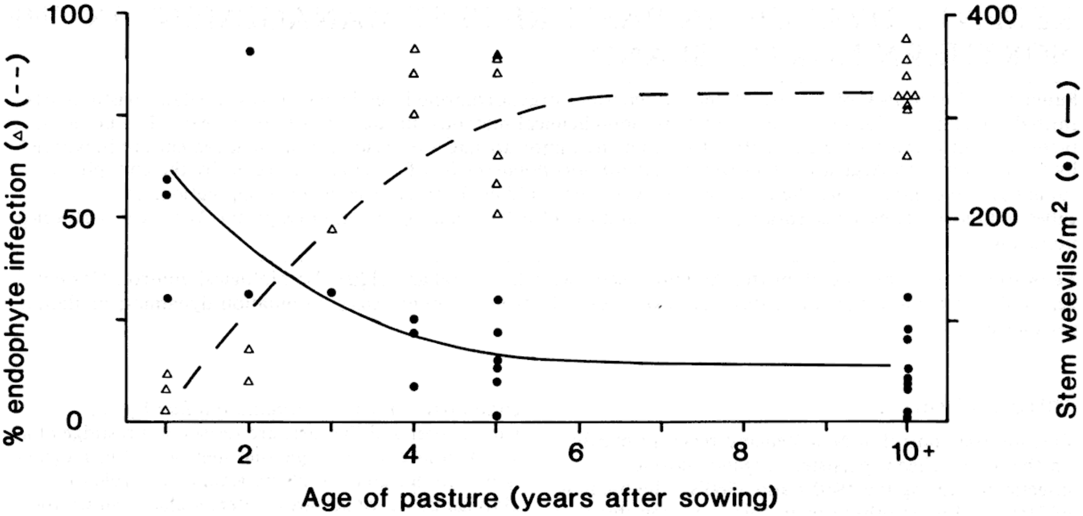

Figure 1 *Surveys of percentage of ryegrass plants infected with the endophyte Acremonium loliae and Argentine stem weevil populations in different-aged volcanic plateau pastures in March/ April 1984 (data from Prestidge et al., (l985c), excluding pastures sown with high-endophyte seedlines of ryegrass). Lines fitted by eye.*

further pasture renovation (Prestidge *et al.,* 1985c). Farmers are, therefore, recommended to sow high-endophyte ryegrasses to prevent stem weevil populations from reaching damaging levels, in order to maximise ryegrass persistence and paSture productivity (Prestidge *et al.,* 1982, 1985a; Pottinger *et al.,* 1985).

Endophytic fungi are also implicated in ryegrass staggers, a nervous disorder of grazing livestock (Fletcher and Harvey, 1981). In several areas of New Zealand farmers regard Argentine stem weevil as a more serious problem than staggers, and this applies to the volcanic plateau where high-endophyte ryegrass cultivars now dominate the grass seed market (Prestidge *et al,,* 1985a). In areas where ryegrass staggers is particularly severe, e.g., Canterbury, there has been less farmer acceptance of high-endophyte ryegrasses. Current research is investigating the development of ryegrasses which retain resistance to Argentine stem weevil but have no detrimental effects on livestock. Possible avenues include reducing the level of *A. loliae* within the ryegrass plant (Prestidge *et al.,* 1985b), or exploiting differences in the chemical mechanisms of Argentine stem weevil feeding deterrence (Gaynor and Rowan, 1985; Prestidge *et al.,* 1985d) and ryegrass staggers (Gallagher *et al.,* 1984).

Effects of Predators: Australian Soldier Fly

The Australian soldier fly is an endemic pest of sugarcane in eastern Australia and an introduced pest of northern New Zealand pastures (Hewitt, 1969; Wilcocks, 1974a). Soldier fly larvae, which feed on plant roots in the soil, and pupae, which occur at the soil surface, are susceptible to predation by soil-dwelling and surface-active predatory invertebrates. Laboratory and field experiments have revealed that polyphagous predators (Coleoptera: Carabidae, Staphylinidae, and Elateridae) can suppress soldier fly populations in New Zealand grasslands (Robertson and Pottinger, 1979; Robertson *et al.,* 1981; Robertson, 1986). Serological tests have confirmed that adults of the staphylinid *Thyreocephalus orthodoxus* (Olliff) and larvae of the elaterids *Conoderus exsul* (Sharp) and *Agrypnus variabil/is* (Candeze) are important predators of soldier fly larvae in New Zealand pastures (Doane *et al.,* 1985). Studies in sugarcane and grasslands in south-eastern Queensland have revealed high levels of predation of soldier fly pupae (13-97%) by surface-active predators, predominantly Carabidae and Staphylinidae (Robertson and Zalucki, 1984, 1985; Robertson, 1986).

Soldier fly was a major pest in New Zealand between 1950 and the early 1970's, which coincided with the widespread use of DDT against grass grub. Soldier fly is relatively tolerant of insecticides (Moller, 1965; Robertson, 1979). DDT may have reduced predator populations, allowing soldier fly outbreaks to occur (Robertson *et al.,* 1981; Robertson, 1986). Population densities of soldier fly have generally declined to well below pasture damaging levels (>2-3,000 per m^2; Wilcocks, 1974b; Dixon 1977) since the use of DDT was terminated, except in newly infested regions (Robertson and Blank, 1982). Similarly, soldier fly outbreaks in Queensland sugarcane appear to have resulted from the suppression of predators by heavy applications of organochlorine insecticides (Moller and Mungomery, 1963; Robertson and Zalucki, 1984). The best strategy for the control of soldier fly in pasture in newly infested regions may therefore be to accept temporary losses until regulation by predators becomes effective.

Predator suppression experiments

Strong evidence that predators are important in the natural control of soldier fly populations has been obtained from field experiments in grassland (New Zealand and Australia) and sugarcane (Australia). Applications of lindane (3.0 - 8.0 kg/ha), dieldrin (2.5 - 3.0 kg/ha), DDT (2.5 kg/ha) or fensulfothion (3.0 kg/ha) were used to suppress predator populations within one plot in each of eight separate paired-plot experiments on previously untreated grassland or sugarcane (plot size 1-2 ha in New Zealand; 50-140 m2 in Australia).

Insecticides were applied in early summer (November-December). Assessment of soldier fly populations in the subsequent spring (September-October) revealed a positive effect of insecticide treatment on population change, with population growth ($N_{t+1}/N_t > 1.0$) occurring in five treated plots but only one untreated (Fig. 2). This was associated with marked insecticidal suppression of predator populations determined by soil sampling (Table 1), and of pitfall trap catches of predators (Table 2). The experimental sites within each country had a comparable fauna of known and likely predators of soldier fly, including the staphylinids *Thyreocephalus chloropterus* (Erichson) and *T. orthodoxus,* the carabid *Rhytisternus miser* Chaudoir, and the elaterids *Conoderus exsul* and *Agrypnus variabilis* at Matangi and Rukuhia; and the staphylinid *T. chalcopterus* (Erichson), carabids *Anisotarsus* spp., and elaterids *Conoderus* spp., at the Australian sites.

The level of predation assessed by classifying pupal remains, extracted from soil samples as intact (adult fly emerged) or fragmented (killed by predators), was also suppressed by insecticide treatment. This method probably underestimates predation mortality, because of greater efficiency of

Table 1: *Effects of insecticide applications on post-treatment populations of predatory insects (Carabidae, Staphylinidae and Elateridae combined) and on percentage predation assessed from soldier fly pupal remains. Data from Robertson et al. (1981), Robertson and Zalucki (1984), and Robertson (1986 and unpublished). N/A = not assessed. *Elateridae only.*

Expt. no.	Site and Year	Post-treatment predator Population (no. per m^2)		% Predation of pupae	
		Insecticide	Untreated	Insecticide	Untreated
Grassland - New Zealand:					
1	Matangi 1978-79	4*	24*	N/A	N/A
2	Rukuhia 1980-81	11	59	N/A	N/A
Grassland - Australia:					
3	North Arm 1981-82	11	83	27	58
4	Coomera 1981-82	12	56	19	59
5	Coomera 1982-83	11	22		
Sugarcane-Australia:					
6	Coomera 1981-82	23	50	7	26
7	Coomera 1982-83	24	153	19	56
8	Yandina 1982-83	28	83	9	56

Table 2: *Effects of insecticide treatments on pitfall trap catches of predatory beetles (experiments numbered as in Table* 1).

Expt. No.	No. Trap-days Per treatment	Total number recovered: Carabidae Insecticide	Carabidae Untreated	Staphylinidae Insecticide	Staphylinidae Untreated
2	1116	3	38	25	140
4	380	4	9	13	20
6	456	1	3	0	8

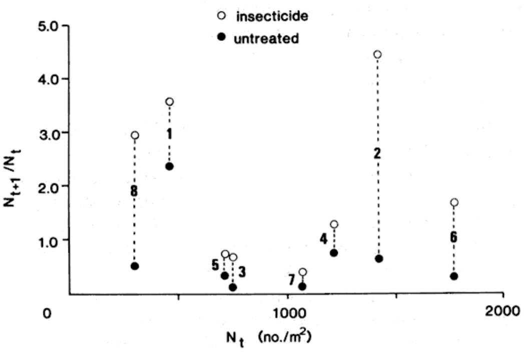

Figure 2: *Ratio of spring/early summer soldier fly larval populations (N) in successive years before (t) and after (t + 1) insecticide treatment to suppress predator densities. Numbers refer to individual experiments (see Table I for sites and sources of data).*

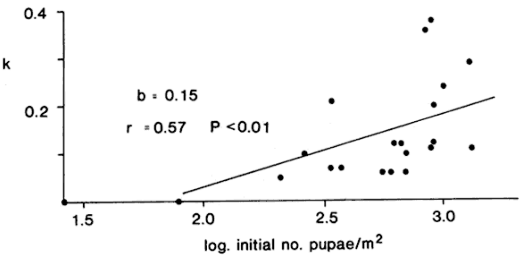

Figure 3: *Effects of local variation in soldier fly population density on pupal predation mortality. expressed as k-values (Varley and Gradwell. 1970). in sugarcane at Bli Bli. South-eastern Queensland, June 1983. Data (from Robertson, 1984) obtained by soil sampling in discrete areas of ca. 0.5 m² within 0.5 ha of uniform sugarcane.*

extraction of intact than fragmented pupal remains, but a marked difference in predation levels is evident between the insecticide-treated and untreated plots at each site (Table 1).

Density-dependence of predation mortality

Estimates of mortality obtained from pupal remains (although probably underestimated) suggest that pupal predation increased as the local density of soldier fly increased from less than 100 to more than 1,000 pupae per m², e.g., Fig. 3. Density dependence can be tested by plotting the population density after the mortality has acted against the initial density on a log-log scale; each regression coefficient (b_{yx} and b_{xy}) should differ significantly from both zero and 1.0, and both lines should lie on the same side of $b = 1.0$ (Varley and Gradwell, 1970; Luck, 1971; Benson, 1973). This test has been criticized on various grounds (e.g., Ito, 1972; Royama, 1977, 1981), but it is an acceptable statistical test of density-dependence provided the relationships are linear (Dempster, 1975). Application of this test to the data in Fig. 3 suggests that the density-dependence observed at Bli Bli in 1983 was real (Fig. 4). This spatial density-dependence in pupal predation within one soldier fly generation may be caused by the functional and/or numerical responses of polyphagous predators such as carabids and staphylinids to prey density. It may contribute to the temporal regulation (Varley and Gradwell, 1970) of soldier fly populations if, for example, predator populations are relatively stable and independent of soldier fly populations because of their ability to switch to alternative prey. Studies of soldier fly population dynamics and the numerical and functional responses of individual predator species support the view that pupal predation plays a major role in the regulation of soldier fly populations (Robertson, 1984, and in preparation).

The scarcity of field evidence that natural enemies regulate populations of phytophagous insects (i.e., maintain their populations below carrying capacity by causing density-dependent mortality) may reflect either a general lack of importance of natural enemies

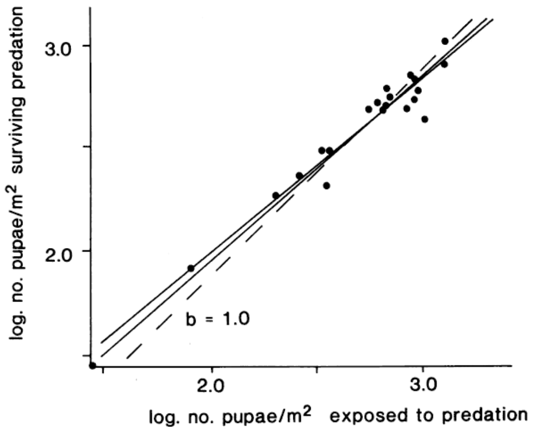

Figure 4: *Test for density-dependence of pupal mortality in Fig. 3. Results of 2-tailed tests on regression slopes and b = 1:* b_{yx} *= 1.12, t = 2.69 (P 0.01). Both slopes differ from b = 0 (P 0.01).*

(Dempster, 1983) or the difficulty of detecting natural enemies as density-dependent factors against a background of stochastic processes (Hassell, 1985). Hassell stressed the importance of identifying spatial density-dependence arising with a generation (e.g., Figs. 3 and 4) as well as intergeneration density-dependence.

Invertebrate predation on soldier fly shows similarities to invertebrate predation on the pupal stage of the winter moth *(Operophtera brumata* (L.)), one of the very few well-documented cases of predators regulating the population of a phytophagous insect (Varley and Gradwell, 1968; East, 1974; Kowalski, 1977; Hassell, 1985). Both cases involve density-dependent predation by polyphagous predators such as carabids and staphylinids occurring late in the life cycle of a relatively immobile prey which does not disperse widely in the adult stage, because of flightless females (winter moth) or limited powers of flight (soldier fly; Dixon and Gerard, 1979).

Effects of pathogens: grass grub

Grass grub, the root-feeding larva of an endemic New Zealand scarab, is a major pasture pest on free-draining soils throughout most of the country (East and Pottinger, 1984). Population monitoring since 1979 at Tihoi, north-west of Lake Taupo, and elsewhere in the northern North Island has revealed that autumn grass grub populations frequently collapse naturally to low levels (<100 per m^2) after reaching a peak of 200-800 per m^2 in previous years (East and Willoughby, 1983). Pathogens of grass grub, including the milky disease bacterium *Bacillus* sp. and the protozoans *Nosema costelytrae* Hall and *Mattesia* sp., playa major role in these population declines (East and Wigley, 1985). Populations usually decline or are stable at low densities (post-collapse) when the peak level of infection in summer by all pathogens combined exceeds about 20% of the population (Fig.5). Longer-term studies are required to elucidate further the role of pathogens in grass grub population dynamics in the northern North Island.

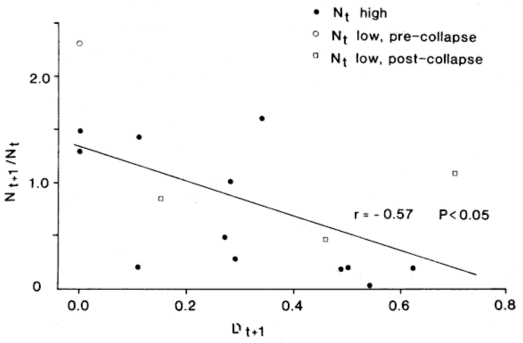

Figure 5: *Relationship between ratio of autumn (late Marchi April) grass grub larval populations (N) in successive years (t, t + 1) at Tihoi and maximum proportion of population diseased in summer (January-early March) in year t + 1* $(D_t + 1)$*. Symbols distinguish populations in which Nt was low (100 m*^{2}*) and the population was in the pre-collapse (e.g., newly sown pasture) or post-collapse phase, and populations in which Nt was high (150-400 m*^{2}*). Data from East and Wigley (1985 and unpublished).*

Protozoan pathogens *(Nosema* spp., *Mattesia* sp.) are important in grass grub population regulation in Hawkes Bay (Miln, 1979, 1982), and Taranaki (Barlow *et al.,* 1985) where milky disease may also be significant (Miln, 1983). In Canterbury, the bacteria *Serratia* spp. appear to be the predominant natural enemies of grass grub (Trought *et al.,* 1982; Jackson, 1984). Predators of grass grub are only locally significant (East *et al.,* 1981).

Despite regional differences in the pathogen complex, the pattern of population change is similar. Grass grub infestations typically comprise a mosaic of populations, with different paddocks containing populations at different phases of growth or decline.

Factors which reduce grass grub numbers to low levels, such as cultivation, insecticides, and drought, also reduce the level of infection by pathogens, creating favourable conditions for subsequent population increase to outbreak levels (Miln and Carpenter, 1979; Miln, 1982, 1983; Trought *et a1.,* 1982; East and Willoughby, 1983; East and Wigley, 1985; Barlow *et a1.,* 1985; Thomson *et a1.,* 1985). Farming practices which synchronise population change, such as widespread cultivation for cropping and subsequent resowing of pasture, can lead to severe outbreaks and should be avoided.

In the absence of cheap, highly effective control methods, most farmers now make little or no attempt to control grass grub directly, but accept pasture damage as a precursor to population regulation by naturally occurring pathogens. Farmers have adopted a range of practices which minimise the occurrence and effects of grass grub damage. These include minimising or avoiding practices such as cultivation and insecticides, which disrupt natural control, renovating damaged pastures by direct-drilling or broadcasting seed (avoiding cultivation) after populations have declined naturally, and balancing allocation of the available feed supply with the requirements of grazing animals to minimise the effects of grass grub damage on animal production (e.g. Thomson *et a1.,* 1984, 1985).

There are several possible methods of utilising pathogens to reduce further the pest status of grass grub and/or effect improved control (Wigley, 1985). These include making greater use of non-disruptive controls such as resistant or tolerant pasture species and cultivars, manipulating naturally occurring pathogens, e.g., by the transfer of infected soil, and the development of microbial insecticides (e.g., Jackson *et a1.,* 1986). It may also be possible to modify pathogens genetically to increase their pathogenicity (e.g., Crawford *et a1.,* 1985).

Concluding Remarks

Plant resistance and biological control are two of the major avenues for developing alternative pest management methods when reliance on insecticides is precluded by such factors as high costs and disruptive long-term effects on pest populations. The discovery of endophyte-conferred resistance to Argentine stem weevil in grasses and the subsequent widespread adoption of high-endophyte ryegrass cultivars by farmers in several areas of New Zealand underline the major potential of plant resistance in pasture pest management. There is an urgent need for greater research inputs by plant breeders to exploit pest-resistance and tolerance against other pasture pests (East, 1985; Pottinger, 1985).

Regulation of soldier fly populations by predators and its suppression by DDT appears to be a classical example of the disruptive side-effects of pesticides, with the use of insecticide to control one pest (grass grub) leading to outbreaks of another (soldier fly). It is highly likely that the widespread use of DDT also suppressed pathogens of grass grub to low levels, allowing severe grass grub outbreaks to occur in the early to mid-1970's after DDT had been replaced by relatively expensive (and hence less frequently applied), less persistent insecticides (Kain, 1979). Whereas predators have now reduced soldier fly populations to low levels throughout most of the species' distribution in New Zealand, grass grub remains a serious problem; the best prospects for improvements in grass grub control may lie in the utilisation of pathogens and the development of resistant or tolerant cultivars of ryegrass and white clover (East 1985).

The examples of soldier fly predators and grass grub pathogens illustrate the value of maintaining and enhancing the biotic pressures against pasture pests. Further research is required to develop management practices which conserve the biological control agents already present in New Zealand pastures, and to increase the natural enemy complex where possible. Soldier fly, for example, lacks parasitoids in New Zealand but is attacked by three species of diapriid wasps in Australia. At least one of these may be a candidate for introduction into New Zealand (Robertson and Zalucki, 1985). The introduction of suitable endemic or exotic insect pathogens into New Zealand pastures could have a major impact on pasture pest control (Wigley, 1985).

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