PROPIONIC ACID SUPPRESSES THE GROWTH AND SPORULATION OF GIBBERELLA ZEAE ON MAIZE STALK RESIDUES

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ABSTRACT

Propionic acid suppressed growth and sporulation of Gibberella zeae on maize stalk residues both when applied by immersion of the residues in aqueous acid solutions or as a spray at 225 l/ha. In the absence of saprotrophs 5% or 8% propionic acid was required to suppress G. zeae, but when saprotrophs were present acid concentrations of 2% or 3% were usually sufficient. G. zeae was recovered from acid-treated tissues indicating that propionic acid did not kill the pathogen. Suppression of G. zeae by 1% or 2% propionic acid in the presence of Trichoderma sp. resulted in massive colonization of the maize residues by this saprotroph. Evidently, when G. zeae has been inhibited by propionic acid, the fungus does not have the competitive ability to recolonize tissues which are then exploited by saprotrophs with high competitive saprotrophic ability.

INTRODUCTION

Stalk and ear rots of maize caused by Gibberella zeae (anamorph: Fusarium graminearum) are of major economic importance in many parts of the world, constraining yield and causing quality deterioration of the grain. Of particular concern are mycotoxins which accumulate in affected grain. The principal mycotoxins produced by G. zeae on maize in Ontario are zearalenone and 4-deoxynivalenol (Sutton 1982). Mycotoxins in the 1985 maize crop caused an estimated loss to the Ontario swine industry of > $50 million (G. Jones, personal communication).

Epidemics of stalk and ear rots appear to be monocyclic (Sutton 1982). Inoculum (ascospores, macroconidia) of G. zeae is produced mainly on maize or wheat residues which remain on the soil surface. In maize ear rot, receptivity to infection by dispersed spores is greatest shortly after the silks emerge and declines thereafter (Sutton & Baliko 1981). A direct proportionality of inoculum density at silking and intensity of ear rot is probable (Sutton 1982).

Conventional moldboard ploughing has been important in suppressing G. zeae in maize fields but is losing favour in Ontario because of soil erosion, water loss and energy costs. Many growers are therefore practicing reduced tillage or no-till methods. These agronomic practices increase survival and potential spore production by G. zeae, and thus the threat of stalk rot and ear rot. Alternative practices are needed for managing G. zeae in crop residues on the soil. The objective of the present study was to examine the effectiveness of propionic acid in suppressing growth and potential spore production by G. zeae on maize residues in the presence and absence of saprotrophs.

MATERIALS AND METHODS

To examine the effects of propionic acid (PA) on potential sporulation of G. zeae, maize stalks were inoculated with the pathogen by the toothpick method (Christensen & Wilcoxson 1966) in mid-August (late silking stage), harvested in November, and stored at 3°C. Diseased portions of the stalks were cut into 3-cm segments and quartered longitudinally. The stalk pieces were dipped in aqueous solutions of 0, 1, 2, 5 and 10% PA for one min and then placed on moist filter papers in Petri dishes which were sealed with Parafilm®. There were eight Petri dishes per treatment each with five pieces of tissue. The dishes were kept at 20-22°C and exposed to a 12 h photoperiod of near ultraviolet (UV) light for three weeks. Numbers of G. zeae perithecia on the stalk pieces were then counted.

Diseased stalk pieces treated as before with the various concentrations of PA were also exposed to microorganisms in the field. The stalk pieces, in nylon mesh bags (10 x 7 cm), were left on the soil surface or buried 5 to 8 cm deep in a maize plot near Guelph in June 1985. There were five replicate bags each with five stalk pieces in each treatment. After two days, the stalk pieces were recovered, placed in Petri dishes and incubated as before. The percentage surface area of the stalk pieces with mycelium of G. zeae was then estimated using the Horsfall & Barratt scale (Horsfall & Cowling 1978).

Effects of microorganisms on growth of G. zeae on stalk pieces colonized by the pathogen in the laboratory and treated with PA were examined. Stalk pieces were sterilized and 100 µl of a G. zeae spore suspension (10^5 macroconidia/ml) applied to each. The inoculated pieces were incubated under moist conditions on sterilized filter papers in sealed Petri dishes for one week and then immersed for one min in 0, 1, 2 or 5% PA. Forty pieces from each treatment were transferred to the surface of sterilized or nonsterilized field soil in Petri dishes (eight per treatment) and kept at 20-22°C under fluorescent lights (12 h photoperiod) for 25 days. Percentage coverage by mycelium of G. zeae was estimated as before.

Other organisms present on stalk pieces from the nonsterilized soil were isolated and identified. To recover fungi, small pieces of stalk tissue were transferred to plates of acidified potato-dextrose agar or weak carrot agar (0.2% carrots, 2% agar) containing 0.05% streptomycin sulphate. To recover bacteria, tissue pieces were crushed in sterilized water and serial dilutions were spread onto nutrient agar (Schaad 1980). The KOH test (Suslow et al. 1982) was used for gram identification and King's B medium (Schaad 1980) used to identify fluorescent pseudomonads.

A Trichoderma sp., isolated from stalk pieces in the preceding experiment, was tested for possible effects on G. zeae in PA-treated maize tissues. Sterilized stalk pieces were inoculated with G. zeae, incubated in moist chambers at 25°C for seven days, then immersed in aqueous 0, 1, 2 or 5% PA for 1 min and incubated in moist chambers at 25°C under a mixture of fluorescent and UV lights with a 12 h photoperiod. Each piece was infested with Trichoderma sp. after one or five days using 100 µl of a spore suspension (about 10^5 conidia/ml water).

To test PA applied as a spray, stalk pieces colonized by G. zeae were placed in Petri dishes (five pieces/dish) on filter papers moistened with sterilized water and sprayed with 0, 5, 8 or 10% PA at 225 l/ha using a motorized pot sprayer with 8002 E flat fan nozzles and a pressure of 276 kPa. Twenty min were allowed for volatilization of PA before the lids of the dishes were replaced and sealed. The dishes were kept at 22-23°C under UV light (12 h photoperiod) for four weeks, after which macroconidia of G. zeae on the pieces were counted using a haemacytometer.

Stalk pieces colonized by G. zeae were also placed on nonsterilized field soil in Petri dishes (15 g soil/dish moistened with seven ml sterilized water). The dishes were sealed, kept at 10°C for 1, 3 or 5 weeks (groups A-C respectively), then sprayed with 0, 3 or 6% PA at 225 l/ha. After 20 min the dish lids were replaced and sealed, and the dishes kept at 22-23°C with a 12 h photoperiod (UV light) for 7, 5 or 3 weeks (groups A-C respectively). Fungi were then isolated and identified, and macroconidia of G. zeae counted.

RESULTS

Propionic acid markedly suppressed perithecial production by G. zeae on maize stalk pieces colonized by the pathogen in the field (Fig. 1). In the immersion method, 1% and 2% PA reduced the numbers of perithecia by >50% and >90%, respectively, when compared with the checks (water only). No perithecia were produced on tissues treated with 5% or 10% PA. Slight growth and sporulation of Trichoderma spp. were observed on stalk pieces where immersion had been in 2% PA but not in 5% or 10% PA. An inverse relationship existed between stalk coverage by Trichoderma spp. and G. zeae in maize pieces treated with 1% PA.

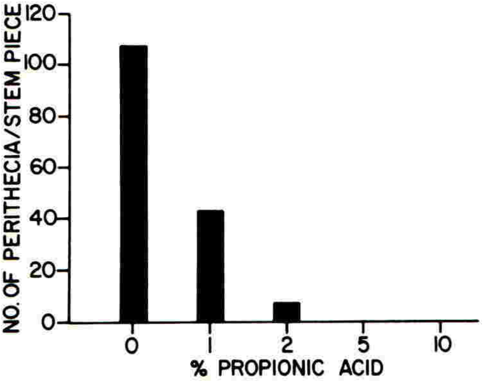

Fig. 1. Mean numbers of perithecia of Gibberella zeae observed on maize stalk pieces colonized by the pathogen in the field, immersed for 1 min in propionic acid and incubated on moist filter papers.

Mycelial growth of G. zeae on maize stalks colonized by the pathogen and exposed in the field was suppressed after treatment with PA (Fig. 2). Growth on stalk pieces exposed on the soil surface was reduced by 2% PA, but growth on pieces which were buried for two days was suppressed by 1% PA.

TABLE 2

Mean numbers of Gibberella zeae macroconidia on colonized maize stalk pieces after spraying with propionic acid and incubating on sterilized filter paper.

% propionic acid in water	Macroconidia/stalk section	
0	64 844 ± 9 120	a*
5	15 000 ± 5 583	b
8	2 144 ± 1 322	c
10	< 1 000	c

* Means followed by the same letter are not significantly different ($P_{0.05}$, Duncan's multiple range test).

DISCUSSION

Propionic acid suppressed mycelial growth and sporulation of G. zeae both when applied by the immersion method or as a spray. In the absence of saprotrophs 5% or 8% PA was required to markedly suppress G. zeae, but when saprotrophs were present 2% or 3% PA was usually effective. Thus saprotrophs inhibited G. zeae in maize tissues treated with PA. Recovery of G. zeae from PA-treated tissues, even when it did not sporulate or grow on the surface of the tissues, indicated that PA did not kill, but only inhibited, the pathogen. The free carboxyl group of PA evidently inhibits fungal growth (Anitox Corp. 1985). Whether G. zeae produced perithecia, macroconidia or mainly mycelium on the surface of stalk pieces appeared related to the state of decomposition of the substrate and the presence of saprotrophs. Growth on nutrient-rich undecomposed tissues was mainly mycelial.

A variety of naturally-occurring saprotrophs appeared capable of inhibiting G. zeae in PA-treated maize hence this inhibition was probably nonspecific. Saprotrophic fungi and bacteria recovered from stalk pieces in which G. zeae had been suppressed by PA possibly inhibited growth and sporulation by the pathogen. The inverse relationships between growth and sporulation of Trichoderma spp. and G. zeae in PA-treated tissues suggested that Trichoderma was an especially effective inhibitor.

Maize tissues colonized by G. zeae and treated with 1% or 2% PA were readily infested by Trichoderma sp. which suppressed growth and sporulation by the pathogen. In contrast, in tissues treated with water, established G. zeae prevented apparent colonization and sporulation by the saprotroph. The competitive ability of Trichoderma in the acid-treated tissues may have been enhanced by low pH (2.3-2.8) of the PA solutions (Cook & Baker 1983). Throughout this experiment, 5% PA was inhibitory to both G. zeae and

Trichoderma sp.

The interactive effects of PA and saprotrophs in suppressing G. zeae in maize stalk tissues appears to depend on differences in the ecology of the organisms. Gibberella zeae readily colonizes senescent maize stalks and normally persists in them after they die (Khonga & Sutton 1986). However, the pathogen is a weak competitor for dead host tissues in the presence of saprotrophs (Baker 1981). By definition, saprotrophs invade maize stalks only after the stalks have died. When G. zeae has been suppressed by PA, it probably has insufficient competitive ability to recolonize the tissues, which are then colonized by saprotrophs with a high competitive saprotrophic ability. Colonization of PA-treated tissues by saprotrophic organisms thus may be critical to the success of PA in limiting growth and inoculum production by G. zeae in crop residues.

REFERENCES

Anitox Corp (1984) Monoprop® Mold Killer Maintains Quality in Feedstuffs. Anitox Corp. Technical Bulletin 2, 39p.

Baker, R. (1981) Ecology of the fungus, Fusarium: competition. In: Fusarium: Diseases, Biology and Taxonomy. P.E. Nelson, T.A. Tousson and R.J. Cook (Eds). Pennsylvania: Pennsylvania University Press, 457p.

Christensen, J.J.; Wilcoxson, R.D. (1966) Stalk rot of corn. American Phytopathological Society Monograph 3, 59p.

Cook, R.J.; Baker, K.F. (1983) The Nature and Practice of Biological Control of Plant Pathogens. St. Paul, Minnesota: American Phytopathological Society, 539p.

Horsfall, J.G.; Cowling, E.G. (1978) Phytopathometry: the measurement of plant disease. In: Plant Disease, An Advanced Treatise Vol. 1 J.G. Horsfall and E.B. Cowling (Eds), New York: Academic Press, pp. 120-136.

Khonga, E; Sutton J.C. (1986) Survival and inoculum production by Gibberella zeae in wheat and corn residues. Canadian Journal of Plant Pathology (in press).

Schaad, N.W. (1980) Laboratory Guide for Identification of Plant Pathogenic Bacteria. N.W. Schaad (Ed), St. Paul, Minnesota: American Phytopathological Society, 72p.

Suslow, T.V.;Schroth, M.N.; Isaka, M. (1982) Application of a rapid method for Gram-differentiation of plant pathogenic and saprophytic bacteria without staining. Phytopathology 72, 917-918.

Sutton, J.C.; Baliko, W. (1981) Methods for quantifying partial resistance to Gibberella zeae in maize ears. Canadian Journal of Plant Pathology 3, 26-32.

Sutton, J.C. (1982) Epidemiology of wheat head blight and maize ear rot caused by Fusarium graminearum. Canadian Journal of Plant Pathology 4, 195-209.

PP321 - SAFETY TO HONEY BEES (APIS MELLIFERA) WHEN USED IN CEREALS

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ABSTRACT

Colonies of honey bees in mesh-covered tunnels were allowed to forage on sucrose solution sprayed on winter wheat, simulating aphid honeydew. Plots were then sprayed with one of 4 treatments: PP321 at 7.5 or 15 g a.i./ha, dimethoate at 500 g a.i./ha or water. PP321 caused no significant increase in mortality, whereas dimethoate killed 2000 bees per hive. In the 2 trials where half the crop was sprayed with PP321 and half with water, foraging was strongly reduced on the PP321-treated half for 24 hours, and the effect was detectable for a further 3 days.

INTRODUCTION

It has been shown that PP321, a novel pyrethroid from ICI, Plant Protection Division, formulated as "Karate", was toxic to honey bees in acute laboratory tests, but had no lethal or sublethal effects on them when applied to flowering winter rape at 10 g a.i./ha. (Gough & Wilkinson 1984). Some workers believe that bees may be at risk from pesticides whilst foraging on aphid honeydew on cereals (Shires *et al*.1984; Hardy 1985). An open-field trial to test for such effects is impractical and a 'semi-field' method was devised at INRA (Institut National de Recherche Agricole, France) (Louveaux, J. 1983, personal communication). The trial described here is a development of that method.

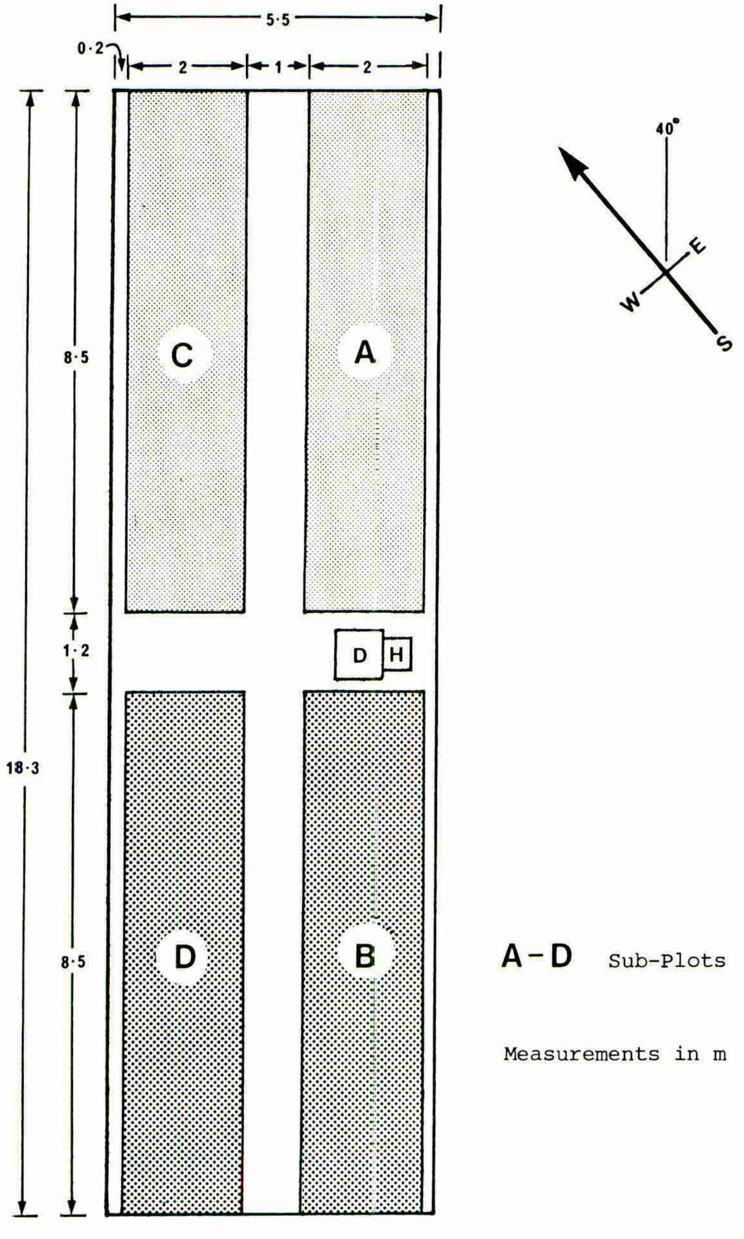
The principle is to apply sugar solution, acting as honeydew, to a crop enclosed in a mesh tunnel and to allow bees to forage on it. Part of the crop is then treated with a test compound and the other part left without insecticide. This enables observations to be made on both mortality and differential foraging. The main part of this study on winter wheat consisted of 2 trials, each with 4 tunnels. The 4 treatments were 7.5 and 15 g a.i. PP321/ha, 500 g a.i. dimethoate/ha and control. In a third trial, using a single tunnel, the entire crop area was treated with 15 g a.i. PP321/ha, giving the bees no alternative on which to forage. The insecticides were applied at a time when bees were actively foraging, to ensure both direct contact and oral hazards.

MATERIALS AND METHODS

Site and tunnels

The tunnels (supplied by Polybuild Ltd of Tewkesbury, UK) were 18.3 x 5.5 m tubular steel frames covered by Tildenet LS (40% shade) woven plastic netting. They were erected on a plot of winter wheat at green-ear stage. The tunnels were several metres apart to avoid shading and to minimise airborne cross-contamination. Within each tunnel the crop had been cut into 4 sub-plots (Fig.1). The cross-path in each tunnel was covered with a sheet of clear polythene, on which a hive was placed. A supply of water was always available to the bees, and pollen was provided each day.

FIGURE 1
Layout of tunnel



Insecticide-sprayed wheat (water only in Control tunnel)

Water-sprayed wheat

H Hive **D** Dead-bee tray

The bees

Nine medium-sized colonies in National hives, with healthy, functioning queens, were used in the trials.

Mortality

An 800 x 800 mm dead-bee tray was fitted to each hive entrance. Bodies were collected from this and from the polythene sheet daily at about midday. The main interest was in worker bees, but drones, worker pupae and drone pupae were also identified and counted. Data were subjected to analysis of variance, after logarithmic transformation for stabilisation of treatment and period variances.

Foraging

The bees were found to forage too unevenly to give sound results from small quadrats, so the observer, carrying a 1 m horizontal cane, defined a 1 x 8.5 m strip on each sub-plot. The number of bees foraging on this area during a 2-minute scan (1 minute in preliminary observations) were counted. The shade temperature for each sub-plot was recorded. On treatment day observations were hourly, using 2 observers. At other times they were 2-hourly (nominally at 10.30, 12.30, 14.30 and 16.30 h BST), made usually by a single observer. In Trial 3 observations were less frequent as there was only one tunnel, with no comparisons possible. The data were analysed similarly to those for mortality.

Other observations

At the hive entrance hyperactivity and aggressive behaviour and uncoordinated movement were looked for as an early sign of toxic effect. Gathering together of apparently fit bees at the entrance was regarded as a sign of repellency by the insecticide.

In Trials 1 and 2 development of the brood was monitored before and after treatment to look for delayed or sublethal effects. A fairly accurate assessment of each frame of brood was made in the field and it was photographed to record fine detail, using electronic flash and fine-grain colour reversal film. The hives were weighed at intervals throughout the trials.

Application of sucrose and water

A hand-held Oxford Precision Sprayer fitted with 4 No 11002 Teejet fan jets at 460 mm spacing was used, giving a 2 m wide swathe. Ten passes at a pre-calibrated pressure, and each of 10 seconds duration per sub-plot, delivered the initial application of 50% sucrose solution at 0.3 litres/m^2. Subsequent applications of 25% sucrose solution and water for remoistening the simulated honeydew were applied at lower volumes. The frequency of application was determined by the weather, but the 4 tunnels in use (Trials 1 or 2) each received the same amount.

Chemical treatments

The insecticides, and the water on the control plots, were applied with the same apparatus as used for the sucrose. A volume of 300 litres/ha (0.03 litres/m^2) was used. Immediately before the application of an insecticide the non-insecticide half of the plot was sprayed with the same volume of water to prevent differential wetting of the sucrose deposits on the crop, which might have affected the bees' foraging behaviour. A 5% wt/vol EC formulation of PP321 was used, at rates of 7.5 and 15 g a.i./ha. The toxic standard was a 40% wt/vol EC of dimethoate at a rate of 500 g a.i./ha. The control plot received water only.

In all 3 trials application was at a time when several hundred foragers were known to be on the crop. Times and dates were as follows: Trial 1, 16.00-16.20 h 30 June; Trial 2, 11.20-11.45 h 25 July; Trial 3, 12.00 h 13 August 1985.

RESULTS

Mortality

The numbers of dead bees collected daily during Trials 1 and 2 are presented as histograms in Figures 2 and 3.

Dimethoate killed about 2000 bees in each trial during the first 24 hours after treatment. The mortality remained high for several days. This was highly significant (P <1%) for 10 days in Trial 1 and for 2 days in Trial 2.

By contrast in Trial 1 the total mortality in the PP321 treatments for the 8 days following application was lower than during the preceding 8 days. In Trial 2 mortality was not significantly (P >5%) above that of the control. Even when the data were re-analysed without dimethoate counts, the differences between control and PP321 treatments were not significant except when colonies had been opened up for a brood assessment. In the third trial, the most severe test, mortality was low throughout.

There was no increased mortality of drones, worker pupae and drone pupae following insecticide treatment except for a few drones in Trial 1. No dead larvae were seen.

Foraging activity

In the statistical analyses of the data the toxic standard was excluded, as post-treatment foraging in those tunnels was negligible after treatment. Data from the other plots were analysed as daily observed totals in 3 ways: (i) total per tunnel, (ii) numbers on untreated and treated ends, (iii) percentage on treated crop within a tunnel.

The most notable post-treatment effect was a marked preference by the bees for the water-sprayed ends of the PP321 tunnels. This was significant on treatment day (Trial 1 P<5%, Trial 2 P<1%) and on the next day (Trial 1 P<1%). In Trial 2 a full day's post-spraying observation was possible (Fig.4), whereas in Trial 1 observations on treatment day were restricted as spraying was done in the late afternoon. The effect was detectable at a weaker level for up to 3 days after treatment on Trial 2 and 2 days on Trial 1. The differences were not always clear due to periods of bad weather, and were not always statistically significant.

The total numbers of bees foraging in the PP321 tunnels were significantly fewer than in the control tunnels on Day 0 (Trials 1 and 2 P<5%) and Day 1 (Trial 2 P<5%).

FIGURES 2 & 3
Numbers of Dead Worker Bees per Hive

Figure 2
Trial 1

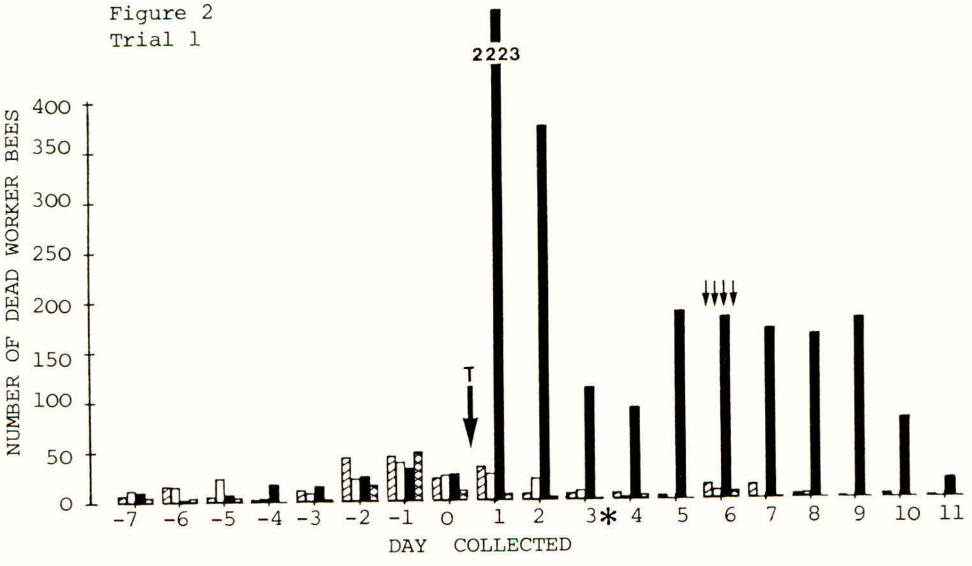
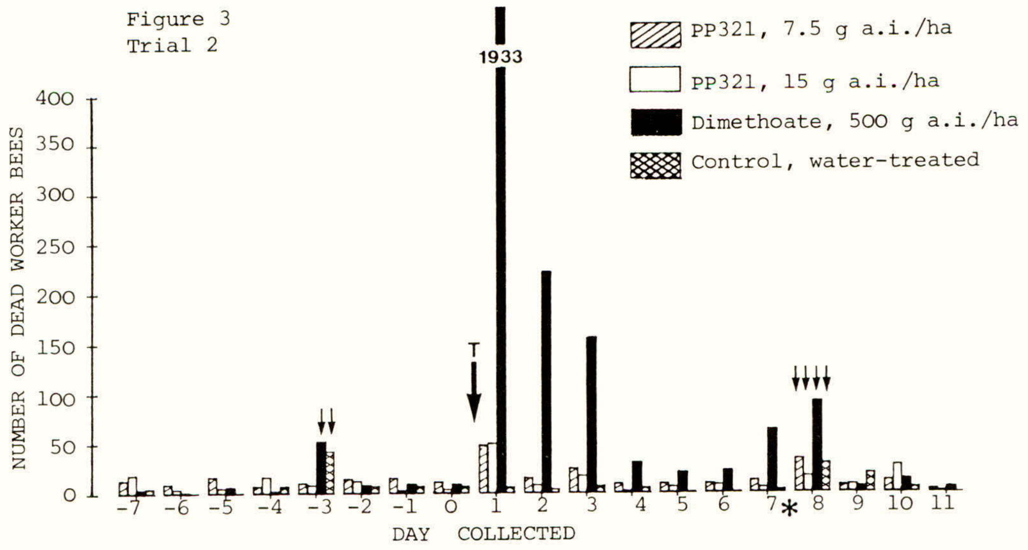


Figure 3
Trial 2



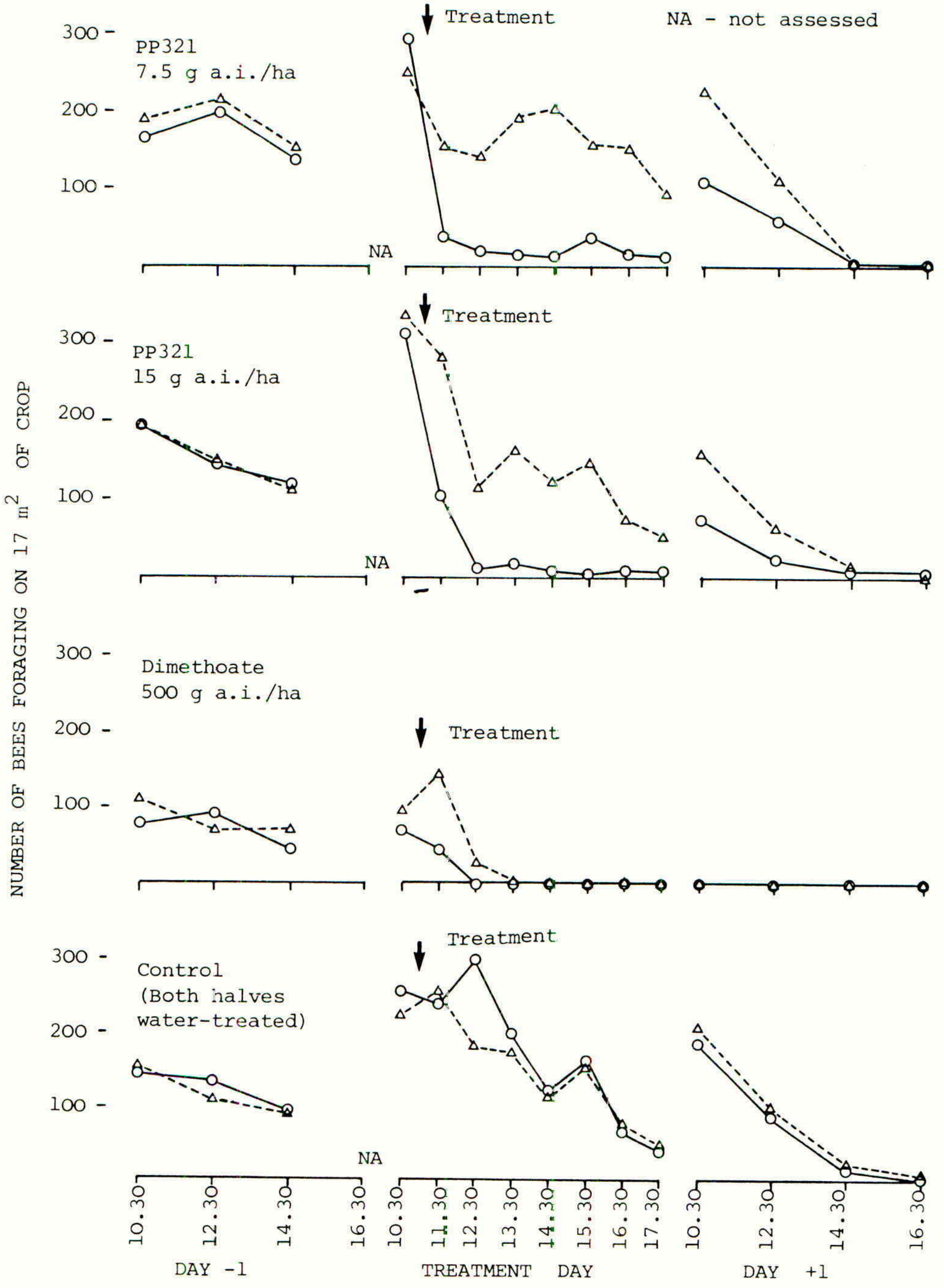
T ↓ Treated

↓ Brood assessed during previous 24 h

* Colonies removed from tunnels

Some brood assessments were done before Day -7 or after Day +11

FIGURE 4
Trial 2 Comparison of numbers of bees foraging on NE (insecticide-treated o——o) and SW (water-treated △----△) halves of the tunnels



There was some evidence of these effects being stronger at the higher rate of application, but this was not significant at the 5% probability level.

Other observations

Within an hour of treatment with dimethoate worker bees showed hyperactivity, uncoordinated flight and walking, and clustering at the hive entrance. Many were dying.

In the tunnels treated with PP321 some bees had difficulty in flying through the mesh of the dead-bee tray or in walking. Others made cleansing movements and there were sometimes groups of up to 50 bees standing, more or less motionless, in front of each hive. This was less evident in the second trial. Such effects lasted up to 4 hours after treatment.

Brood production in both trials using four treatments was disrupted by wet weather or by shortage of pollen or by both factors. However, PP321 had no effect on the brood whilst dimethoate seems to have prevented egg-laying in the first trial.

Changes of weight of the hives should have indicated the relative amounts of sucrose collected by each colony. However, no consistent treatment-related pattern was found.

DISCUSSION

The bees were clearly at risk from the insecticides. This was shown by the presence of up to 600 foragers on the crop at the time of treatment, by their subsequent behaviour, and by the high mortality from dimethoate. Nevertheless there was no significant increase in mortality from PP321, even when the entire crop was sprayed at the higher rate. It is well known that bees subjected to sublethal doses of pyrethroids usually recover within a few hours.

The principal effect of PP321 on foraging behaviour was a clear preference for the halves of the plots sprayed only with water. This repellency was strongly marked for 24 hours, and may have persisted to a lesser degree for a further 3 days. The true duration was masked by periods of poor foraging conditions. There was probably also a fall in the total numbers foraging in the PP321 tunnels for 1 or 2 days. This can be interpreted as suppression of foraging because of the absence of bodies.

Observations on egg laying, brood development and accumulation of sugar in the hives were inconclusive, due to unfavourable weather, but no harmful effect could be attributed to PP321.

The observations are supported by several tunnel trials on PP321 done in France (Delabie, J.; Massenot, F. personal communications).

CONCLUSIONS

The application of PP321 at 7.5 or 15 g a.i./ha to cereals bearing honeydew is of low hazard to foraging honey bees, even if the honeydew is re-moistened by rain. Even when bees are directly sprayed little or no mortality can be expected. Repellency or suppression of foraging for a period after application may further reduce exposure of the bees to the insecticide.

ACKNOWLEDGEMENTS

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REFERENCES

Gough, H.J.; Wilkinson, W. (1984) PP321: Effect on honeybees. Proceedings 1984 British Crop Protection Conference - Pests and Diseases 1, 331-335.

Hardy, A.R. (1985) Hazards to honeybees assessed from reports of beekeepers. Report of International Commission for Bee Botany. Third Symposium on the Harmonisation of Methods for Testing the Toxicity of Pesticides to Bees, Rothamsted Experimental Station, England 18-21 March,1985. Appendix 21.

Shires, S.W.; Le Blanc, J.; Debray, P.; Forbes, S.; Louveaux, J. (1984) Field experiments on the effects of a new pyrethroid insecticide WL-85871 on bees foraging artificial aphid honeydew on winter wheat. Pesticide Science 15, 543-552.

PEAS - CONTROL OF ESTABLISHMENT PESTS AND DISEASES USING METALAXYL BASED SEED COATINGS

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ABSTRACT

Furathiocarb and bendiocarb, when applied as polymer seed coatings to peas, gave excellent control of field thrips, Thrips angusticeps. Furathiocarb was also highly effective against pea weevil, Sitona lineatus. Metalaxyl + thiabendazole applied as a seed coating gave c. 84% control of seed-borne Ascochyta pisi but this activity was further improved by the addition of thiram. In 1985 trials, a polymer coating treatment of metalaxyl + thiabendazole + furathiocarb gave good insect control and some reduction in foot rot diseases (Phoma medicaginis var. pinodella, Fusarium solani) and gave a mean yield improvement of 67% over untreated in two trials.

INTRODUCTION

In recent years the use of fungicide seed treatments for control of establishment diseases of peas has become a widely accepted agricultural practice. Initially, purely protectant, slurry or powder treatments such as captan or thiram were used. These products gave some protection against soil-borne damping-off disease, but they were not sufficiently effective against deep-seated seed-borne infections. In 1970 (Maude, Presly & Dudley, 1972) the benzimidazole fungicides, thiabendazole and benomyl, were shown to be capable of controlling seed-borne infections of Ascochyta pisi and in 1980 (Biddle, 1981) the same products proved to be effective against another seed-borne disease, Mycosphaerella pinodes. A further breakthrough was made in the late 1970's, namely effective treatments for control of downy mildew, (Peronospora viciae). These treatments were metalaxyl (Miller & de Whalley, 1981; King, 1980) and fosetyl-aluminium. By combining these new treatments for downy mildew control with a benzimidazole for Ascochyta control, a broad spectrum treatment for seed and soil-borne diseases of peas could be developed.

Recently, much interest has centred on the introduction of a combined fungicide/insecticide seed coating package for peas (Baughan & Toms, 1984). This utilised a polymer-based seed coating process which allowed an accurate and even application of pesticide to the seed. This process has the added advantage that high chemical loadings, not previously attainable using conventional application methods, can now be achieved. Results from the Baughan & Toms (1984) study indicate that the addition of an insecticide (bendiocarb) to a standard fungicide seed treatment reduces feeding damage caused by pea weevil, Sitona lineatus, and increased yield.

It was the intention in this study to provide a broad spectrum seed treatment for peas by combining a range of fungicide treatments with a novel insecticide, furathiocarb, (Bachmann & Drabek, 1981). This is a systemic, carbamate insecticide which has activity against a large number of invertebrate pests including pea weevil and thrips (Thrips angusticeps) the major seedling pests of peas.

MATERIALS AND METHODS

Six trials, carried out during the 1985 and 1986 seasons are quoted in this study. For individual site details see Table 1.

Chemical formulations

metalaxyl 45.6% + thiabendazole 24.6% as (Apron T 69WS)

fosetyl-aluminium 52.8% + captan 17% + thiabendazole 12.9% as (Aliette Extra WP)

thiram 80% w.p. as (Tripomol 80WP)

bendiocarb 80% as (Ficam 80WP)

furathiocarb 50%, code name CGA 73102 as a 50% DS

Application methods

Conventional slurry seed treatments (ST) were applied using a hand operated rotating drum dresser. Polymer coating treatments (SCT) were applied using novel application equipment.

Seed loadings

Seed loading analysis was carried out on a range of treatments. The polymer coating process yielded chemical loadings within the range, 86% - 108% of the target dose.

Seed source

The seed used for all of the trials quoted in this study was of the combining pea variety Progreta. All seed used was of high vigour and seed health, unless otherwise stated in the text.

Assessment methods

When assessments of insect control were made it was not thought necessary to include data for all of the fungicide only comparisons. Likewise when fungicidal activity was assessed insecticide treatments were not included.

Field thrips

Field thrip attack in Trial 1 was severe and in Trial 2, was moderate. Consequently Trial 1 was assessed by counting thrip numbers per 10 plants per plot and Trial 2 by a count of severely distorted plants per plot.

Pea weevil

An assessment of foliar damage was made at the 2-3 true leaf stage, by counting the total number of leaf notches per plant, with a sample size of ten plants per plot.

Seed-borne Ascochyta

Seed infected with Ascochyta pisi (41%) and Mycosphaerella pinodes (3%), determined using the OSTS seed health test, was used on Trials 3 and 4 to facilitate a comparison of fungicidal seed treatments. Assessments were made by counting the total number of seedlings per plot showing obvious leaf and stem disease lesions.

Foot rot diseases

Assessments were made by counting the number of plants per plot showing severe symptoms (severe root and stem discolouration, wilting and premature senescence). Samples of infected plants from untreated plots were examined by MAFF Plant Clinic (ADAS Cambridge) and Fusarium solani and Phoma medicaginis var. pinodella were positively identified.

RESULTS

Field emergence

The results given in Table 2 show that, with healthy, high vigour, seed, none of the treatments tested adversely affected field germination. Subsequent assessments showed no reduction in crop establishment or overall crop vigour from any of the treatments.

Field thrips

The results are given in Table 3. Both bendiocarb and furathiocarb (at both rates tested) gave excellent control when assessed 41 or 27 days after drilling.

Pea weevil

Damage caused by Sitona weevil was considerable on both Trials 1 and 2. Table 4 shows that furathiocarb was the better treatment with c. 90% control. Bendiocarb was less effective with c. 60% control.

Seed-borne Ascochyta

The results in Table 5 show that all treatments containing thiabendazole gave good control of 80-90%. The control by metalaxyl + thiabendazole was consistently improved by the addition of thiram, to over 90% in both trials.

Foot rot diseases

A foot rot complex of diseases developed on one of the trials (Trial 6) in the 1985 season. The complex consisted of Phoma medicaginis var. pinodella, Fusarium solani, known to be pathogenic on peas and an unidentified Fusarium sp. The results in Table 6, are not statistically significant but the lowest levels of disease were in the metalaxyl + thiabendazole treatments. The addition of furathiocarb to the metalaxyl + thiabendazole mixture brought about a further useful improvement in disease control at 99 days after drilling.

Yield

At the time of writing no yield data are available for the 1986 trial series (Trials 1-4). Results from Trials 5 and 6 in 1985 are given in Table 7; these were variable due to adverse harvest conditions in that year, however it is clear that there can be considerable benefit in the addition of the insecticide, furathiocarb to metalaxyl + thiabendazole with a 76% and 58% yield increase recorded. The rate of the insecticide used was high as these trials were basically crop tolerance tests, although specific insect attack evaluations were made on Trial 5 (Table 8) and for furathiocarb these correlate well with yield.

DISCUSSION

The results from these field trials demonstrate the benefits of a broad spectrum seed coating for peas, particularly under conditions of severe pest and disease attack. The major establishment pests are effectively controlled by a combination of metalaxyl + thiabendazole + furathiocarb applied as a polymer seed coating. In addition, the data indicates that such a combination may be capable of a supression of foot rot, a late season disease complex not so far well controlled by chemical means.

Furathiocarb is a safe, insecticidal, seed treatment with a broad spectrum of activity (Bachmann & Drabek, 1981) and as such could be expected to exert a beneficial effect against a range of insect pests. Some activity against nematodes is cited, which would be beneficial against pea cyst nematode or pea early browning virus at the dose rates appropriate to weevil and thrip control.

To be cost effective, the relatively sophisticated seed coating treatments described here will have to satisfy several of the following criteria:

i) Provide good control of (insurance against) common establishment pests and diseases

ii) Give yield benefits by controlling pests and diseases not traditionally thought to be of economic importance

iii) Replace foliar applications of pesticide

iv) Give the grower more flexibility in choice of fields by permitting the planting of peas on sites at high risk from pest and disease attack

v) Control pests and diseases not previously controlled by chemical means

A combination of metalaxyl + thiabendazole + furathiocarb, with the possible inclusion of thiram, applied as a polymer seed coating, has the potential to satisfy most, if not all, of these requirements.

Seed coating treatments are as yet, in their infancy, however the signs point to an exciting future. With improved chemical loading, greater eveness of application and the potential to apply larger quantities of pesticide to the seed, the prospect of providing season-long protection is real or within sight. Research should continue towards this end.

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REFERENCES

Bachmann, F. & Drabek, J. (1981). CGA 73102, a new soil-applied systemic carbamate insecticide. Proceedings 1981 British Crop Protection Conference - Pests and Diseases 1, 51-58.

Baughan, P.J. & Toms, A.M. (1984). The development of a complete seed coating package for peas. 1984 British Crop Protection Conference - Pests and Diseases 3, 965-970.

Biddle, A.J. (1981). Fungicidal seed treatment - control of Ascochyta spp. Report of The Processors and Growers Research Organisation for 1980, p.17.

King, J.M. (1980). Disease control. Report of The Processors and Growers Research Organisation for 1979, p.18.

Maude, R.B., Presly, A.H. & Dudely, C.L. (1972). Leaf and pod spot of peas. Report of The National Vegetable Research Station for 1972, pp.92-94.

Miller, M.W. & De Whalley, C.V. (1981). The use of metalaxyl seed treatments to control downy mildew. Proceedings 1981 British Crop Protection Conference - Insecticides and Fungicides 1, 341-348.

TABLE 1

Site Details

Trial No.	Location	Drilling Date	Soil Type	Previous Crop	Plot Size
1	Whittlesford Cambs.	21.03.86	Sandy loam	Spring Barley	12 m x 1.5 m
2	Elmdon Essex	25.04.86	Clay loam	Winter Wheat	12 m x 1.5 m
3	Whittlesford Cambs.	21.03.86	Sandy loam	Spring Barley	6 m x 1.5 m
4	Elmdon Essex	25.04.86	Clay loam	Winter Wheat	6 m x 1.5 m
5	Whittlesford Cambs.	16.05.85	Sandy loam	Sugar Beet	12 m x 1.5 m
6	Elmdon Essex	17.06.85	Clay loam	Winter Wheat	12 m x 1.5 m

All trials were planted using a Hege Plot drill at a seed rate of 316 kg/ha. Treatments were replicated four times and the trials were of a randomized complete block design.

TABLE 2

Plant stand (the number of plants per 3 m row, 5 counts per plot) expressed as a % of the untreated.

Treatment	Type	Dose*	Trial 1	Trial 2	Mean
untreated	-	-	27.9/3 m	31.4/3 m	29.7/3 m
polymer only	SCT	-	99%	103%	101%
metalaxyl + thiabendazole conventional	ST	68.5 + 37	106%	98%	102%
metalaxyl + thiabendazole seed coating	SCT	68.5 + 37	99%	100%	100%
fosetyl-aluminium + thiabendazole + captan	SCT	154 + 37.5 + 50	102%	102%	102%
fosetyl-aluminium + thiabendazole + captan + bendiocarb	SCT	154 + 37.5 + 50 + 200	102%	90%	96%
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 200	95%	102%	99%
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 400	106%	97%	102%
metalaxyl + thiabendazole + thiram	SCT	69.9 + 37 + 30	103%	90%	97%
Assessed (days after drilling)			40 nsd	17 nsd	

* Dose rates are expressed as grams of active ingredient per 100 kg of seed.

TABLE 3

% control of field thrips

Treatment	Type	Dose*	Trial 1 Number thrips/plant	Trial 2 Number severely attacked plants/plot
untreated	-	-	(3.8/plant)	(69.8/plot)
polymer only	SCT	-	0%	0%
metalaxyl + thiabendazole conventional	ST	68.5 + 37	-	-
metalaxyl + thiabendazole seed coating	SCT	68.5 + 37	5%	0%
fosetyl-aluminium + thiabendazole + captan	SCT	154 + 37.5 + 50	-	-
fosetyl-aluminium + thiabendazole + captan + bendiocarb	SCT	154 + 37.5 + 50 + 200	96%	88%
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 200	83%	84%
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 400	99%	78%
metalaxyl + thiabendazole + thiram	SCT	69.9 + 37 + 30	-	-
Site assessed (days after drilling)			41	27
LSD P = 0.05			27%	53%

TABLE 4

% control of leaf notching by Sitona weevil

Treatment	Type	Dose*	Trial 1	Trial 2	Mean
untreated	-	-	15.5#	8.4#	12.0#
polymer only	SCT	-	17%	14%	16%
metalaxyl + thiabendazole conventional	ST	68.5 + 37	-	-	-
metalaxyl + thiabendazole seed coating	SCT	68.5 + 37	24%	27%	26%
fosetyl-aluminium + thiabendazole + captan	SCT	154 + 37.5 + 50	-	-	-
fosetyl-aluminium + thiabendazole + captan + bendiocarb	SCT	154 + 37.5 + 50 + 200	58%	66%	62%
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 200	89%	85%	87%
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 400	95%	91%	93%
metalaxyl + thiabendazole + thiram	SCT	69.9 + 37 + 30	-	-	-
Site assessed (days after drilling)			48	28	
LSD P = 0.05			21%	41%	

= notches/plant; - = assessment not done

* Dose rates are expressed as grams of active ingredient per 100 kg of seed

TABLE 5

% control of Ascochyta pisi

Treatment	Type	Dose*	Trial 3	Trial 4	Mean
untreated	-	-	27.8#	36.8#	32.3#
polymer only	SCT	-	0%	28%	14%
metalaxyl + thiabendazole conventional	ST	68.5 + 37	80%	84%	82%
metalaxyl + thiabendazole seed coating	SCT	68.5 + 37	79%	89%	84%
fosetyl-aluminium + thiabendazole + captan	SCT	154 + 37.5 + 50	93%	88%	91%
fosetyl-aluminium + thiabendazole + captan + bendiocarb	SCT	154 + 37.5 + 50 + 200	-	-	-
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 200	-	-	-
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 400	-	-	-
metalaxyl + thiabendazole + thiram	SCT	69.9 + 37 + 30	94%	95%	95%
Site assessed (days after drilling)			53	27	
LSD P = 0.05			55%	61%	

- = assessment not done

= infected plants/plot

TABLE 6

Trial 6: the number of plants per plot severely infected with foot rot diseases (Phoma medicaginis var pinodella, Fusarium solani and Fusarium sp.)

Treatment	Type	Dose*	Days After Drilling 85	99
untreated	-	-	13.5	30.3
polymer only	SCT	-	13.5	32.0
metalaxyl + thiabendazole conventional	ST	68.5 + 37	7.5	23.8
metalaxyl + thiabendazole seed coating	SCT	68.5 + 37	6.8	24.0
fosetyl-aluminium + thiabendazole + captan	SCT	154 + 37.5 + 50	12.3	26.5
fosetyl-aluminium + thiabendazole + captan + bendiocarb	SCT	154 + 37.5 + 50 + 200	9.8	20.0
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37.0 + 1500	6.3	14.0
LSD P = 0.05			9.57	22.0

* Dose rates are expressed as grams of active ingredient per 100 kg of seed.

TABLE 7

Yield of dried peas as a percentage of the untreated

Treatment	Type	Dose*	Trial 5	Trial 6	Mean
untreated	-	-	(1.09 kg/plot)	(4.41 kg/plot)	(3.2 kg/plot)
polymer only	SCT	-	104%	103%	104%
metalaxyl + thiabendazole conventional	ST	68.5 + 37	88%	122%	106%
metalaxyl + thiabendazole seed coating	SCT	68.5 + 37	99%	129%	115%
fosetyl-aluminium + thiabendazole + captan	SCT	154 + 37.5 + 50	95%	122%	109%
fosetyl-aluminium + thiabendazole + captan + bendiocarb	SCT	154 + 37.5 + 50 + 200	128%	100%	113%
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 1500	176%	158%	167%
LSD P = 0.05			42%	60%	

TABLE 8

Pea weevil and thrip damage scored on a 1-9 scale (1 = no damage, 5 = moderate damage, 9 = severe damage)

Treatment	Type	Dose*	Trial 5 Thrips	Trial 5 Weevils	Mean
untreated	-	-	3.0	4.0	3.5
polymer only	SCT	-	3.5	3.5	3.5
metalaxyl + thiabendazole conventional	ST	68.5 + 37	4.0	4.5	4.25
metalaxyl + thiabendazole seed coating	SCT	68.5 + 37	4.0	4.0	4.0
fosetyl-aluminium + thiabendazole + captan	SCT	154 + 37.5 + 50	-	-	-
fosetyl-aluminium + thiabendazole + captan + bendiocarb	SCT	154 + 37.5 + 50 + 200	1.5	1.5	1.5
metalaxyl + thiabendazole + furathiocarb	SCT	68.5 + 37 + 1500	1.0	1.0	1.0

- = assessment not done

* Dose rates are expressed as grams of active ingredient per 100 kg of seed.

EFFECT OF BARLEY FLY, DELIA FLAVIBASIS STEIN (DIPTERA: ANTHOMYIIDAE), ON THE GROWTH AND YIELD OF BARLEY

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ABSTRACT

Field experiments were carried out to determine the effects of D. flavibasis on growth and yield of barley. The effects of attack on the malting quality and commercial value of harvested barley crop was also assessed. Attacked plants suffered a check in their growth and were observed to compensate by recovery growth. The slow rate of development and compensatory growth delayed ripening. In attacked plants, the shoots developed unevenly and the ears did not ripen evenly. D. flavibasis infestation caused high yield losses, especially in cv Proctor, Tumaini, K. Research and MPYT 169-2Y; the lowest yield loss occurred in Can B35/2. However, D. flavibasis attack did not affect the grain quality, hence, no effect on the malting quality of barley. The pest incidence did not reduce the commercial value of the harvested barley crop.

INTRODUCTION

Previous published information on D. flavibasis damage to barley is restricted to data on percentage of plants attacked, qualitative statements on degree of damage and complete loss of crop under drought conditions (Bullock 1964; De Lima 1976). Recommendations for control have been given (Wheatley & Crowe 1967; De Lima 1976), but the economic significance of damage has not been quantified and is expressed only in general terms such as "major pest" (De Lima 1976).

No work on the effect of attack by D. flavibasis on growth and yield of barley has been reported. The present work was aimed at obtaining information about the effect on growth of barley attacked by D. flavibasis and hence assess yield losses caused by this pest. The effects of incidence of barley fly infestation on reduction in grain quality for malting purposes and value of the crop was studied in the present work.

MATERIALS AND METHODS

Five barley cultivars (Proctor, K. Research, Tumaini, MPYT 169-2Y and Can B35/2) were seeded in the field in a randomised block split plot design with four replications. The five varieties formed the main plots which were designed to be split to receive the protected and unprotected treatments. Each plot was 1.5 x 5.0m with eight rows of barley and an inter-row spacing of 18 cm; there were 2 subplots per plot. One subplot was left unprotected to be infested naturally by the barley fly.

Sowing was done by machine at a seed-rate of 80kg/ha. Compound fertilizer 11:52:0 (MAP) was applied at the rate of 120kg/ha. Broad-leaved weeds were controlled by using 2, 4-D amine applied at the rate of 1.5

litres/ha at the 15-16 growth stage (Zadocks et al. 1974).

Screen cages of 2.5m long by 1.5m wide and 1.0m high made from plastic mosquito mesh of 1mm size supported by wooden frame were used. The cages were placed on the subplots when germination was noticed one week after seeding, and the bottom frame of the cage partly covered with soil. The cages were lifted for a few minutes to facilitate sampling. Care was taken to ensure that adult barley flies were not introduced into the cages when sampling. A piece of cloth 7.5m long, which was pined on three sides of the base of the cage along the paths, was used as a protective device. The cage was lifted from the end away from the unprotected subplot. A piece of cloth was left hanging covering the space from which the height of the cage was lifted and thus preventing entry of any flying insects. The light intensity under the cages was slightly reduced but there was little interference with weather conditions affecting the subplots. The cages were finally removed after five weeks when the infestation declined and when they were too advanced for barley fly attack.

The symptoms of barley fly attack i.e. "dead hearts" were noticed one week after germination. Plant samples were taken at random from both the protected and unprotected subplots twice weekly starting one week after germination up to the fifth week for estimation of larval population. The sample for each subplot was made up of four subsamples randomly collected from a total of 0.5m row. All shoots from each sample were dissected in the laboratory for larval counts. Counts were recorded of the number of larvae, tillers attacked and unattacked plants from both the protected and unprotected subplots.

Both the protected and unprotected subplots were harvested by sickles and then threshed mechanically. The grain weight from each subplot was obtained after cleaning. The yield figures were adjusted to a standard 12.5% moisture content. The effects of attack of D. flavibasis on growth and yield of barley were determined by calculating the percentage reduction (% yield loss) in yield of each attacked subplot relative to its corresponding unattacked subplot. Percentage yield losses were calculated by the notation:

$$\frac{A - B}{A} \times 100$$

where A = yield data recorded for unattacked crop and B = yield data recorded for attacked crop.

The harvested grain crop was also graded according to size (% screenings) and tested for malting quality. Using the samples obtained from a mixture of grains from corresponding replicated entries, grain quality analysis was done to determine whether the barley fly attack affects the malting quality and commercial value of the barley crop. Analysis for grain quality included % moisture content, % dry nitrogen, % germinative capacity, % water sensitivity and % screenings. The European Breweries convention methods adopted by the Kenya Breweries quality laboratory were applied in the analysis.

Malting quality basically depends upon germination, grain nitrogen and the level of screening. Germination should be above 95%, grain nitrogen as low as possible (ideally below 1.85%) and grain size greater than 2.4mm. In addition, water sensitivity should be below 20% (Briggs 1968; Anon. 1981). The commercial value of the harvested barley crop was calculated using the 1980 (Anon. 1981) price structure indicated below:

(a) Grade I malting barley with grain size of 2.4mm or over at KSh.130.00 per 80 kg bag;

(b) Grade II malting barley with grain size of 2.2 - 2.4mm at KSh.116.00 per 80 kg bag;

(c) Non-malting barley with grain size below 2.2mm at KSh 84.00 per 80 kg bag.

A combined analysis of variance was used to analyse the data to determine whether significant differences existed between protected and unprotected plots from D. flavibasis attack. The means were separated using the least significant difference (little & Hills 1975).

RESULTS

Field observations revealed that unprotected plants took a longer time to mature as a result of D. flavibasis attack and their subsequent growth took place under climatic conditions different from those that prevail for plants that were protected. A slight infestation of the protected subplots by D. flavibasis larvae was noticed which may have been caused by larvae migrating from the edges.

From field observations, it was noticed that heading of barley was not uniform and there was delayed emergence of ears in the unprotected subplots compared with protected subplots. Unprotected plots in all the varieties had significantly ($P < 0.05$) higher larval population than protected plots (Table 1). Unprotected plots incurred significantly high percentage damage (% "dead hearts") compared with protected plots in all the varieties at the 5% level. Significant ($P < 0.05$) differences were noted in tillering capacity between the unprotected and protected plots from barley fly attack. Unprotected plots had more tillers than protected plots on cv K. Research, MPYT 169-2Y and Can B35/2. No differences were noticed in the mean number of tillers in cv Proctor and Tumaini between the protected and unprotected plots.

TABLE 1

Influence of barley cultivars on larval infestation by D. flavibasis

Cultivar	Mean number of larvae/0.5m		Mean % "dead hearts/0.5m		Mean number of tillers/0.5m	
	P	U	P	U	P	U
Proctor	0.18	4.64*	3.8	73.6*	37.7	37.7
K. Research	0.22	5.16*	5.2	79.8*	29.2	22.7*
Tumaini	0.16	5.29*	3.7	80.8*	34.1	34.0
MPYT 169-2Y	0.28	6.04*	6.3	81.9*	35.2	38.2*
Can B35/2	0.29	3.17*	5.2	78.5*	29.2	37.0*

The letters P and U refer to protected and unprotected.

Field observations revealed that the attacked plants in the unprotected plots in all the varieties were particularly able to compensate by recovery growth by producing late tillers. It was further observed that heading occurred earlier and evenly in all the varieties in the protected plots while in the unprotected plots there was delayed emergence of ears. The data on the moisture content of grain at harvest showed that there were significant differences between the protected and unprotected plots at 5% level except in Can B35/2 (see Table 2). This suggests that plants in the protected plots had ripened earlier than the plants in the unprotected plots except in cv Can B35/2. Field observations confirmed this.

TABLE 2

Effect of D. flavibasis on barley yields

Cultivar	Mean% moisture content		Mean grain yield (kg) at 12.5% M.C.		Mean % yield loss
	P	U	P	U	
Proctor	20.7	26.8*	0.57	0.32*	43.9
K. Research	20.8	24.6*	0.63	0.41*	34.9
Tumaini	17.3	22.0*	0.83	0.48*	42.2
MPYT 169-2Y	14.7	17.8*	0.79	0.57*	27.9
Can B35/2	14.7	14.6	0.78	0.72	27.7

The letters P and U refer to protected and unprotected.

Plants in the protected plots yielded more ($P < 0.05$) than unprotected plots in all the varieties except cv Can B35/2. In all the five varieties some yield loss was attributed to D. flavibasis. The highest yield losses were recorded in cv Proctor, Tumaini, K. Research and MPYT 169-2Y, while the lowest yield loss was recorded in cv Can B35/2.

Table 3 shows that barley seeds germinated adequately and water sensitivity was extremely low. However, all the nitrogen figures are too high and very few varieties would be accepted for malting. Despite the high grain nitrogen, no significant differences were observed between protected and unprotected plots on % grain nitrogen, % water sensitivity and % germinative capacity.

TABLE 3

Effect of D. flavibasis on grain quality of barley according to the procedure used by the Kenya Breweries Limited.

Cultivar	Mean% grain nitrogen		Mean% water sensitivity		Mean % germination capacity	
	P	U	P	U	P	U
Proctor	2.53	2.61	5.0	4.8	98.8	97.8
K. Research	2.41	2.39	4.0	5.0	98.0	96.5
Tumaini	2.45	2.44	6.0	5.0	97.0	96.8
MPYT 169-2Y	2.44	2.49	6.3	5.3	96.3	95.0
Can B35/2	2.16	2.26	1.0	1.3	98.0	99.0

The letter P and U refer to protected and unprotected.

N.B. The means are not statistically significant at 0.05 level of probability.

Overall, the screening figures were rather variable but most seemed to be acceptable. No variation was noticed in the commercial value of the harvested barley crop between the protected and unprotected plots.

DISCUSSION

Field observations revealed that D. flavibasis infestation at the 12th growth stage killed plants or the plants suffered a severe check in growth. Comparison of the mean number of tillers with yield figures showed some discrepancy. Attacked plots in cv K. Research, MPYT 169-2Y and Can B35/2 had more tillers than unattacked plots, yet the yield was low. This indicated that compensatory growth after infestation did not result in an increased yield.

In unprotected plots, cv K. Research, MPYT 169-2Y and Can B35/2 had more tillers than in protected ones. This shows that attacked plants responded by producing more tillers. It is possible that differences existed in the tillering response of different barley varieties to attacks by D. flavibasis. Data on moisture content of grains after harvest showed that protected barley plants ripened earlier than unprotected ones.

D. flavibasis attacks the first main shoots and the attacked plants respond by producing late tillers after the infestation is over. This compensatory growth results in late ripening of the produced tillers. Similar results have been reported by Bardner (1968) and Bardner & Fletcher (1974).

Since infestation ceases before heading, it is possible that infestations affect yield losses by lessening the number of ear-bearing shoots or slowing their development. The slower development of shoots in attacked crop may delay ripening and contribute to yield loss. Shoots were observed to develop unevenly in the attacked plots and the ears did not ripen uniformly. Yield losses were perhaps great because D. flavibasis attacked the crop when it was at the 12-13th growth stages and the initial attack killed the greatest number of plants as most of them were in the susceptible stage. Yield losses might have been greater if the plants had not responded by compensatory growth. Weather was also observed to have profound effect on the recovery of plants from attack and under drought conditions, attacked plants were observed to die.

Grain quality data showed that D. flavibasis infestation did not affect the malting quality. However, all the nitrogen figures were high and very few varieties would have been accepted for malting. Nitrogen content of grain has been reported by Briggs (1968) to be a varietal character which is depended on applied doses of N-fertilizer. Fertilizer used in planting was 11:52:0 (MAP) and it is suspected to increase nitrogen in seeds (Anon. 1981). The data on commercial value of the harvested barley crop showed that D. flavibasis infestation did not reduce the market value of the crop since it did not lower the grade of the harvested crop.

From this study it was realised that D. flavibasis infestation inflicted a high yield loss, thus emphasizing the need for more effective control measures. The knowledge gained in this study on the physiology of growth and yield in unattacked barley crop has provided a useful insight into the probable nature of the relationship between attacks of D. flavibasis and their effects on growth yield. The balance between the rate at which injuries are inflicted and the capacity of barley to compensate after injury can be used to minimise effects of possible pest infestations by manipulation of factors such as planting dates and seed rates.

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REFERENCES

Anonymous (1981) Barley 1980, Report on National Performance Trials. Min. of Agric. Kenya. External Report No. 59, 10 pp.
Bardner, R. (1968) Wheat bulb fly, Lephohylemya coarctata Fall., and its effects on growth and yield of wheat. Ann. Appl Biol. 61: 1-11.
Bardner, R.; Fletcher, K.E. (1974) Insect infestations and their effect on growth and yield of field crops: a review. Bull. Ent. Res. 64: 141-60.

Briggs, D.E. (1968) Barley. Chapman and Hall. London, 612 pp.

Bullock, J.A. (1964) The control of Hylemya arambourgi Seg (Diptera: Anthomyiidae) on barley. Bull. Ent. Res. 55: 645-61.

De Lima, C.P.E. (1976) A guide to the Biology and control of Pests of Field Crops and Stored Produce in Kenya. Min. of Agric., Republic of Kenya. 194 pp.

Little, T.M.; Hills, F.J. (1975) Statistical methods in Agricultural Research. University of California, Davis. 242 pp.

Wheatley, P.E.; Crowe, T.J. (1967) Pest Handbook. The recognition and control of the more important pests of Agriculture in Kenya. Government Printer, Kenya. 32 pp.

Zadoks, J.C.; Chang, T.T.; Konzak, C.F. (1974) A decimal code for the growth stages of cereals. Weed Research 14: 415-21.

ASSESSMENT OF THE IMPACT OF DELTAMETHRIN ON AQUATIC SPECIES

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ABSTRACT

The impact of deltamethrin, a pyrethroid insecticide, on aquatic environments has been extensively studied. The acute toxicity to fish which was very high in the laboratory, was not confirmed under field conditions. Various laboratory data and some physical chemical properties of deltamethrin are reviewed to explain this discrepancy. Strong adsorption and metabolization appear to be the most significant parameters to explain the actual safety of deltamethrin on fish in the field. This has been observed in rice fields under normal use and after aerial sprays over water sources when treating forests or against insect vectors of endemic diseases.

INTRODUCTION

Deltamethrin, a broad spectrum pyrethroid insecticide, has been widely used throughout the world for almost 8 years, mainly for crop protection but also in public health. During that period much attention has been paid to its impact on the environment, especially since laboratory studies predicted possible adverse effects, e.g., on honeybees and aquatic species.

This review confirms that actually, under normal outdoor field exposure, aquatic species, in particular fish, are not affected by deltamethrin, and outlines some parameters which may explain the discrepancy between results from the field and those obtained in acute toxicity tests in the laboratory.

SYNOPSIS OF MAIN UTILIZATION METHODS

In agriculture

Crop protection

Deltamethrin is used only as a foliar treatment, essentially by ground spray but also from the air. The application rates lie within a range of 5 to 15 g a.i./ha, those in rice culture being in most cases restricted to around 6 g a.i./ha. With regard to the latter crop, there is much concern about toxicity to fish species which are often bred simultaneously, especially in South-East Asia.

Forest protection

More recently, great interest has been shown in the control of certain pests with deltamethrin since doses as low as 1 to 5 g a.i./ha, are effective, generally applied by aerial spray.

Non agricultural usage

Deltamethrin is also used, more recently, against insects that are a nuisance to man and in the fight against insect vectors of the major endemic diseases (malaria, filariosis, leishmaniasis, onchocerchiasis,...).

Control of malaria essentially involves applying adulticidal and larvicidal treatments against mosquitoes at extremely low doses (0.5 to 3 g a.i./ha), usually by aerial spraying or ground fogging. Against the tsetse fly (*Glossina* spp), deltamethrin currently offers the most realistic, large scale alternative to compounds of the organochlorine group, used now for many years.

SUMMARY OF SOME PHYSICAL-CHEMICAL PROPERTIES

Deltamethrin has a single stereoisomer structure (Elliott *et al* 1974). The technical grade material has a purity higher than 98 % a.i. and well specified properties (Roussel-Uclaf 1982, WHO 1985). Being slightly polar, deltamethrin has an extremely low solubility in water (< 2 ng/ml at 20°C) and in other hydroxylic solvents. In addition, its octanol-water partition coefficient (Log Kow = 6.2, estimated by reverse-phase HPLC) puts deltamethrin, like many other pyrethroids, among the most hydrophobic pesticides in use (Muir *et al* 1986). Its vapour pressure at 25°C is also extremely low (2 µPa).

A hydrolysis study of deltamethrin in EC formulation has confirmed its unstability in alkaline conditions.

Deltamethrin is stable in light for many weeks in tropical conditions. A study of photodegradation products under normal solar radiation on glass plates (Ruzo *et al* 1977) concluded that the molecule was degraded into photolytic compounds less toxic overall than the parent compound.

Leaching studies have shown that deltamethrin is strongly adsorbed on soil particles (Kaufman *et al* 1981). Therefore the run-off water from treated areas does not transfer deltamethrin into streams and rivers. Similarly, percolating water does not redistribute deltamethrin within soil : deltamethrin and its metabolites are thus practically immobile.

PREDICTIVE LABORATORY DATA

Acute toxicity to aquatic organisms

Fish

Numerous laboratory tests have been carried out with deltamethrin alone (as technical grade) or included in formulations, such as the 25 g/l EC or 1 g/l solution for ULV application. These tests were based on the detection of lethal effects resulting from short exposures in natural or artificial media. On the various species tested (Table 1) deltamethrin had a very high acute toxicity under a range of species and experimental conditions (pH, temperature, oxygenation, hardness of medium) : indeed, the LC 50 values are of the order of 1 µg/l, although the data suggest that the 1 g/l ULV formulation is more tolerable than the 25 g/l EC.

Other aquatic organisms

The data available are fragmentary and concern mainly a few species of fresh water or marine crustaceans. The results presented (Table 2) confirm that toxicity to these organisms is similar to that for fish under laboratory conditions, except for oyster which is more tolerant.

Analysis of some parameters influencing acute toxicity

Protocol

In these tests a total absence of opercular movement and the failure to react to tactile stimuli are generally taken as a mortality criterion. In fact it would seem that a prolonged reversible comatose state precedes actual death (Lhoste *et al* 1979). During this coma, detoxification of the compound by enzymatic degradation takes place and fish can recover later on, so that removal of these apparently dead subjects can lead to an overestimation of acute toxicity.

Stage of development

Within a given species, Lhoste *et al* (1979) demonstrated that susceptibility of Salmo trutta to deltamethrin varied with its stage of development and age. An absence of ovicidal effect was confirmed even after immersion of

TABLE 1

Acute toxicity of deltamethrin tested as technical or formulated product on fish ; lethal concentrations all expressed as µg/l of active ingredient (96h)

Species	LC 50 (µg/l) tested as technical product	LC 50 (µg/l) tested as formulated product (**)	
Alburnus alburnus	0.69	82	ULV
Brachydanio rerio	2.0	-	
Cyprinodon macularius	-	0.6	EC
Cyprinodon variegatus	-	0.9	EC
Cyprinus carpio	1.84	0.65 EC ; 210.0	ULV
Gambusia affinis	-	1.0 (*)	EC
Ictalurus nebulosus	1.2	2.3	EC
Ictalurus punctatus	0.63	-	
Idus idus melanotus	-	1.2	EC
Lebistes reticulatus	-	1.8	EC
Lepomis gibbosus	0.58	0.87	EC
Lepomis machrochirus	1.2	-	
Osteochilus hasselti	-	1.2	EC
Puntius gonionotus	-	0.87	EC
Rhodeus sericeus amarus	1.12	140	ULV
Salmo gairdneri	0.39	2.2	EC
Salmo salar	1.97	0.59	EC
Salmo trutta	-	4.7 (*)	EC
Sarotherodon mossambicus	3.5	2.0	EC
Tilapia mossambica	-	0.8	EC

(*) LC 50/48 h
(**) EC 25 g a.i./l - ULV 1 g a.i./l - Value in a.i. equivalent obtained by calculation.

TABLE 2

Acute toxicity of deltamethrin tested as technical or formulated product on other aquatic organisms - Lethal concentration expressed as µg/l of active ingredient (96 h).

Species	LC 50 µg/l tested as technical product	LC 50 µg/l tested as formulated product (**)
Bufo bufo (larvae)	-	0.93
Crassostrea virginica	-	12.0
Daphnia magna	5 (*)	
Gammarus pulex	-	0.03 (*)
Penaeus duorarum	-	0.35
Uca pugilator	-	1.1

(*) LC50 / 48 h
(**) EC 25 g a.i./l - Values in a.i. equivalent obtained by calculation.

Despite these repeated exposures, Neto *et al* (1983) did not observe any mortality, only a slight agitation with highest doses.

Specific case of paddy fields

Impact assessment studies have been made in the Ivory Coast, the Philippines, Indonesia, Taïwan and Spain. Many fish species, including Tilapia spp, Cyprinus carpio, Gambusia spp have been found to tolerate doses of deltamethrin lower than 18.75 g a.i./ha. Since for deltamethrin there is no agronomic justification to treat in early stages on the crop, nor to use such high rates (about 6.5 g a.i./ha are sufficient), it is unlikely that its use will be unsafe. The low residues in water, as assessed in Taïwan, the strong adsorption on suspended colloids and the screening role of the rice vegetation, all contribute to this safety.

The safety of deltamethrin in paddy fields is also illustrated by some preliminary Indonesian work on fish productivity. Results obtained to date suggest that fish productivity is not affected by deltamethrin at the rate of 10 g a.i./ha.

Observations in non-agricultural conditions

Impact of applications made against insect vector of endemic diseases

Large scale trials have been performed mainly in Africa, on the control of tsetse flies either by ground or by air applications. For a non residual insecticide efficacy, the dose is 0.5 g a.i./ha only, whereas residual control needs about 12.5 g a.i./ha.

Environmental effects have been extensively followed and reported by Takken *et al* (1978), Koeman *et al* (1980) from Burkina Faso, by Everts *et al* (1983) from the Ivory Coast and by Smies *et al* (1980) from Nigeria. Fish populations were practically unaffected whereas 2 freshwater shrimps, Macrobrachium raridus and Caridina africana were more susceptible. However, subsequent observations showed that populations recovered as well as those of aquatic insects, since unaffected stages exist in the natural reservoir : this has been confirmed after aerial applications in Botswana by Davies (1980).

Impact of applications made against nuisance insects

Deltamethrin is highly effective on mosquitoe larvae at 1 g a.i./ha or less. At such doses, it is not harmful to fish as reported by Mulla *et al* (1978) and Erdös *et al* (1983).

DISCUSSION

Many experiments, as well as large use of deltamethrin for 8 years, confirm that its normal use does not cause mortality in fish populations. Tentative explanations can be given for the differences observed between acute toxicity tests in the laboratory and the actual good tolerance in outdoor conditions.

Information to date shows that, the more deltamethrin is adsorbed on suspended colloids and microphytes, the less it is bioavailable for fish which in turn are capable of metabolizing the product. A fraction seems also to be entrained by water vapour. It is also possible that natural media become alkaline, thus promoting the hydrolysis of the molecule. Fish species present in nature are probably more resistant than those used in laboratories and also may escape from the presence of deltamethrin, as observed in many trials. In large volumes of water, even if deltamethrin causes a knock-down effect, the exposure is likely to be more transient than under laboratory conditions, thus explaining the reversibility of the comatose state.

It is clear that further studies are needed to elucidate the mechanism and kinetics of penetration of pyrethroids into the fish body, as well as their successive degradation.

CONCLUSION

Without at all minimizing the importance of laboratory acute toxicity tests, field observations have supplemented and corrected them ; however, some special tests also conducted in the laboratory have proved to be of interest in trying to determine which parameters can explain the lack of toxicity of deltamethrin to fish populations under natural conditions.

This innocuousness to fish in the field, together with its lack of toxicity to mammals, birds and bees and its exceptional efficacy explain why deltamethrin, after almost 10 years use in agriculture and more recently in forestry and public health, is confirmed as one of the best means of controlling harmful insects, while respecting the environment.

REFERENCES

Cary G.A. (1978) Kinetics of 14C-NRDC-161 in a model aquatic ecosystem. Bionomics Aquatic Toxicology Laboratory. Unpublished report.

Chapman R.A.; Tu C.M.; Harris C.R.; Cole C. (1981) Persistence of five pyrethroid insecticides in sterile and natural, mineral and organic soil. Bulletin of Environmental contamination and Toxicology 26, 513-519.

Davies J.E. (1980) The effects of aerial spraying with decamethrin (NRDC 161) on non target tree canopy and grassland arthropods. Unpublished report. Department of Tsetse fly control, Botswana.

Elliott M.; Farnham A.W.; Janes N.F.; Needham P.H.; Pulman D.A. (1974) Synthetic insecticide with a new order of activity. Nature (London) 248, 710-711.

Erdös G.; Koncz A.; Kecskemeti (1983) Application possibility of synthetic pyrethroids in Hungary with special regard to biting mosquito control. Unpublished report.

Everts J.W.; Van Frankenhuyzen K.; Roman B.; Koeman J.H. (1983) Side effects of experimental pyrethroid applications for the control of tsetse flies in a riverine forest habitat Africa. Archives of Environmental Contamination and Toxicology, 12, 91-97.

Kaufman D.D.; Russel B.A.; Helling C.S.; Kayser A.J. (1981) Movement of cypermethrin, decamethrin, permethrin and their degradation products in soil. Journal of Agriculture and Food Chemistry, 29, 239-245.

Koeman J.H.; Den Boer W.M.J.; Feith A.F.; De Jongh H.H.; Spiethoff P.C. (1978) Three years observation on side effects of helicopter applications of insecticides used to exterminate Glossina species in Nigeria. Environmental Pollution, 15, 31-59.

Lhoste J., François Y., Rupaud Y. (1979) Ichtyotoxicité de la décaméthrine vis-à-vis de Salmo trutta en fonction de l'âge et des conditions expérimentales. Congrès sur la lutte contre les insectes en milieu tropical.

Mestres R. (1979) Etude de la dégradation de la deltaméthrine dans l'eau. Unpublished report.

Muir D.C.G., Rawn G.P., Townsend B., Lockhart W.L., Greenhalgn R. (1985) Bioconcentration of cypermethrin, deltamethrin, fenvalerate and permethrin by Chironomus tentans larvae in sediment and water. Environmental and Toxicology Chemistry, 4, 51-61.

Muir D.C.G., Hobden B.R., Servos M.K. (1986) Effect of dissolved organic carbon on bioconcentration of synthetic pyrethroids by fish. Abstract. 6th IUPAC Congress of Pesticide Chemistry.

Mulla M.S., Navvab Gojrati H.A., Darwazeh H.A. (1978) Toxicity of mosquito larval pyrethroid to four species of freshwater fishes. Environmental

Entomology, 7, 428-430.

Neto P.X.R., Rodrigues I.C.F., Filho A.M. (1983) Etude sur les effets secondaires de la deltaméthrine sur l'ichtyofaune de la région du projet "Rio Formoso". Unpublished translated report.

Rawn G.P., Muir D.O.G., Grift P.G. (1985) Fate of the pyrethroid insecticide deltamethrin in small ponds, a mass balance study. Journal of Agriculture and Food Chemistry, 33, 603-609.

Roussel-Uclaf (1982) Effects of deltamethrin on the environment. Deltamethrin Monograph, Chapter 9, 321-353.

Ruzo L.O. Holmstead R.L., Casida J.E. (1977) Pyrethroid photochemistry Deltamethrin. Journal of Agriculture and Food Chemistry, 26, 1385.

Smies M., Evers R.H.J., Reijnenburg P.H.M., Koeman J.H. (1980) Environmental aspects of field trials with pyrethroids to eradicate tsetse fly in Nigeria. Ecotoxicology and Environmental Safety, 4, 114-128.

Takken W., Balk F., Jansen R.C., Koeman J.H. (1978) The experimental application of insecticides from a helicopter for the control of riverine populations of Glossina tachinoides in West Africa. VI. Observations on side effects. P.A.N.S., 24, 455-466.

Tooby T.E., Thompson A.N., Rycroft R.J., Black I.A., Hewson R.T. (1981) A pond study to investigate the effects on fish and aquatic invertebrates of deltamethrin applied directly onto water. Fisheries Laboratory, Ministry of Agriculture, Fisheries and Food U.K. Unpublished report.

WHO (1985) Specifications for pesticides used in Public Health Sixth Edition, 270-296.

THE NEW SOLUTION AGAINST SOIL PESTS AND EARLY SEASON PESTS WITH FURATHIOCARP TREATMENT

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ABSTRACT

The specific properties of the systemic broad-spectrum insecticide furathiocarb, in particular its good toleration by seeds, make it ideally suitable for use in the treatment of seed for insecticidal purposes. Its protective action, which has been demonstrated in numerous trials, is effective against all important pests occuring in the eartly growth stages of many crops in particular sugar-beet, maize, sorghum and sunflower. The risk of birds being poisoned by eating treated seed is small owing to the pronounced repelent effect of active ingredient. The technique of treating seed with insecticide prevents economic damage to the treated crop using quantities of insecticide, per hectare, well below those used in treatment of the seed furrows with granules as already practised. Ecologically, this is of course an important advantage.

INTRODUCTION

The properties of furathiocarb were described for the first time by Bachmann & Drabek (1981). Its broad-spectrum of activity, systemic action, satisfactory stability in the soil and very good toleration by the seeds were discussed and the compound was considered worthy of development as a seed treatment against insect pests.

Protection against pests is required not only throughout germination but also during the early stages of plant growth, a period lasting several weeks. The amount of insecticide required to achieve this is 1% and more of the weight of the seed. This quantity of active ingredient is 10-20 times that needed for fungicides, and its application to the see presents technical problems. By way of example, the maximum amount of seed dust that can be applied to maize is 10 g of formulation per kilogram of seed. The theoretical dosage rate obtained for a seed dust (DS) 40 is 4 g a.i./kg; in practice this will never be achieved. In the intensive development work carried out since 1981 efforts have therefore been concentrated on the search of liquid formulations and their application in varying amounts to different sorts of seed. The active ingredient, which is sticky and viscous, had to be bound with a powder additive. A polymer was then used to give the coated seed good mechanical stability and a smooth surface. The main problem in pelleting sugar-beet seed was good release of the active ingredient from the pelleting material. The problem was solved only through very close collaboration with pelleting firms.

The various formulations based on furathiocarb for the treatment of seed against insect pests will be made available to agriculture and seed companies under the tradename 'Promet'. The results attainable with the treatment are discussed below.

RESULTS

The technique of pelleting seeds to protect seedlings against a whole range of pests is most advanced in the case of sugar-beet. Table 1 gives the results of a trial in France in which the cv Bettimo was sown on 2, May 86. The plants were subsequently heavily infested with wireworms.

TABLE 1

Control of wireworms by insecticidal seed pelleting and its effects on the stand of sugar-beet

Insecticide	g a.i./u*	Relative number of plants 19 DAP	24 DAP	41 DAP
Furathiocarb	40	129	137	154.5
	60	143	157	192
Carbofuran	45	131	131	155.5
Control	-	100	100	100
Actual number/100m: of plants		255	198	167.5

* u = unit = 100 000 pelleted seeds.
DAP= days after planting.

In two trials at Middenmeer in Holland extremely heavy infestation by the pigmy mangold beetle, [(Atomaria linearis)] was experienced. The pelleted cv Regina was sown on 22, April 85. The effect of the infestation is shown in Table 2 by indicating the number of plants that survived.

In the trial reported in Table 3 naked seed of the variety Kawepoly was treated and then sown in Spain (Valladolid) on 22, April 86. The purpose of this trial was to protect young plants, as soon as they emerged, against feeding damage by the flea beetle Chaetocnema tibialis.

TABLE 2

Control of pygmy mangold beetle by insecticidal seed pelleting and its effects on the stand of sugar-beet

Insecticide	g.a.i./u	Relative number of plants 44 DAP (trial 1)	41 DAP (trial 2)
Furathiocarb	60	374	1880
Carbofuran	30	178	1600
Control	-	100 = 18000/ha	100 = 4500

TABLE 3

Control of beet flea beetle on sugar-beet by treatment of naked seeds

Insecticide	g a.i./kg	% of reduction of damage 23 DAP	36 DAP
Furathiocarb	20	96 a	97 a
	30	98 a	98 a
Benfuracarb	20	97 a	88 b
Carbofuran	20	90 b	91 b
Control [rate of damage (0-20)]:		12.4 c	13.2 c

Furathiocarb treatment also protects against first generation beet leaf miner (Pegomya betael) and early infestation with black bean aphid (Aphis fabae). In East Europe the product is used successfully for protection against beet weevil Bothynoderes punctiventris.

The most important pests which threaten young maize in Europe are wireworms and frit fly. In East Europe there is also the weevil Tanymecus dilaticollis. One example of the many successful trials conducted against these pests is given in Table 4. In this trial the plants had to be protected against very heavy infestation by wireworms. For comparison, 'Deltanet 5 GR', the granular formulation of furathiocarb, was applied in the seed furrow. The cv G 4507 was sown at Apicat in Spain on 10 May 85.

TABLE 4

Control of wireworms on maize and the effect on yield

Insecticide	g a.i.	% reduction of damage	Relative yield
Furathiocarb (ST)	10/kg	74	392 a
	15/kg	73	429 a
Furathiocarb (GR)	600/ha	90	395 a
Control (% plants destroyed):		77	100 b

Sorghum and sunflower are also subject in their early stages to attack by wireworms in their early stages. Their thousand-seed weight is very much lower than that of maize. However, the dosage rate for treatment of the seed requires scarcely any increase for protection to be successful, as is evident from Tables 5 and 6. Both trials took place in Paradou, France. The sorghum variety Savana was sown on 17 May 85 and the sunflower cv Mirasol on 24 April 85. Here again, furathiocarb granules were applied in the seed furrow.

TABLE 5

Control of wireworms on Sorghum and the effect on yield

Insecticide	g a.i.	% reduction of damage	Relative yield
Furathiocarb (ST)	10/kg	84	159 a
	15/kg	92	160 a
	20/kg	78	149 a
Furathiocarb (GR)	600/ha	99	163 a
Control (% plants destroyed):		73	100 b

TABLE 6

Control of wireworms on sunflower and the effect on yield

Insecticide	g a.i.	% of reduction of damage 27 - 41 DAP	Relative number of plants 41 DAP	Relative yield
Furathiocarb (ST)	10/kg	80	161	116 b
	15/kg	61	151	128 a
Furathiocarb (GR)	600/ha	85	166	128 a
Control (% of plants attacked):		24	100	100 b

The main pest in winter rape is the cabbage stem flea beetle (Psylliodes chrysocephala). Ceutorhynchus picitarsis is also of importance at times. In addition to furathiocarb seed dust, 'Rapcol', a special formulation of 40% furathiocarb with two fungicides, was also developed to control these pests. As can be seen from Table 7, in the trial at Houlbec in France fairly heavy infestation by P. chrysocephala led to a slight reduction in the number of plants. The cv Bienvenu was sown on 29 August 85.

TABLE 7

Control of cabbage stem flea beetle on winter rape by seed treatment

Insecticide	g a.i./kg	Adults % reduction of damage 28 DAP	Larvae % reduction of attack 219 DAP	Relative number of plants 28 DAP
Furathiocarb (ST)	25	71	83	109.5
Furathiocarb (mixture)	25	65	77	116
Methiocarb	25	23	63	100
Control (number of bites/plant):		3.1		100
(number larvae/25 plants):			162	

The latest reports of trials in England indicate that treating pea seeds with Furathiocarb at the rate of 2 g a.i./kg provides good control of the pea and bean weevil (Sitona lineata), and of thrips.

The use of furathiocarb on upland rice against the shoot fly Atherigona, and on paddy rice against plant and leafhoppers is undoubtedly of greater economic importance, however. The unusual rough surface of rice seed permits heavier coating with powder than is the case with other seed. Furathiocarb seed dust can therefore be used without difficulty.

Table 8 shows the efficacy of a seed treatment as compared with the application of granules against shoot fly in upland rice (cv Harapan) in Indonesia in 1984.

TABLE 8

Control of shoot fly attack on rice

Insecticide	g a.i.	% reduction of attack 15 DAP	22 DAP	29 DAP	Relative plant size 29 DAP
Furathiocarb	2/kg	82	74	80	172
	4/kg	96	78	80	172
	6/kg	100	100	80	173
Diazinon	10/kg	73	0	0	121
Carbofuran	750/ha	90	74	76	178
Control (% dead hearts):		21	32	26	100

In paddy rice, plant and leafhoppers may attack already in seed the bed or, in the case of direct-seeded rice, shortly after emergence. Table 9 shows that infestation at this early stage by the brown planthopper (Nilaparvata lugens) can be successfully prevented by seed treatment. Furathiocarb was applied to the cv Pelita either to the dry seed before soaking (DBS) or to the wet seed after soaking (WAS). The seeds were sown in Cikampek, Indonesia, on 14 November 85 and artificially infested with planthoppers eight days later. Without control, this infestation resulted in increasing hopperburn.

TABLE 9

Control of brown planthopper in rice by seed treatment

Insecticide	g a.i./kg	method	% hopperburn 25 DAP	39 DAP	47 DAP
Furathiocarb	8	DBS	0	0	3
		WAS	0	0	5
Control			55	68	99

DISCUSSION

Demonstration and proof of the biological performance of seed treatments with furathiocarb may be taken as largely complete. The favourable results obtained in field trials can therefore be translated, in summary form, into the use recommendations given in Table 10. It is also evident from the table that protection of the crops as desired is achieved using far less insectide than is possible in treatment with granules in the seed furrow. To take sunflowers as example, only 50-75 g of active ingredient instead of 600 g were required per hectare for a seed quantity of about 5 kg/ha.

One important aspect remains to be discussed, and it may be crucial to the practical application of insecticidal seed treatment. The aspect in question is the risk of wild birds being poisoned by feeding on treated seed. In special trials with pheasants and crows it was found that furathiocarb has a marked repellent effect on birds. We have excluded small grains from our use recommendations, even though a furathiocarb seed treatment dressing has demonstrated a highly beneficial protective effect against soil pests and frit fly in these crops too. Before any use recommendations are made for cereals, further data have to prove that there is no risk for the environment.

TABLE 10

Use recommendation

Crop and pest	Type of formulation	Rate g/kg seed
Sugar beet	Pelleting with DS or liquid	40-60 (per unit)
Pest complex	Naked seed with DS or liquid	15 - 30
Maize		
Frit fly, (wireworms)	DS or liquid	4
Pheasants (repellent)		
Wireworms	Liquid	10
Weevil (*Tanymecus*)		
Rice		
Shoot fly	DS or liquid	4
Leaf and planthoppers	Liquid or DS	8
Sorghum		
Wireworms	Liquid	10 - 15
Sunflower		
Wireworms	Liquid	10 - 15
Rape seed		
Flea beetle, weevil	DS or liquid	25

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REFERENCES

Bachmann, F; Drabeck, J. (1981) CGA 73 102, A new Soil Applied Systemic Carbamate Insecticide. *Proceedings BCP conference*, 51-58.

THE EFFECTIVENESS OF NEW FUNGICIDES IN THE PROTECTION OF WINTER WHEAT IN POLAND 1983 - 1985

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ABSTRACT

Candidate fungicides containing dimiconazole, fenpropimorph, flutriafol, prochloraz and triadimefon + anilazine were evaluated in plot and in production trials under conditions of natural infection for their effectiveness in controlling a disease complex of winter wheat in Poland. Two sprays were applied and compared with the standard fungicides, propiconazole and triadimefon and with non-fungicide treated controls.

The efficacy of the candidate fungicides in the control of the winter wheat disease complex including *Erysiphe graminis* f.sp. *tritici*, *Puccinia recondita* f.sp. *tritici*, *Septoria tritici*, *Septoria nodorum*, *Pseudocercosporella herpotrichoides*, *Rhizoctonia cerealis* and *Fusarium spp*. was determined.

The effect of the candidate fungicides on the grain yield and 1000-grain weight of winter wheat was estimated.

In the trials carried out under normal production conditions, an average economically profitable grain yield increase was obtained.

On the basis of the results obtained the new fungicides have been included in programmes for protection of winter wheat against the disease complex.

INTRODUCTION

The number of fungicides presently registered in Poland for spraying winter wheat is not large and there is a need to seek new ones which could be effective under local conditions.

With that in view, the Institute of Plant Protection in Poznan is conducting studies on new domestic and foreign fungicides intended for the profitable control of fungal diseases of cereals. These studies cover active ingredients in various chemical groups characterized by different modes of action with the aim of creating spray regimes in which the different modes of action are alternated.

The results of the studies provided a basis for registration in 1985 of fungicides containing fenpropimorph and prochloraz. Recommendations concerning registration of further chemicals are made annually after finishing studies.

MATERIALS AND METHODS

Plot Trials

Trials were conducted during 1983-1985 on land of the Experimental Plant Protection Department at Winnagora/III region of wheat cultivation; in fields with pseudopodzol soil of class IVA. The trial crop was naturally infected winter wheat cv. Grana. The plot trials were randomised blocks; 25 m^2 plots; in 4 replications. The seed was treated with Polish Oxafun T dressing (carboxin + thiram).

Husbandry and fertiliser procedures were in accordance with obligatory recommendations.

In studies on the effectiveness of fungicides (Table 1) plots were sprayed twice with the five candidate fungicides and the two standards. The first spray was applied at the 1-node growth stage and the second one at the full earing stage. An estimate of disease infection on 100 random plants per plot was made on each spray date.

TABLE 1

Fungicides studies during 1983-1985

No.	Fungicide	% active ingredients	Product	Group
1.	Dimiconazole	12.5	Sumi-8	Triazoles
2.	Fenpropimorph	75.0	Corbel	Morpholines
3.	Flutriafol	12.5	Impact	Triazoles
4.	Prochloraz	45.0	Sportak 45 EC	Imidazoles
5.	Propiconazole*	25.0	Tilt 250 EC	Triazoles
6.	Triadimefon*	25.0	Bayleton 25 WP	Triazoles
7.	Triadimefon + Anilazine	48.0	Dyrene 480 SC	Triazoles + heterocycl.

* standard fungicides

The percentage of the surface of upper leaves infected by *Erysiphe graminis*, *Puccinia recondita* and *Septoria tritici*, and of *Septoria nodorum* on the ear was determined using pictorial assessment keys. Stem infection by a complex of *Pseudocercosporella herpotrichloides*, *Rhizoctonia cerealis* and *Fusarium* spp. was determined as the percentage of diseased plants. The results were subjected to an analysis of variance and means compared by the T-Tukey's and t-Student's tests.

Production-crop trials

Trials were carried out at 101 sites under different agrotechnical, climatic and soil conditions in Poland on a total area of 50.5 ha of winter wheat. Crops were sprayed twice; first, at the 1-node growth stage, with prochloraz; second, at full earing with one of the three fungicides fenpropimorph, flutriafol or prochloraz. Yield of fungicide-treated areas of crop were compared with those for untreated control areas.

RESULTS OF PLOT TRIALS

Severity of disease and effectiveness of fungicide

In the trials region in 1983-1985, the weather was unfavourable to the development of the pathogens. During the 3-years the occurrence of diseases in the controls varied and was in most cases, low or average.

Erysiphe graminis f.sp. *tritici*

In 1983, 1984 and 1985 the occurrence of mildew in the control at full ear emergence was 1.10, 1.40 and 0.11% of the flagleaf surface respectively. Despite this low severity, a statistical analysis of the results showed that the chemicals were effective in controlling the fungus. The average efficacy of the candidate chemicals was 85.2% in comparison with that obtained for the standard fungicides which was 89.8%.

Puccinia recondita f.sp. *tritici*

This disease was most severe in 1985 when 6.70% of the area of the flagleaf surface was affected in the controls. Among the studied chemicals, propiconazole showed no significant control. The mean % effectiveness of the candidate fungicides was 8.53 in comparison with the figure of 77.6% obtained for the standard chemicals.

Septoria tritici

The disease severity in the controls was, on average, 2.19% of the flagleaf area. Among the candidate fungicides, only prochloraz gave significant control. Statistically significant control was also obtained after use of the standard fungicides. The remaining chemicals retarded disease development relative to the controls, but not significantly.

Septoria nodorum

An estimate of fungicide efficacy was based on the results in 1984 and 1985 since in 1983 high temperatures, droughts, sunshine and low relative humidity resulted in the absence of the pathogen. The diease was particularly severe in 1985 when the average per cent infection of the ear surface in the controls was 14.20%. All fungicides retarded disease development but only triadimefon + anilazine reduced it significantly.

Disease complex of the stem base

Only the imidazole, prochloraz resulted in significant reduction in stem weakening caused by *Pseudocercosporella herpotrichoides*. This fungicide reduced stem infection by 49.7%. None of the chemicals was significantly effective in controlling *Rhizoctonia cerealis* and *Fusarium* spp.

Yield and 1000-grain weight

Tables 2 and 3 present the average results for grain yield and 1000-grain weight obtained in the trials. The increase in grain yield was, average, 14.2% (range 9 to 19%) and the 1000-grain weight increased on the average by 5.7% (range 3.2 to 8.6%).

TABLE 2

The average grain yield of winter wheat cv. Grana in disease control trials by fungicides during 1983-1985

Fungicides	Average yield in t/ha	Average yield increase in relation to the control	
		t/ha	%
Flutriafol	5.976	0.96	19.0
Triadimefon + Anilazine	5.909	0.89	17.7
Dimiconazole	5.751	0.73	14.6
Triadimefon*	5.702	0.68	13.6
Propiconazole*	5.678	0.66	13.1
Fenpropimorph	5.658	0.64	12.7
Prochloraz	5.470	0.45	9.0
Means:	5.735	0.72	14.2

* standard fungicides

TABLE 3

The average 1000-grain weight of wheat in the years 1983-1985

Fungicides	Average weight in grams	Average yield increase in relation to the control	
		g	%
Flutriafol	40.71	3.23	8.6
Triadimefon + Anilazine	40.31	2.83	7.5
Triadimefon*	39.63	2.15	5.7
Propiconazole*	39.47	1.99	5.3
Fenpropimorph	39.34	1.86	5.0
Prochloraz	39.19	1.71	4.6
Dimiconazole	38.62	1.19	3.2
Means :	39.62	2.14	5.7

* standard fungicides

RESULTS OF PRODUCTION-CROP TRIALS

Means of the results obtained from the 101 crop trials are summarised in Table 4. Depending on the applied fungicide programme, the grain yield increase was from 10.4 to 14.6% and was significant. These fungicide programmes, under conditions in Poland, appeared to be economically profitable.

TABLE 4

Results of fungicide application for disease control of winter wheat under production conditions during 1985

Objects	No. of Trials	Average of untreated	Yield treated	Average yield increase	
		t/ha		t/ha	%
I Prochloraz II Flutriafol	35	3.58	4.18	0.60	14.6
I Prochloraz II Prochloraz	32	3.88	4.35	0.47	11.1
I Prochloraz II Fenpropimorph	34	3.75	4.18	0.43	10.4
Means :	101	3.74	4.24	0.50	12.0

DISCUSSION

The fungicides applied in these trials have already been the subject of many studies in a number of countries (Goebel, 1983; Saint-Blanquart et al 1982; Wiese et al., 1984).

Results of the trials carried out in Poland confirmed the usefulness of the studied compounds in the control of the fungal disease complex on winter wheat.

It should be recognised that profitability of fungicide application, even when disease occurrence is not large, is an important fact. In 1983-1985, when the climatic conditions in Poland were unfavourable to disease development the average yield increases obtained in these trials were significant in both plot and production-crop trials, and the application of treatments was economically profitable.

Results obtained in the plot trials are indicative of the different effectiveness of fungicides in relation to the disease present. This makes it possible to adapt protection programmes for winter wheat depending on the severity of the individual pathogens.

Field trials carried out under production conditions showed a high profitability of the imposed treatment. The grain yield increase was, on average, 12%. The best of the tested programmes appeared to be: the application of prochoraz at the 1-node growth stage followed by flutriafol at full ear emergence. This resulted in a grain yield increase of 14.6%. The effective disease control obtained by this programme could be explained by a long-term fungicidal effect of flutriafol.

REFERENCES

Goebel, G. (1983) Corbel (R) - systemisches Fungizid fur Getreide mit neuer Wirkungsart. Gesunde Pflanzen (Germany F.R.): ISSN 0367-4223: v. 35 (9) p. 243-247.

Saint-Blanquart, A. de; My, J. (1982) - Utilisation du prochloraz pour lutter contre les maladies des organes aeriens des cereales en France. Mededel Fac. Landbou. Rijksuniv. Gent.; v. 47 (3, pt, 3) p. 925-934.

Wiese, M.V.; Herman, T.; Grube, M. (1984) - Impact of diseases on wheat yields in Idahos Kootenai Valley in 1981. Plant Dis.; v. 68 (5), p. 421-424.

ACCELERATED DEGRADATION OF SOIL INSECTICIDES USED FOR CORN ROOTWORM CONTROL

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ABSTRACT

The possibility that the repeated application of an insecticide to the soil could condition the soil to degrade the chemical at an increased rate was first suspected in Iowa cornfields in 1975. Replicated field trials beginning in 1976 confirmed this fact for carbofuran "Furadan®". In cooperation with other scientists, it was determined the reduced persistence was caused by an increased ability of microorganisms to degrade the insecticide. Documenting and reproducing corn rootworm control failures with chemicals in the organophosphorous class has raised the question of how soil insecticides should be managed to preserve them as agricultural tools.

INTRODUCTION

Two species of corn rootworms make up our most troubling pest complex of maize in the Corn Belt of the United States. They are the western, Diabrotica virgifera virgifera, and the northern Diabrotica barberi. The species differ in that the northern is believed to be indigenous to the Corn Belt, having evolved on grass hosts (Branson and Krysan 1981), whereas the western is believed to be indigenous to Central America (Krysan 1982). The western was introduced into the United States with maize. The species are similar in that they have a single generation per year and feed, nearly exclusively, on maize. If not controlled, larval feeding on the roots of maize commonly causes serious yield reductions and reduces harvestability because of plant lodging. The adults are found most commonly on maize; they lay the majority of their eggs in maize fields, and the larvae that hatch the following year must have maize roots to survive. Because the insects are so closely associated with maize and have a one-year cycle, their survival depends on having maize planted following maize. If the host crop is rotated with other crops on an annual basis, the corn rootworms cannot persist at economically damaging population levels.

With the development of synthetic fertilizers and herbicides, it became feasible to grow maize continuously. As this agronomic practice became more common, the northern populations increased and the western spread east from the Rocky Mountain region where it was first discovered in the United States. The growing of maize continuously offered a sufficiently large economic advantage that farmers adopted the new synthetic cyclodiene insecticides to protect their maize roots rather than returning to crop rotation to disrupt the pest's life cycle. By 1961, resistance to the cyclodienes was reported in Nebraska (Ball and Weekman 1962). The immunity to this class of chemicals was carried rapidly across the Corn Belt by the western species. To continue to grow maize continuously, farmers switched to the new classes of chemicals being developed, the organophosphates and the carbamates. Materials such as carbofuran "Furadan®" earned the reputation of providing outstanding protection from attack by corn rootworm larvae. This promoted their heavy use, often habitually in the same field.

While it may be common to have some performance complaints with most pesticides in heavy use, by the early 1970s the Iowa State Extension Service began having complaints more consistently with some products. The first product that seemed to draw inordinate attention was bufencarb "Bux®", a member of the carbamate class of insecticides. At that time it was not possible to duplicate the poor performance of bufencarb in University research plots to identify the specific reason(s) for a decline in control. By 1974, performance complaints with bufencarb had become persistent enough, however, that the Extension Service ceased recommending the chemical for corn rootworm larval control in Iowa.

During the early 1970s, our typical soil insecticide evaluation protocol did not include testing chemicals under any specific scenario of previous chemical exposure. The prime concern was to insure an insect infestation. Two techniques were used to accomplish this: (1) planting maize so that it matures later than the surrounding fields and not treating it with an insecticide to attract and preserve insects for the following season's research, and (2) using farmers' fields that have been documented to be heavily infested with rootworms. Because University research fields that have not been treated with an insecticide the previous season or private fields that were not considered on the basis of previous insecticide exposure were used for insecticide evaluations, there was no relationship seen between chemical use history and current insecticide performance.

At the same time as unexplainable performance complaints concerning bufencarb reached a magnitude sufficient for the withdrawal of its recommendation, complaints began to be received from "carbofuran users" that the insecticide was no longer providing root protection in their fields. As a consequence, I deviated from the historical test scenario and used insecticide treatment pattern as an additional criterion in selecting evaluation sites to determine if there was a relationship between insecticide performance and prior insecticide use.

MATERIALS AND METHODS

A randomized complete block experimental design with four replications was used for all insecticide evaluation studies. Insecticides were applied to single rows as granular formulations with modified Noble® metering units. Each unit was calibrated in the laboratory to deliver accurately the formulated insecticides at their recommended rates at a tractor speed of 4.8 km/h. The applicators were mounted on a Model 71B, John Deere® 4-row unit planter. The insecticides were directed onto the soil surface in a 17-cm band ahead of the planter's press wheel and final incorporation was accomplished with a drag chain mounted behind the press wheel.

Corn rootworm larval damage was evaluated by digging five roots from each treatment, washing the soil from the roots, and visually rating the root damage on a 1 to 6 scale (Hills and Peters 1971). On this scale, 1 = no damage, 2 = root feeding but no root pruning, 3 = at least one root but less than a whole node of roots pruned, 5 = two nodes of roots pruned, and 6 = three nodes of roots destroyed.

RESULTS

During 1975, the performance of soil insecticides was compared at three locations. One had not been exposed to an insecticide for at least nine years. The second had a history of carbofuran use and had suffered unacceptable levels of root damage in 1974. The third was on an Iowa State University research field with the typical alternate-year use as a test plot rotating with an insect trap crop to insure pest populations. It appeared the performance of carbofuran was significantly influenced by prior chemical treatment (see Table 1). In the field treated previously with carbofuran, noticeably less root protection (0.65 rating improvement compared to the untreated) resulted than in the fields that had a treatment the previous year (1.95 and 1.65 rating improvement). The results from 1975 were not considered incriminating because only one field had a history of carbofuran use and the insect pressure was only moderate.

During 1976, soil insecticides were evaluated in six fields, only one of which was a University field that had an alternate-year history of insecticide screening. The remaining five were commercial production fields with histories of persistent use of soil insecticides. Root-damage ratings from two fields with carbofuran histories and the University field with no treatment the previous year are presented in Table 2. The data from three fields that had been repeatedly treated with organophosphates, two with phorate "Thimet®" and one with ethoprophos "Mocap®", are presented in Table 3. The performance of carbofuran was striking! In the four fields where it had not been used before, it provided the best root protection. In the fields that had historically been treated with carbofuran it ranked last of the insecticides tested.

TABLE 1

Average root damage for planting-time soil insecticides in Iowa, 1975

Furadan History		No Insecticide		Alternate Year Treatment	
Insecticide	Rating[1]	Insecticide	Rating	Insecticide	Rating
Dyfonate	2.25	Furadan	2.55	Furadan	2.15
Counter	2.40	Counter	2.60	Counter	2.25
Furadan	3.30	Dyfonate	3.55	Thimet	2.40
Thimet	3.55	Thimet	3.95	Dyfonate	2.60
Mocap	3.65	Mocap	4.10	Mocap	2.60
UNTREATED	3.95	UNTREATED	4.50	UNTREATED	3.80

[1]Root-damage rating scale includes 6 categories ranging from 1 = no damage to 6 = severe damage.

TABLE 2

Average root damage for planting-time soil insecticides in Iowa, 1976

Furadan History		Furadan History		Alternate Year Treatment	
Insecticide	Rating[1]	Insecticide	Rating	Insecticide	Rating
Lorsban	3.25	Counter	2.70	Furadan	3.05
Counter	3.35	Thimet	3.55	Counter	3.35
Dyfonate	3.40	Dyfonate	3.97	Lorsban	3.90
Thimet	4.00	Lorsban	3.98	Dyfonate	4.20
Mocap	4.55	Mocap	4.22	Mocap	4.40
Furadan	4.75	Furadan	4.74	Thimet	4.50
UNTREATED	5.10	UNTREATED	4.85	UNTREATED	4.95

[1]Root-damage rating scale includes 6 categories ranging from 1 = no damage to 6 = severe damage.

A similar trend could not be seen for the organophosphorous class of materials. Phorate performed as well in the fields where it had been used before as it did in the field with no treatment the previous year and in one of the fields previously treated with carbofuran. Ethoprophos ranked as one of the best treatments in the field that had a history of ethoprophos use.

TABLE 3

Average root damage for planting-time soil insecticides in Iowa, 1976

Mocap History		Thimet History		Thimet History	
Insecticide	Rating[1]	Insecticide	Rating	Insecticide	Rating
Furadan	2.63	Furadan	1.97	Furadan	2.48
Mocap	3.00	Mocap	3.00	Counter	2.68
Dyfonate	3.50	Counter	3.12	Lorsban	2.68
Thimet	3.65	Lorsban	3.20	Dyfonate	2.82
Counter	3.95	Dyfonate	3.22	Mocap	2.92
Lorsban	4.20	Thimet	3.32	Thimet	3.15
UNTREATED	5.50	UNTREATED	4.22	UNTREATED	3.55

[1]Root damage rating scale includes 6 categories ranging from 1 = no damage to 6 = severe damage.

Since these tests have been conducted, similar results have been generated enough times to support strongly the conclusion that repeated use of one or more of the carbamate insecticides for corn rootworm larval control in the same field can result in a decline in its performance. What is the cause of this decline? Does the insect build up a tolerance to the insecticide, or is the material not persisting in the soil long enough to control larvae that are hatching four to six weeks after the material is applied?

During 1975 and 1976, we collected corn rootworm larvae from fields where carbofuran appeared not to provide control and from fields where it did. These larvae were sent to the USDA, Northern Grain Insects Laboratory, Brookings, SD, where the larvae, adults reared from the larvae, and larvae produced from eggs laid by the adults were tested for insecticide susceptibility. To date, I have no evidence that tolerance of the corn rootworm larvae to currently used insecticides has increased with repeated exposure.

Soil from fields with specific histories of insecticide use, with and without diagnosed rootworm problems, has been collected and sent to toxicologists and microbiologists, treated with insecticides in the laboratory, and the degradation rate of the insecticides monitored. It has been shown that the rate of degradation of some chemicals, such as carbofuran, is significantly faster in soil from fields where that chemical has been shown not to provide acceptable corn rootworm larval control (Kaufman and Edwards 1983). The fact that the accelerated degradation of materials such as carbofuran is biological has been demonstrated by using steam and radiation to sterilize aggressive soils (Read 1983). Attempts to identify specific organisms have been conducted by researchers such as Felsot et al. (1981) who innoculated broths containing carbofuran with specific microorganisms and measured very rapid degradation of the insecticide compared to a sterile broth.

DISCUSSION

To date, certain of the carbamate agricultural chemicals have been most convincingly shown to be susceptible to enhanced microbial degradation. Are we likely to lose more of our chemical pest control tools due to induced, accelerated degradation following application? In the ten years of testing, insecticides for efficacy against soil pests in an admittedly small number of locations with respect to the total number of acres treated, I have found two sites where organophosphorous insecticides have not provided acceptable corn rootworm larval control and I have confirmed the fact with replicated experiments the following year (see Table 4). In both cases, the chemical that had been used historically gave little, if any, improvement over the untreated areas.

TABLE 4

Average root damage for planting-time insecticides in Iowa

Counter History - 1982 Test		Thimet History - 1983 Test	
Insecticide	Rating [1]	Insecticide	Rating
Furadan	2.20	Furadan	2.03
Dyfonate	2.85	Broot	2.17
Lorsban	2.90	Dyfonate	2.93
Mocap	3.05	Counter	3.68
Counter	3.60	Lorsban	3.83
UNTREATED	4.25	Mocap	3.88
Thimet	4.50	UNTREATED	4.73
		Thimet	4.80

[1]Root damage rating scale includes 6 categories ranging from 1 = no damage to 6 = severe damage.

The most striking conclusion to date is that farmers need to practice stewardship in their use of chemical pest control tools. In nearly all Corn Belt states there is research under way to understand the mechanisms of enhanced degradation, but until the research is more complete we do not know: (1) how long a chemical will be effective if it is repeatedly applied; (2) how flexible the microorganisms will be in adapting to different chemicals; (3) if rotation among classes of insecticides will avoid the aggression problem, merely delay it, or cause the soil to become aggressive toward more than one chemical simultaneously; or (4) how long a soil will remain aggressive once it is conditioned. It appears quite certain, however, that the more frequently a soil is exposed to a chemical, the greater the chance it will "learn" to degrade it, thus reducing or eliminating its effectiveness, as happened with isofenphos "Amaze®" after only two seasons of use for corn rootworm control (Racke and Coats 1987).

REFERENCES

Ball, H.J.; Weekman, G.T. (1962) Insecticide resistance in the adult western corn rootworm in Nebraska. Journal of Economic Entomology 55, 439-441.

Branson, T.F.; Krysan, J.L. (1981) Feeding and oviposition behavior and life cycle strategies of Diabrotica: An evolutionary view with implications for pest management. Environmental Entomology 10, 826-831.

Felsot, A.; Maddox, J.V.; Bruce, W. (1981) Enhanced microbial degradation of carbofuran in soils with histories of Furadan® use. Bulletin of Environmental Contamination and Toxicology 26, 781-788.

Hills, T.M.; Peters, D.C. (1971) A method of evaluating postplanting insecticide treatments for control of western corn rootworm larvae. Journal of Economic Entomology 64, 764-765.

Kaufman, D.D.; Edwards, D.F. (1983) Pesticide/microbe interaction effects on persistence of pesticides in soil. In: IUPAC Pesticide Chemistry: Human Welfare and the Environment. J. Miyamoto et al. (eds.) N.Y.: Pergamon Press, pp. 177-182.

Krysan, J.L. (1982) Diapause in the neartic species of the virgifera group of Diabrotica: Evidence for tropical origin and temperate adaptions. Annals of the Entomological Society of America 75, 136-142.

Racke, K.D.; Coats, J.R. (1987) Enhanced degradation of isofenphos by soil microorganisms. Journal of Agriculture and Food Chemistry 9, In press.

Read, D.C. (1983) Enhanced microbial degradation of carbofuran and fensulfothion after repeated applications to acid mineral soil. Agriculture, Ecosystems and Environment 10, 37-46.

EVALUATION OF LARGE SCALE HOT WATER DIPPING AND FORCED VENTILATION OF SEED POTATOES TO REDUCE TUBER CONTAMINATION WITH BLACKLEG BACTERIA (ERWINIA SPP)

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ABSTRACT

Using a large scale, batch, hot water dipping process with a timed heating period of 44.5°C for 30 min, Erwinia contamination of seed potatoes was significantly reduced. Dipping was undertaken 2, 16 and 30 days after harvest and was found to have no effect on sprouting or growth. Forced ventilation of undipped tubers was shown to decrease contamination immediately after harvest. Subsequent storage of dipped or undipped tubers increased contamination except where dipping or ventilation took place 30 days after harvest. The majority of pectolytic Erwinia identified were Erwinia carotovora pv atroseptica.

INTRODUCTION

Scotland has a thriving seed potato export trade to countries in the Mediterranean basin. One of the most important pathological problems affecting exported seed is the frequent high incidence of diseases such as blackleg caused by soft rot Erwinia spp in crops grown from them (Perombelon, 1985). Using artificial inoculation, Perombelon has shown that the incidence of blackleg in a crop is directly related to the level of contamination with Erwinia on the planted tubers.

On a laboratory scale MacKay & Shipton (1983) showed that heat treatment of tubers by immersion in hot water could significantly reduce Erwinia contamination and subsequent blackleg in the field without adverse effect on growth and yield. The local availability of hot water dipping tanks used to free Narcissus of stem and bulb eelworm for commercial bulb growers presented an opportunity to try hot water treatments on a scale large enough to be applied to seed potatoes for export. This paper reports the effect of hot water dipping and force ventilation on bacterial contamination, sprouting and subsequent growth of 1 tonne batches of seed potatoes.

MATERIALS AND METHODS

Heat treatment of tubers

A stock of tubers, cultivar Desiree, was obtained from a crop whose certification had been reduced from Super Elite 2 to no grade because of the field expression of blackleg. The crop, which was harvested on 26 September 1984, was stored in one tonne boxes after removal of surplus soil, stones and rotted tubers. The tubers were allowed to dry naturally. Subsequent ventilation when required later in storage was achieved using a Proctor ventilation system (A. Proctor (Insulation) Ltd., Blairgowrie, Scotland).

Facilities for hot water dipping were sited 51 miles from the store and comprised two front-loading tanks capable of holding 4 x 1 tonne boxes each, a reservoir for storage of water preheated to operating temperature, a diesel powered heating unit and a pump which circulated water to maintain temperature during dipping and to empty or fill the tanks (Akerboom, Holland). Preliminary studies into the heat resistance of pectolytic Erwinia (Robinson & Foster, 1987a) indicated that a temperature of 45°C for 30 min would be required to achieve a useful reduction in tuber contamination. On the basis of this evidence a timed heating period using a circulated water temperature of 44.5°C (the temperature used to dip bulbs) for 30 min was used, plus the time required to empty and fill the tank and to allow the water to return to operating temperature after flooding. After dipping, the boxes of tubers were placed on a letterbox ventilation system (Anon., 1981) for 48 hours before their return to the store of origin where they remained until grading prior to planting.

Dipping was conducted 2, 16 and 30 days after harvest. On each occasion 3 boxes were transported to the dipping site, two of which were hot water dipped (HD) and one used as an undipped control (UDC). The treated boxes were placed one above the other in the tank. During dipping the temperatures in the middle of each box, of the circulating water and of the air were continuously monitored (Grant temperature recorder, Grant instruments (Developments) Ltd., Cambridge).

Immediately prior to grading in March, handpicked samples of 500 tubers from each box were placed in paper sacks and stored at a constant temperature of 4°C until 21 days before planting when they were placed in chitting trays.

Sampling and assessment of tuber contamination

Samples of tubers were taken from 12 of the 32 boxes selected for trial work immediately after harvest. Each box sent for dipping was sampled at the surface and at depth before and immediately after dipping, after cooling and ventilation and finally at grading. Tuber-borne contamination with pectolytic Erwinia was determined by the examination of 25-tuber sub-samples using the Most Probable Number method of Robinson & Foster (1987b). Normally six sub-samples were taken per treatment. The identity of a number of isolates of pectolytic Erwinia from each sample was determined using a limited number of biochemical tests in combination with cell-free protein analysis in polyacrylamide gel (Robinson & Sauve, 1985).

RESULTS

Temperature variation during heating

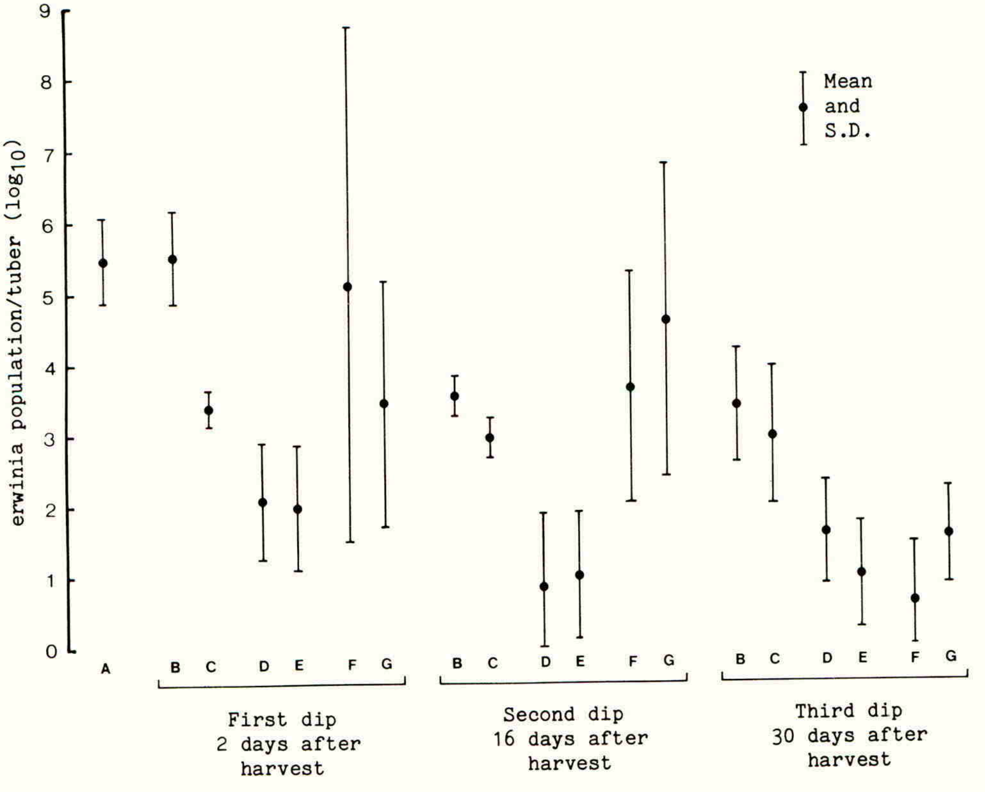
Insufficient heated water was available for the first dip (HD1) and additional cold water had to be added to fully immerse the tubers. Since a longer time was required to reheat the water, the timed heating period was reduced to 20 min.

In the second and third dips (HD2, HD3), initial flooding of the dipping tank resulted in a drop of 5-6°C in the water temperature and there was an inevitable delay before the water returned to the operating temperature of 44.5°C. Reheating took up to 45 min depending on the air temperature. When the water did return to operating temperature the temperature in the centre of the boxes remained consistently 2-3°C lower and failed to reach 44.5°C by the end of the 30 min timed heating period. Comparison of the treatment conditions recorded for the three dipping occasions shows that tubers in HD1 had a total heating time of 90 minutes but the temperature only exceeded 42°C (taking median values of the circulating water and the bottom box in the heating tank) for 32.5 mins and the maximum temperature was 43°C. The equivalent values for HD2 were; 67 mins total heating time, 23 minutes above 42°C and 43.5°C maximum temperature; and for HD3, 90 minutes, 41 minutes and 43.8°C.

Cooling to ambient using letter box ventilation required approximately four hours and drying, determined by visual examination, approximately 15 min.

Effects on tuber contamination

The mean number ($\log_{10}$) of pectolytic *Erwinia*/tuber immediately after harvest was 5.47 ± 0.59. Changes in the tuber population of pectolytic *Erwinia* on dipped tubers and their respective controls for the three dipping experiments are illustrated in Fig 1.



A = immediately after harvest
B = undipped control - pre-ventilation
C = undipped control - after ventilation
D = dipped tubers - immediately after dipping
E = dipped tubers - after ventilation
F = undipped control - at grading
G = dipped tubers - at grading

Fig.1 Changes in *Erwinia* population of dipped and undipped tubers

The undipped control tubers at the time of the first dip (UDC1) had an Erwinia population almost identical to that determined for the trial stock as a whole immediately after harvest. The population on the control tubers, UDC2 and UDC3, 16 and 30 days after harvest, had fallen significantly due to natural drying alone. Forced ventilation of UDC1 reduced the Erwinia population to the level achieved by natural drying in the control tubers for UDC2 and UDC3. Ventilation of control tubers for UDC2 and UDC3 did not significantly reduce tuber populations further (Fig 1).

There were significant reductions in Erwinia populations as a result of the heat treatment at each dip. The reductions in the mean (Log_{10}) tuber population were 64%, 72% and 71% respectively for HD1, HD2 and HD3 (Fig 1). No further significant changes in populations were observed as a result of drying and cooling the heated tubers by forced ventilation.

In the first dip, however, the larger initial population, shorter timed heating period and consequent lower population reduction produced a less satisfactory result. The position of the box in the heating tank and the tubers in a box were observed to influence the population reduction. The trend was for the top box to have a smaller reduction than the bottom box and surface tubers to show a greater reduction than inner tubers.

During subsequent storage, up to the time of grading, there was a rise in Erwinia populations in the dipped and control tubers of HD1 and HD2.

Identity of pectolytic Erwinia

Ninety-four percent of the Erwinia spp isolated from tubers were characterised as E. carotovora pv atroseptica (Eca). 5% of isolates were E. Carotovora pv carotovora (Ecc) and the remainder were unidentified.

Effect on tubers

Dipped tubers when visually inspected at grading before planting appeared cleaner, in better condition and to have fewer rotted tubers than undipped tubers. No difference in sprouting or emergence after planting was observed between the dipped and undipped tubers.

DISCUSSION

In order to minimise the contamination of seed potato tubers with Erwinia spp capable of causing blackleg, the technique of using hot water dipping has been shown in this study to have commercial potential. This confirms the laboratory studies of MacKay & Shipton (1983). The reduction in contamination achieved for Eca put the populations below a 'threshold' level of (Log_{10}) 3.0/tuber indicated in studies by Perombelon (1985), below which limited blackleg developed. In order to reduce the risk of blackleg, this technique could be applied to those stocks which, by bacteriological examination, had levels of contamination above this threshold, especially stocks destined for export.

In practice, it is clear that, for a batch dipping process such as the one tested, the attainment of a uniform temperature throughout a 1-tonne box is difficult to achieve. The targeted temperatures may not be reached for a sufficient time in the centre of the box. In order that the central tubers achieve the targeted treatment a higher temperature may be necessary but this, in turn, might cause tuber damage. Another method which might improve the uniformity of treatment would be to flood the boxes at a temperature c. 5°C higher than needed for operating and with an immediate and similar drop in temperature the timed period could begin straight away.

The drawbacks of the batch system of treatment are the extra time needed to fill and empty the tank and raise the water back to the operating temperature. In addition, there is always likely to be a temperature differential between the inner and outer tubers in a 1 tonne box. These difficulties could be overcome if a continuous flow system was devised where relatively small quantities of tubers enter a large volume of heated water at any one time. The temperature/time combination used for the batch process would be impractical for a continuous system since the throughput would be too low. Using a higher temperature and shorter time, such as that suggested by MacKay & Shipton (1983), would be more appropriate in order to allow a faster throughput.

In vitro determinations of the heat resistance of Eca have shown that no significant destruction of the organism occurs at temperatures below 42°C even for periods in excess of 30 min. Prediction curves indicate that greater destruction can be achieved by raising the temperature (even by 1°C) than by extending the period of heating (Robinson & Foster, 1987a). The percentage reductions in population achieved by each dip support this. The smallest reduction was in HD1 where the maximum temperature recorded in the middle of the bottom box was 43°C. In HD2 and HD3 the maximum temperatures recorded were only 0.5-0.8°C higher than this but the reductions in population were larger.

Once tubers have been dipped it is clearly essential to dry and cool tubers. If this is not done and moisture and heat remain in a box of tubers, multiplication of those bacteria surviving treatment is likely. By the time of planting, the Erwinia population of all sets of tubers, except those in HD3 had increased significantly (1.8-3.6 times) from that present when the tubers were returned to store after heat treatment. This indicates that the storage environment can influence the contamination of tubers. Thus, in order to maintain the low levels of contamination achieved by dipping in hot water, careful attention has to be made to the subsequent storage conditions.

The results of this study clearly indicate that forced ventilation can have a significant effect on Erwinia contamination of potato tubers. When applied after harvest ventilation reduced contamination rapidly to the levels that were achieved by natural drying 16 days after harvest. Such an effect might be valuable on stocks which have such high levels of contamination that they are at risk from bacterial soft-rotting. However, there appears to be an interesting interaction with the time of ventilation. Undipped tubers in HD3 that received ventilation 30 days after harvest did not show the increase in contamination during subsequent storage that the controls of HD1 and HD2 did. This interaction requires further investigation.

Although this study has indicated that hot water dipping of potato tubers is commercially viable, further experimentation is needed to refine the techniques. In particular the optimum time to dip needs to be evaluated. The experiment here on cv Desiree has shown that dipping up to one month after harvest gave satisfactory results. However, if storage subsequent to dipping encourages the multiplication of Erwinia, then the effect would be lost. A delay in dipping until nearer grading-out might reduce this risk but dormancy may have broken and sprouts could be affected.

ACKNOWLEDGEMENTS

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REFERENCES

Anon. (1981) Potato Storage. A Farm Electric Handbook. The Electricity Council, National Agricultural Centre, Stoneleigh, Kenilworth. pp 25-27.

MacKay, J.M.; Shipton, P.J. (1983) Heat treatment of seed tubers for control of potato blackleg (Erwinia carotovora subsp. atroseptica) and other diseases. Plant Pathology 32, 385-393.

Perombelon, M.C.M. (1985) The blackleg problem in the Mediterranean region. In: Report of the International Conference on Potato Blackleg Disease 26-29 June 1984. D.C. Graham & M.D. Harrison (Eds). Potato Marketing Board. pp 57-59.

Robinson, K.; Foster, G. (1987a) Control of potato blackleg using tuber pasteurisation: the determination of time-temperature combinations for the inactivation of pectolytic erwinia. Potato Research - in press.

Robinson, K.; Foster, G. (1987b) Quantitative assessment of tuber contamination by pectolytic erwinia and its possible use in the prediction and control of blackleg. Potato Research - in press.

Robinson, K.;Sauve, Elaine (1985) Differentiation of Staphylococci. In: Isolation and Identification of Micro-organisms of Medical and Veterinary Importance. C.H. Collins & J.M. Grange (Eds). Society for Applied Bacteriology Technical Series 21, Academic Press, London. pp161-175.

TEFLUTHRIN - A NOVEL SOIL PYRETHROID FOR CONTROL OF MAIZE PESTS

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ABSTRACT

Tefluthrin, 'Force', is the first pyrethroid designed as a soil insecticide. It is sufficiently stable in the soil to provide good residual control of major soil insect pests. It is highly active against pests of the orders Coleoptera, Lepidoptera and Diptera, and in particular it possesses sufficient volatility to allow adequate mobility in the vapour phase for controlling soil insects. It is therefore extremely well suited for control of the soil pest complex of maize, one of the most important of the world's insecticide uses. In addition, the novel chemistry of tefluthrin will allow rotation of chemicals to be recommended and will enable farmers to help prevent resistance build-up in maize pests. As tefluthrin is active at low rates of application, a markedly reduced application rate of active ingredient can be employed compared with existing standards.

INTRODUCTION

Tefluthrin was discovered at the Jealott's Hill Research Station of ICI Plant Protection Division, and has been extensively tested against a wide range of pests and crops in a large number of countries. The properties and spectrum of activity of tefluthrin have already been described in detail at this conference (Jutsum *et al*. 1986), and the trials results presented here illustrate the activity of tefluthrin against the major pests of maize (*Zea mays*).

EXPERIMENTAL: SOIL APPLICATION

The results of trials have been grouped according to the main pest target. The data presented are summaries of replicated trials. Granules containing tefluthrin at 0.5% a.i. were used in all European trials, whilst granules containing 1.5% a.i. were used elsewhere. In all trials, granules were applied using normal farmer practice for that pest and country. Seed treatment and granular treatments were also compared.

Corn rootworm (Diabrotica) (Coleoptera: Chrysomelidae spp.)

Corn rootworms are the most serious insect pests of maize in North America. Corn rootworm larvae cause economic damage when they feed on the root systems of maize plants. Feeding first occurs on the third whorl of roots and moves outward as new whorls of roots are formed. In the final instar, the larvae feed on the largest primary roots and often destroy these roots by making large tunnels through the centre. One of the most noticeable visual symptoms of rootworm damage to maize is lodged plants. Heavy rootworm damage to brace roots can cause the maize stalk to fall over (or lodge) in windstorms. Lodged plants cannot grow efficiently and suffer a yield loss. Badly lodged plants are also difficult to harvest. Based on a root damage rating scale devised by Iowa State University (where '1' represents no damage and '6' represents three or more nodes or roots destroyed) the economic threshold of corn rootworm damage is classed as '3' or above.

At the present time, only two groups of insecticides (organophosphates and carbamates) are available for use. Products from both groups of chemicals now appear to be having some problems with rapid chemical breakdown in the soil and possibly reduced rootworm susceptibility. To make these products last as long as possible, rotating between chemical groups and even rotating different products within chemical groups is now recommended (Anon. 1986). Products based on new chemistry, are urgently needed to give farmers a broader selection.

Various methods can be used to apply soil insecticide granules, including broadcast preplanting incorporated, banded application at planting, in-furrow application at planting, and banded application at cultivation. The planting-time band application is by far the most commonly used treatment method, and tefluthrin has given good results against corn rootworm in the United States when used in this way (Table 1).

TABLE 1

Relative effectiveness of granular insecticides applied as a banded treatment at planting for control of corn rootworm - USA, 1979-1985

Treatment	Rate g a.i./ha	No. of trials	Root rating*
Tefluthrin	112	77	2.68
Carbofuran	1,120	64	3.02
Chlorpyrifos	1,120	112	2.66
Ethoprophos	1,120	34	2.89
Fonofos	1,120	97	2.49
Terbufos	1,120	221	2.21
Control	-	321	4.56

*1 = no damage and 6 = three or more nodes of roots destroyed.

Black cutworm (Agrotis ipsilon) (Lepidoptera: Noctuidae)

Black cutworm is an important economic pest of maize, occurring together with corn rootworm in USA crops. For this situation an insecticide that controls both pests is an ideal control method for the farmer. Soil moisture content can often be a critical factor in the effectiveness of a soil insecticide, dry soils causing migration of insects to deeper in the soil and wet soils causing leaching from the soil of water soluble chemicals. In various trials, over a range of soil moisture contents, tefluthrin has given consistently good control (Tables 2 and 3).

TABLE 2

Comparison of number of damaged plants in plots receiving planting-time insecticide granular treatments for control of black cutworm larvae - Colombia, Missouri, USA, 1981

Treatment	Rate g a.i./ha	Mean no. damaged plants*
Tefluthrin	84	5.7 b
Flucythrinate	112	7.7 b
Chlorpyrifos	1,120	8.0 b
Methomyl	50	9.3 b
Ethoprofos	1,120	12.7 ab
Chlorfenvinfos	1,120	21.3 a
Control	-	21.7 a

*Mean separation by Duncan's Multiple Range Test; P = 0.05. Treatments followed by a letter in common are not significantly different at the 5% probability level.

TABLE 3

Comparison of % damaged plants in plots treated at planting time for control of black cutworm larvae - Colombia, Missouri, USA, 1981.

Insecticide	Rate g a.i./ha	% damaged plants*
Tefluthrin	84	17.2 b
Methomyl	50	30.1 ab
Chlorpyrifos	1,120	29.9 ab
Flucythrinate	112	31.9 ab
Ethoprofos	1,120	46.9 ab
Chlorfenvinfos	1,120	63.9 a
Control	-	60.0 a

*Treatments followed by a letter in common are not significantly different at the 5% probability level.

Wireworms (Agriotes spp) (Coleoptera: Agrotidae)

In central and southern Europe wireworms are serious pests in potatoes, sugar beet and, especially, maize. The use of soil-applied insecticide granules is now a common farmer practice. Application of granules into the seed furrow has given good results against wireworms in several crops, including maize (Tables 4, 5 and 6).

TABLE 4

Effects of granular insecticides applied in the seed furrow on control of wireworms and hence establishment of maize - France, 1982

Treatment	Rate g a.i./ha	No. of healthy plants/9 m 71 DAT*
Tefluthrin	50	38.1 a
Terbufos	260	32.6 b
Control	-	32.5 b

*Treatments followed by a letter in common are not significantly different at the 5% probability level.

TABLE 5

Effects of granular insecticides applied in the seed furrow on control of wireworms and hence emergence of maize - France, 1982

Treatment	Rate g a.i./ha	No. of plants emerged/10 m 63 DAT*
Tefluthrin	30	33.6 bc
Tefluthrin	60	46.9 a
Terbufos	200	40.1 ab
Carbofuran	600	41.6 a
Control	-	29.7 c

*Treatments followed by a letter in common are not significantly different at the 5% probability level.

TABLE 6

Effect of granular insecticides applied in the seed furrow for wireworm control on maize plant emergence and establishment - Italy, 1985

Treatment	Rate g a.i./ha	No. of plants/10m 39 DAT	55 DAT
Tefluthrin	50	43.9	42.7
Tefluthrin	75	44.7	45.1
Chlorpyrifos	900	41.7	40.3
Phorate	810	34.8	34.6
Control	-	41.0	38.7

Symphylids (Scutigerella spp)

In-furrow application of granules gave good control of symphylids in maize, even under high infestation pressure.

TABLE 7

Effects of granular insecticides applied to the seed furrow on the establishment and yield of maize attacked by symphylids - France, 1984

Treatment	Rate g a.i./ha	No. of Plants emerged per ha*	% plants destroyed Stage: 6-7 leaves*	No. of plants at harvest/ ha*	Yield t/ha* 15% Humidity
Tefluthrin	50	93,800 a	1.9 a	78,700 a	5.32 a
Carbofuran	600	83,300 b	2.5 a	69,600 b	5.12 a
Control	-	65,000 c	46.6 b	29,700 c	3.48 b

*Treatments followed by a letter in common are not significantly different at the 5% probability level.

EXPERIMENTAL: FOLIAR APPLICATION

Corn borers (*Sesamia nonagrioides*) (Lepidoptera: Noctuidae)
(*Ostrinia nubilalis*) (Lepidoptera: Pyralidae)

Whorl application of tefluthrin granules has given good results against corn borers in various countries including the USA and Spain (Tables 8 and 9).

TABLE 8

Control of corn borers after application of granular insecticides to the whorl of maize (sweetcorn) - USA, 1983

Treatment	g a.i./ha	No. of corn borers/ 10 plants*
Tefluthrin	55	4.2 bc
Tefluthrin	84	4.9 bc
Tefluthrin	112	3.1 c
Tefluthrin	168	2.3 c
Carbofuran	1,120	7.5 ab
Control	-	10.7 a

*Treatments followed by a letter in common are not significantly different at the 5% probability level.

TABLE 9

Control of corn borers after application of granular insecticides to the whorl of maize (sweetcorn) - Spain, 1983

Treatment	Rate g a.i./ha	% affected plants 26 DAT*	No of live larvae/40 cobs 28 DAT*	
			S. nonagrioides	O. nubilalis
Tefluthrin	125	17.8 b	15.2 b	60 b
Carbofuran	1,000	13.5 b	13.7 b	60 b
Control	-	50.8 a	41.0 a	113 a

*Treatments followed by a letter in common are not significantly different at the 5% probability level.

The first application was applied when plants were 1.4 m high and tassels were beginning to emerge. First-instar larvae were present. The second application was applied 15 days later when the plants were 2 m high, just after flowering.

EXPERIMENTAL: SEED TREATMENT

Black cutworm (*Agrotis ipsilon*) (Lepidoptera: Noctuidae)

Tefluthrin as a seed treatment formulation was compared to tefluthrin as a 1.5% granule treatment in Canada in 1984.

Seed was treated and mixed on a roller for 20 minutes. The trial was seeded by hand on 30 May into 75-cm diameter microplots. Plots contained 50 seeds each and were replicated 4 times in a randomised block design. Ten cutworms (3rd to 5th instar) were placed in each microplot on 7 June. The corn seedlings were approximately 2 cm tall at this time. Microplots were covered with screens to prevent bird predation. Data were collected on emergence, cutworm mortality and damage to plants. The results are summarised in the Table 10.

Emergence was not affected by any treatment. Plant stand following cutworm introduction was highest with tefluthrin 1.5% granules followed by tefluthrin seed treatment at 0.4 g a.i./kg seed.

TABLE 10

Effects of granule (GR) and seed treatment (ST) application on maize plants - Canada, 1984

Treatment	Rate g a.i./kg	Emergence+ 6 June	Remaining plants 11 June		Plants damaged
Tefluthrin ST	0.2	30.0	31.5 b	(90)x	3.8
Tefluthrin ST	0.4	29.3	36.5 ab	(105)	3.0
Tefluthrin GR	0.99*	30.3	41.5 a	(119)	2.3
Chlorpyrifos GR	11.25*	27.8	34.8 b	(100)	4.5
Control	-	25.3	22.3 c	(64)	5.8

*Amount of active ingredient per 100 m of row applied in a 15 cm band.
+Average number of seedlings emerged per plot (50 seeds per plot).
xPercent plant stand relative to the standard chlorpyrifos treatment.
Treatments followed by a letter in common are not significantly different at the 5% probability level.

DISCUSSION

Tefluthrin has been applied by conventional farmer practice in numerous field trials over a number of years. It has proved to be equal to or better than today's leading maize soil insecticides when used as a granule or seed treatment. The new chemistry and high biological activity of tefluthrin promise farmers an exciting new dimension in soil pest control, especially where rapid microbial degradation in the soil of other pesticide groups occur. Tefluthrin offers farmers a new choice of a crop-safe soil insecticide whose low rate of use presents a low handler hazard. Whilst conventional farmer practice for maize has been the key note of this research novel placement techniques could open still more opportunities for this highly active soil insecticide.

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We thank all the ICI field trialists and co-operators for the field data upon which this presentation is based.

REFERENCES

Anon.(1986) Illinois Pest Control Handbook, Cooperative Extension Service, University of Illinois at Urbana-Champaign.

Jutsum, A.R., Gordon, R.F.S. and Ruscoe, C.N.E. (1986). Tefluthrin - a novel pyrethroid soil insecticide. Proceedings 1986 British Crop Protection Conference - Pests and Diseases. (In press).

ESTIMATING SLUG POPULATIONS FROM BAIT-TRAP CATCHES

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ABSTRACT

Bait trapping was compared with soil sampling for estimating slug numbers in the field. Few of the small slugs that predominated in soil samples were found in traps baited with methiocarb pellets, and the mean weight per slug was considerably greater in trapped specimens than in soil samples. For large specimens (*Deroceras reticulatum* and *Arion silvaticus* > 100 mg, *Arion intermedius* > 50 mg) numbers in traps were correlated with numbers in soil samples, when allowance was made for soil surface moisture. Thus, traps provided an estimate of the number of large slugs in the top 10 cm of soil, but they gave no indication of numbers of smaller slugs, which can cause considerable damage. Traps under-estimated the effects of straw burning and ploughing on slug numbers, but over-estimated the impact of methiocarb pellets, probably because they caught predominantly large slugs. Possible uses for traps in damage forecasting are discussed.

INTRODUCTION

Traps consisting of a cover to provide shelter, with or without bait beneath to attract slugs, provide a convenient method of sampling slug populations. They have been widely used in damage forecasting (Anon. 1984) and in assessing the effects of agricultural practices on slugs (e.g. Edwards 1977, Frain & Newell 1983, Glen & Orsman *in press*). However, numbers of slugs in traps do not necessarily reflect the size of slug populations (South 1964, Hunter 1968). Hunter found that the field slug (*Deroceras reticulatum*) was more likely to be recorded in unbaited refuge traps than *Arion hortensis* agg. and *Milax budapestensis*, and suggested that this was because *D. reticulatum* was more likely to be active on the surface than the other species. As slugs tend to leave traps unless they contain a poison bait, slug pellets are often put under each trap. Methiocarb pellets are usually used for this purpose, since slugs are less likely to recover from methiocarb than metaldehyde poisoning, and some pest species of slug are more likely to be found after exposure to methiocarb than metaldehyde (Martin & Forrest 1969, Crawford-Sidebotham 1970, Webley 1969).

Soil sampling provides the most accurate estimate of slug populations. Slow flooding over a period of several days gives a high (*c*. 90%) recovery rate and provides slugs in good condition for recording body weights (South 1964, Hunter 1968). However, as soil sampling is labour-intensive, it is unlikely to achieve widespread use.

The aim of this study was to assess the value of bait traps for estimating slug populations in arable crops by comparing the numbers and weights of slugs extracted from soil samples by slow flooding with those caught in traps baited with methiocarb pellets. In the course of this we were able to assesss the value of bait traps as a method for investigating the effects of straw disposal, cultivation and molluscicide application on slugs in winter wheat at two sites in southern England.

MATERIALS AND METHODS

Field sites

One site was a straw disposal experiment started by the AFRC Letcombe Laboratory in 1979 on heavy clay loam at Northfield Farm in the Vale of the White Horse, Oxfordshire, and now controlled by Rothamsted Experimental Station. During the period reported here (September 1984 to January 1986) winter wheat (cv Avalon) was sown following one of three straw disposal treatments: (1) straw residues burnt in situ, (2) cut straw baled and only stubble left, and (3) all straw left chopped and spread by a combine-mounted chopper. Treatments 1 and 2 were each replicated four times and treatment 3 replicated eight times in a 4 x 4 Latin Square. Each plot (32.7 x 20 m) was divided into four subplots (8.2 x 20 m) which were either uncultivated and direct drilled, or sown after ploughing to different depths (5, 15 or 25 cm).

The other site was an experiment started on a silty clay soil at Long Ashton Research Station in autumn 1984 to investigate the effect of straw disposal on the incidence of pests and diseases in winter wheat. There are four different methods of straw disposal and cultivation replicated four times in a randomized block design: (1) straw burnt *in situ* then direct drilled, (2) straw baled and wheat direct drilled into stubble, (3) straw baled and stubble ploughed in to 20-cm depth and (4) entire straw residues chopped and ploughed in to 20-cm depth. Each plot (40 x 24 m) was divided into two subplots (20 x 24 m) with or without additional crop protection treatments (five fungicide treatments, and one application of methiocarb pellets ('Draza', Bayer Agrochemicals, 4% a.i.) for slug control, each year).

Sampling methods

From autumn 1984 onwards bait trapping was done in conjunction with soil sampling at *c*. monthly intervals, at Northfield Farm and less frequently at Long Ashton. This comparison is continuing, but the period reported here goes up to early 1986. Square-root transformations of numbers were used for analysis of variance.

Bait traps consisted of an inverted plastic flower-pot saucer, 18 cm diameter (terracotta coloured), supported on the soil surface to allow slugs to crawl beneath, covering a small heap (5 cm teaspoonful) of methiocarb pellets. One or two traps were placed in each subplot (same number/subplot on a given date) and left for a period of 7 days. When traps were examined, up to 20 fresh slugs of each species, as available, were placed between layers of moist paper towel and left to become fully hydrated before each slug was weighed individually. The soil surface condition during the trapping period was visually classified as dry, intermediate (wet and dry at times) or wet.

One soil sample (25 x 25 cm square x 10 cm deep) was dug in each subplot on each sampling occasion. Samples were placed immediately in plastic tubs (355 mm diameter, 184 mm deep) with three 20-mm diameter holes covered in 1 mm mesh at the base of the walls. The tubs were covered with wooden lids and transported to large wooden troughs in a soil-flooding unit. The troughs were charged initially with a 2 cm depth of water, and a drip feed from a header tank introduced to each trough, which caused the water level in the samples to rise steadily until they were completely flooded after 8-10 days. Samples were examined daily and all slugs removed, identified to species and weighed individually.

RESULTS

Weights of slugs in traps and soil samples

The mean weights of slugs of all species in traps were considerably greater than the weights of the same species in soil samples. The weight distribution in the soil showed a skewed distribution with a predominance of small slugs, whereas slugs found in traps were much larger, with few of the small individuals that made up the bulk of the population in soil samples (Fig. 1). The small size of A. intermedius compared with A. silvaticus and D. reticulatum is shown clearly in Fig. 1.

For each species of slug on each sampling occasion, the numbers in three weight classes were calculated for traps and for soil samples. For D. reticulatum and A. silvaticus these weight classes were 0-10 mg, 10-100 mg and > 100 mg, for A. intermedius 0-5, 5-50 and > 50 mg. With small- and medium-sized individuals there was no correlation between numbers in soil samples and numbers in traps, but for large slugs of each species, numbers recorded in traps were correlated with numbers in soil samples, with different relationships for different soil moisture conditions. When the soil surface was dry for all or part of the trapping period, few slugs were trapped and there was a low slope for the relationship between numbers in soil and numbers trapped (A. silvaticus) or no significant slope (A. intermedius and D. reticulatum) (Fig. 2). In wet soil conditions there was a significant slope for this relationship for all species (Fig. 2). The slope for A. intermedius was considerably less than for the other two species. This simple relationship accounts for 61% of the variance for D. reticulatum, 52% for A. intermedius and 89% for A. silvaticus.

Bait traps for studying the effects of farming practices

Straw residues and cultivation

In the experiment at Northfield, which had been continuing for 5 years before the observations described here were made, significant and interacting effects of straw residues and ploughing were recorded from both bait traps and soil samples. In the experiment at Long Ashton, which started in 1984, at the beginning of the period of this study, no significant effects of straw disposal or cultivation were observed on overall slug numbers by either method. Thus, the remainder of this section is restricted to a comparison of the effects measured by trapping and soil sampling at Northfield.

Significantly fewer slugs were found on burnt plots than on plots with straw residues (stubble or entire straw). On average the number of slugs on burnt plots was 15% of the numbers on plots with straw residues for soil samples and 37.1% for traps. For plots with straw residues, both methods recorded significantly fewer slugs on ploughed areas than on areas with zero-tillage. However, the reduction in slug numbers following cultivation recorded by traps was less marked than that measured by soil samples (Table 1). In soil samples from burnt plots the percentage reduction in numbers following ploughing was less than on plots with straw residues, but still a distinct reduction (Table 1). Trap samples however showed no effect of ploughing on burnt plots.

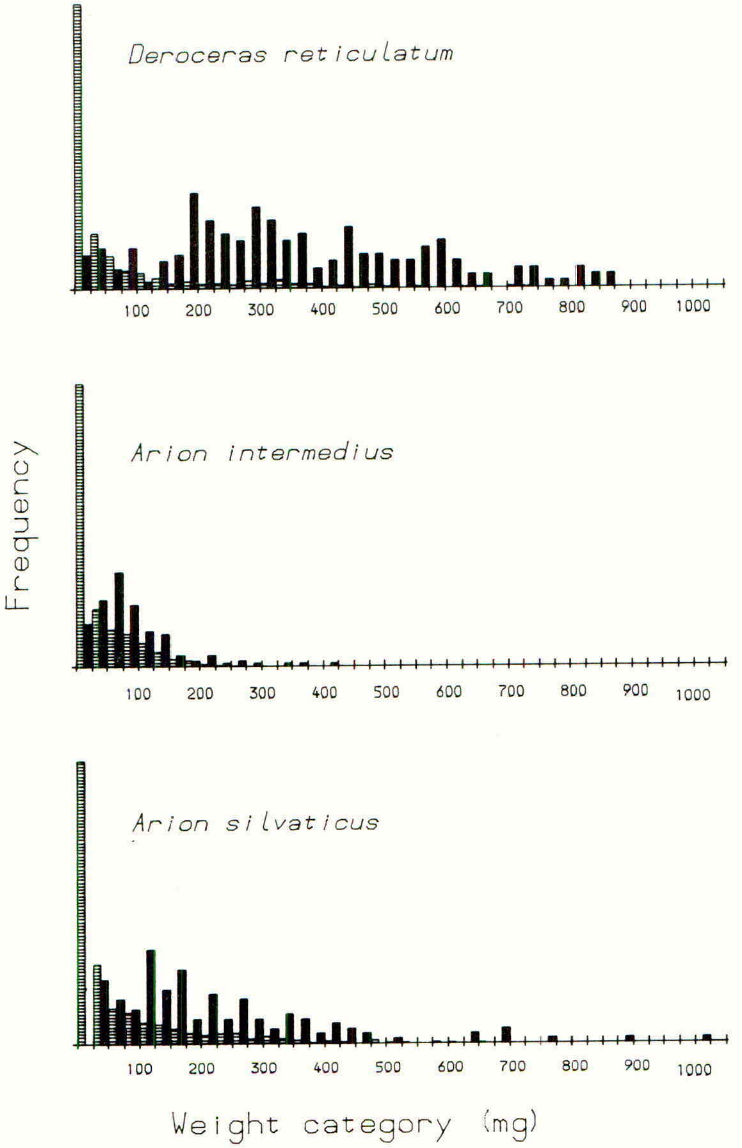

Fig. 1. Weight distribution of three species of slugs (in 25-mg weight classes) in bait traps (solid histograms) and soil samples (horizontal shading) at Northfield.

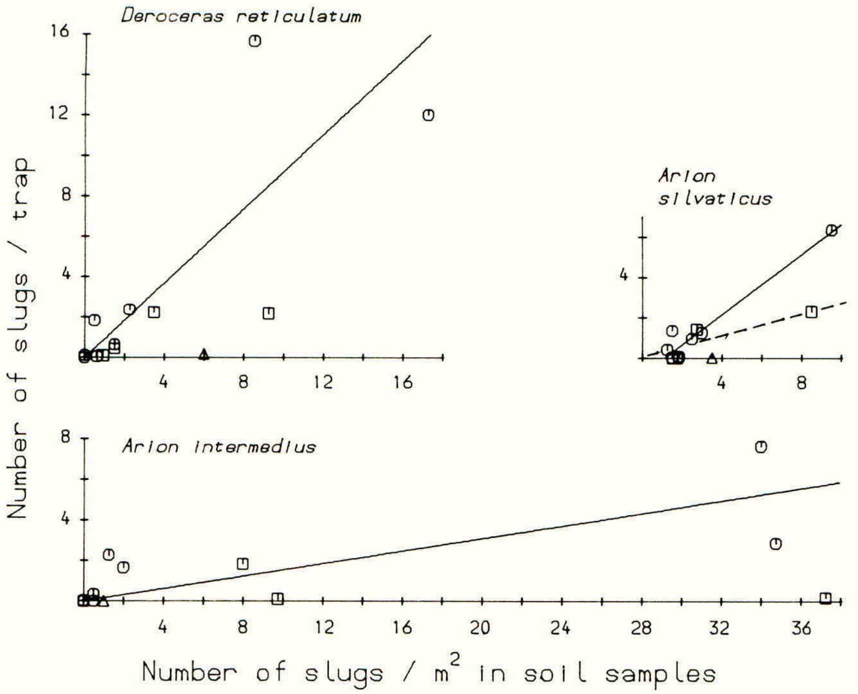

Fig. 2. Relationships between numbers of large slugs/trap and number of large slugs in soil samples at Northfield when the soil surface is dry (triangles) intermediate (squares) or wet (circles). [Solid fitted lines in wet soil ($P < 0.001$), $y = 0.922x$ (D. reticulatum), $y = 0.155x$ (A. intermedius), $y = 0.747x-0.828$ (A. silvaticus); dashed fitted line in intermediate soil, $y = 0.276x$ ($P < 0.05$) for A. silvaticus].

TABLE 1

Comparison of bait trapping with soil sampling for estimating effects of ploughing with and without burning of straw residues on slug numbers

Method of straw disposal	Method of sampling	Slug numbers at different depths (cm) of cultivation, as a percentage of numbers recorded on untilled areas			
		0	5	15	25
entire straw or stubble	soil samples	100	50.9	26.7	30.1
	traps	100	77.8	61.3	69.3
burnt straw	soil samples	100	81.0	50.0	44.6
	traps	100	106.6	77.2	100.7

Methiocarb pellets

In the experiment at Long Ashton, fewer slugs were recorded following broadcast applications of methiocarb pellets in October 1984 and 1985 than on untreated plots (Fig. 3). Whereas soil samples indicated that slug populations had substantially recovered by January or February at the latest each year, greater and longer-lasting effects on slug numbers were recorded with bait traps (Fig. 3).

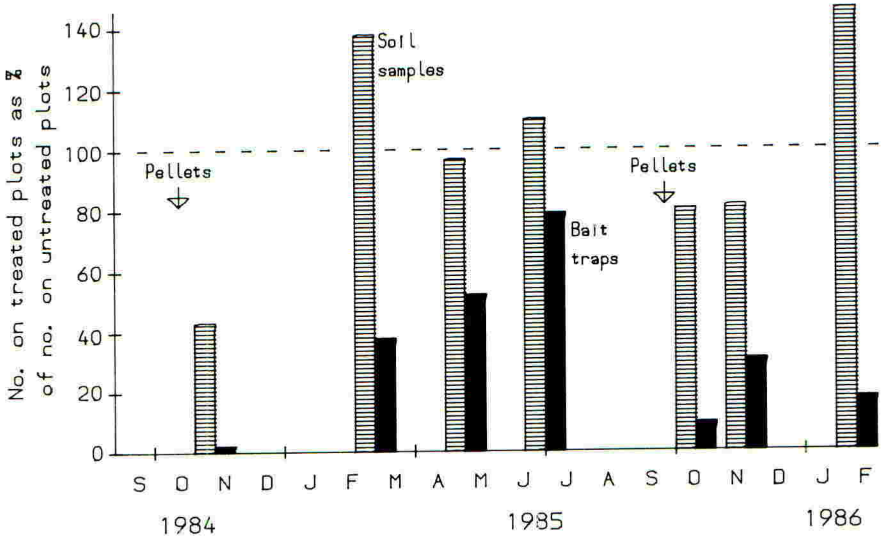

Fig. 3. Numbers of slugs on plots with broadcast application of methiocarb pellets expressed as a percentage of the numbers on untreated plots on the same date, as estimated by means of bait traps (solid histograms) and soil samples (horizontal shading). Arrows show approximate dates of pellet applications on 11 October 1984 (11 kg/ha) and 7 October 1985 (5.5 kg/ha): arrow indicating second application is slightly offset to left.

DISCUSSION

The skewed weight distribution of slugs, with a predominance of small individuals, in soil samples is as expected from prolific invertebrates. There are several possible reasons why larger individuals are more likely to be recorded in bait traps than smaller individuals. They probably move greater distances over the soil surface than small slugs, so that they are more likely to come in contact with the bait. In addition large individuals are more likely to be killed by poison baits (Godan 1966, Crowell 1977, Frain & Newell 1983), and small slugs are easily overlooked in bait traps. Since the number of small individuals recorded in traps is not related to the population present in the soil, they can probably be ignored when traps are used by farmers.

The relationship between numbers of large slugs of a given species in bait traps and those of similar size in soil samples indicates that bait traps can give an estimate of the number of large slugs present in an arable field, if the soil surface is moist throughout the trapping period. (The seven-day trapping period used in this study may be too long for farmers and advisers to use and further studies are continuing with a three-day trapping period). This simple relationship, which accounted for 55-89% of the variance, depending on slug species, can probably be further improved by taking account of the effects of temperature on activity (e.g. Dainton & Wright 1985, Wareing & Bailey 1985, Port & Port 1986) and average body weight of large slugs in the traps. The results presented here suggest that to estimate the number of large slugs/m^2 the numbers/trap should be multiplied by 1.1 for _D. reticulatum_, 1.3 for _A. silvaticus_ and 6.5 for _A. intermedius_. As the mean size of 'large' _A. intermedius_ was considerably less than the mean of the other two species, these differences between species may be largely due to differences in body size.

Our finding that bait traps underestimated the effects of straw burning and ploughing compared with the effects measured by soil samples suggests that traps are less likely to detect differences between such treatments. This could arise because of movement between plots by more mobile large slugs or because, by the time slugs have grown to a size at which they are likely to be recorded in bait traps, the differences between populations have become less pronounced, due to density-dependent mortality. These effects could perhaps explain why Edwards (1977) in a four-year study using baited traps, found that straw burning had little effect on slug numbers, whereas in this study and in Glen _et al_. (1984) we have recorded substantial effects at one site (Northfield). There may have been insufficient time (1.5 years) for differences to develop at Long Ashton.

The overestimation by traps of the effect of a broadcast application of methiocarb pellets is self evidently due to the kill by pellets of those slugs that would have responded to traps baited with the same material. It seems likely that traps without pellets would also overestimate the effect of molluscicides on the slug population, since the predominantly large slugs also found in them are more likely to be killed by pellets than are small slugs.

When traps are used for damage forecasting, it is important to remember that the breeding cycle of each species will determine whether individuals are of sufficient size to be recorded in bait traps: for some time after breeding there may be large numbers of small or medium-size individuals present without these being recorded. Thus, knowledge of slug breeding cycles and population dynamics is needed to enable estimates of the entire population of each species to be made from bait-trap catches. It seems likely that trapping at regular intervals for a period will be more likely to give an accurate population estimate than a single bait-trapping session just before the time when damage is expected. Further studies are being made into this aspect of the use of bait traps. At the very least bait traps operating when the soil surface is wet will indicate the numbers of slugs likely to be affected by a broadcast application on wet soil of pellets of the same type. This suggests possible uses for traps baited with different types of pellets as a means of deciding the most effective control measures to be used against slugs. For example when slug damage is observed after a broadcast application of pellets, bait trapping should indicate whether an application of pellets of the same or different type is likely to result in a substantial kill, or whether effort should concentrate on cultural measures because the slugs causing damage are not likely to be affected by pellets.

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REFERENCES

Anon. (1984) Slugs and snails. Leaflet of the Ministry of Agriculture, Fisheries and Food, London No.115, 12pp.

Crawford-Sidebotham, T.J. (1970) Differential susceptibility of species of slugs to metaldehyde/bran and to methiocarb baits. Oecologia 5, 303-324.

Crowell, H.H. (1977) Chemical control of terrestrial slugs and snails. Bulletin Agricultural Experiment Station Oregon State University, Corvallis No.628, 70pp.

Dainton, B.H.; Wright, J. (1985) Falling temperature stimulates activity in the slug Arion ater. Journal of Experimental Biology 118, 439-443.

Edwards, C.A. (1977) Investigations into the influence of agricultural practices on soil invertebrates. Annals of Applied Biology 87, 515-520.

Frain, J.M.; Newell, P.F. (1983) Testing molluscicides against slugs - the importance of assessing the residual population. Journal of Molluscan Studies 49, 164-173.

Glen, D.M.; Orsman, I.A. (in press) Comparison of molluscicides based on metaldehyde, methiocarb or aluminium sulphate. Crop Protection.

Glen, D.M.; Wiltshire, C.W.; Milsom, N.F. (1984) Slugs and straw disposal in winter wheat. Proceedings 1984 British Crop Protection Conference - Pests and Diseases 1, 139-144.

Godan, D. (1966) Untersuchungen uber die molluskizide Wirkung der Carbamate. II. Teil. Abhangigkeit von Art, Grosse und Ernahrung der Schnecke. Zeitschrift fur angewante Zoologie 53, 417-430.

Hunter, P.J. (1968) Studies on slugs of arable ground: I. Sampling methods. Malacologia 6, 369-377.

Martin, T.J.; Forrest, J.D. (1969) Development of Draza in Great Britain. Pflanzenschutz-Nachrichten Bayer 22, 205-243.

Port, C.M.; Port, G.R. (1986) The biology and behaviour of slugs in relation to crop damage and control. Agricultural Zoology Reviews 1, 253-297.

South, A. (1964) Estimation of slug populations. Annals of Applied Biology 53, 251-258.

Wareing, D.R.; Bailey, S.R. (1985) The effects of steady and cycling temperatures on the activity of the slug Deroceras reticulatum. Journal of Molluscan Studies 51, 257-266.

Webley, D. (1969) A comparison of methiocarb and metaldehyde baits for the control of four species of slugs. Proceedings 5th British Insecticides and Fungicides Conference 2, 442-444.

FARMERS' PERCEPTIONS AND THE DESIGN OF COMPUTERISED ADVISORY PACKAGES FOR DISEASE CONTROL

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ABSTRACT

Computerised advisory systems for disease control often depend on the skills of the local decision maker to make accurate disease observations. This paper reports a survey of 75 Kent farmers. Results indicate that the farmers generally underestimated the importance of cultural factors in determining disease levels. They could usually recognize mildew, eyespot and brown rust but other diseases were often confused. The paper then discusses the implications of these and other results for the design of computerized advisory packages.

INTRODUCTION

The successful application of disease control technology involves the manipulation of information about (a) crop cultivars, (b) fungicide and pesticide materials, (c) application methods, and (d) local environmental factors. Given the recent rates of change of all of these factors, farmers have no option but to depend on outside sources of information.

Agencies providing this type of information include state advisory services, private crop consultants and chemical suppliers. Experience has been that specialist advisory staff are necessary. But specialists are expensive and many organisations are finding that the new 'Information Technology' provides an increasingly attractive method of supplying information. In particular, developments are taking place which allow the local decision-maker (i.e. the farmer) to combine local information about environmental and crop characteristics with more generally applicable experimental knowledge, thus enabling crop-specific recommendations to be made but without the expensive on-farm presence of the specialist.

But if the new methods of delivery of information are to be successful, they must build upon the existing perceptual abilities of farmers and they must provide advice in a form which farmers can understand and relate to the overall financial objectives of their business. Without a firm knowledge of the strengths, weaknesses and requirements of farmers in these directions, resources will be wasted both in terms of the research and design effort and also in terms of continued wrong decisions by farmers. The underlying aim of the study is to provide evidence about farmers' perceptions of the identity and importance of those factors which influence losses from disease in winter wheat.

Large areas of crops are now heavily treated with fungicides (King

(Unpublished). But with the prospect of declining real product prices, farmers must ensure that each chemical application is worthwhile. Heavy dependence on chemicals is also undesirable for environmental and safety viewpoints (Anon. 1984b). There is also evidence that some pathogens are becoming resistant to the chemicals used in their control (Dekker 1972).

It seems likely that farmers' perceptions of the level of attack and the amount of damage caused by pests and diseases influence their decisions about control. Mumford (1978) reported that farmers over-estimated the 'worst loss' from sugar beet pests and there was evidence that this resulted in uneconomic spray application. The accuracy of estimation of losses will be determined firstly by the farmer's skill in identifying those factors which influence losses, and secondly by his skill in relating the factors to a particular level of loss.

METHOD

A survey of 75 wheat growers was carried out in Kent during 1984. It was hypothesized that the ability to identify and relate various factors to their importance in causing losses might be influenced by the farmer's experience of the particular disease levels in his locality and by, amongst other things, the size of his wheat enterprise. The final sample size is shown in Table 1. The interviews were carried out in May and June. The timing of the survey was chosen so that it would be likely that disease control decisions would be under consideration.

TABLE 1

Number of Farms in Sample Strata

Size of Wheat Enterprise (ha)	Area 1	Area 2	Area 3	Total
Less than 40	8	7	7	22
40-100	12	15	7	34
More than 100	6	5	8	19
Total	26	27	22	75

Area 1: N.E. Kent and Romney Marsh: good soils, close to sea, high disease-risk, high yields.

Area 2: Downs: medium soils, undulating topography, some exposed areas, medium yields.

Area 3: Weald of Kent: heavy, poor soils, lower yields, lower disease risks.

RESULTS

Factors Affecting the Decision to Apply Fungicides

Many factors which affect disease development and hence the decision to take control action are by now well known (Anon. 1984a). The respondents were presented with a list of possible factors and asked to classify these factors as 'important' or 'not important' in their decision to apply fungicides against the four common diseases. While almost all of the crop factors have some influence, the advisory literature (e.g. Anon. 1984a) emphasises the role of particular factors. Table 2 shows the results as percentages of the sample farmers who listed the particular factors as 'important' or 'very important'. Underlinings in Table 2 show those cultural factors which the advisory literature emphasises.

TABLE 2

Factors Regarded as Important in the 'Spray' Decision

Factor	Disease			
	Mildew	Rust	Septoria	Eyespot
Level of disease	<u>87</u>	<u>68</u>	<u>66</u>	<u>48</u>
Weather conditions	53	41	<u>53</u>	21
Previous crop	13	11	11	<u>63</u>
Variety of crop	43	<u>45</u>	29	32
Planting date	12	11	<u>13</u>	<u>24</u>
Local disease history	32	<u>32</u>	32	48

Percentage of 75 respondents listing factor as 'important' or 'very important'. Underlining indicates important factors (Anon. 1984).

The level of disease was considered to be most important in the decision to control Mildew; less than 50% of farmers believed it to be important in the decision to control Eyespot. Farmers who considered disease levels to be important were also asked to state the level above which they would apply a spray. There was little agreement on this level. Only half the respondents considered weather to be important for Septoria decisions. Over 60% considered the previous crop to be important for Eyespot decisions and few farmers considered the particular variety of the cereal crop to be important for any disease. This last finding was not unexpected since respondents also said that they chose the wheat varieties mainly for yield and quality rather than for disease resistance rating. Farmers said that they did not attach a high level of importance to planting date and most farmers did not judge the local history of disease to be important in the spraying decisions. Other crop conditions were not often mentioned as important.

Table 2 also shows an apparent lack of importance placed on some of the site factors which many advisors would take into account. Except in the case of previous crop, farmers judged the factors of similar importance for each disease. The results indicate that some farmers did not appreciate the importance of cultural conditions that predispose a crop to attack from a particular disease. Thresholds were not well understood even though the level of disease was considered to be important.

Farmer's Ability to Recognise Disease

If diseases are not recognised, a threshold approach to their control cannot be implemented. Farmers' ability to recognise disease was investigated by showing twelve colour photographs of diseases and of other problems commonly found in winter wheat. Photograph identification can only give an indication of farmers' ability to recognise disease because diseases are also recognised by touch and by the general appearance of the crop.

Table 3 shows the ability of farmers to recognise the diseases, and the diseases which they found confusing. Mildew, Eyespot and Brown Rust were recognised by over 70% of the farmers. Early Yellow Rust, Septoria, Fusarium, Sharp Eyespot and non-disease symptoms were recognised by less than 25% of farmers.

TABLE 3

Ability of 75 Farmers to Recognize Diseases

No.	Disease	% of farmers correct	% of farmers incorrect	% "don't know"	Disease no. most often confused with
1)	Mildew	89	3	8	7(2)*
2)	Eyespot	80	4	16	11(2)
3)	Brown Rust	72	5	23	13(3)
4)	Yellow Rust - early	13	28	59	15(5)
5)	Yellow Rust - late	57	18	25	3(3)
6)	Stress	37	35	28	7(13)
7)	Septoria spp. - leaf spot	28	27	45	3(7)
8)	Septoria spp. - early glume blotch	24	23	53	11(5)
9)	Septoria spp. - late glume blotch	23	38	39	14(18)
10)	Sharp Eyespot	21	54	25	2(28)
11)	Fusarium	12	39	49	7(18)
12)	Manganese deficiency	8	38	54	3(13)
13)	Rhynchosporium	-	-	-	-
14)	Smut	-	-	-	-
15)	Insect damage	-	-	-	-

* Numbers in parentheses indicate numbers of respondents making the confusion.

Farmers with large wheat enterprises recognised Rust significantly more readily than farmers with small wheat enterprises ($p<5\%$). They were also better at recognising Mildew ($p<10\%$), Eyespot ($p<5\%$), Fusarium ($p<10\%$) and stress symptoms ($p<10\%$), but not Septoria. Brown rust was more likely to be recognised if it had been observed on the respondent's farm often over the last five years ($p<5\%$). Farmers who monitored their crops more often were better able to recognise Eyespot ($p<5\%$), Brown Rust ($p<10\%$) and Septoria leaf spot ($p<10\%$). Farmers who sought more information on disease recognition were better able to recognise Brown Rust ($p<5\%$), Yellow Rust ($p<10\%$), Mildew ($p<10\%$) and Sharp Eyespot ($p<10\%$) but not Septoria, Fusarium and non-disease symptoms. Experienced (in terms of number of years growing wheat) farmers did not appear to recognise diseases any better than inexperienced farmers.

The frequency with which farmers said that they had observed disease was not well correlated with their ability to recognise disease. This may reflect the fact that photographs are less easy to identify than actual diseases in the crop. Alternatively some farmers' knowledge about the presence of disease may be a result of advisors information only.

Farmers' Perceptions of the Frequency of Disease Occurrence

Table 4 compares farmers' perceptions of the frequency of observing disease over the last five years with the percentage of samples affected by disease in the S.E. of England as measured from MAFF's survey of stem base and foliar diseases in winter wheat 1979-1982 (King Unpublished).

TABLE 4

Disease Observation and Recognition

Disease	% Respondents reporting observation of disease between '79-83	Average No. of years observed by respondents between '79-83	% of Samples in MAFF Surveys affected '79-82
Eyespot	69	4.0	49
Mildew	96	4.5	72
Septoria nodorum (Leaf)	72	3.6	92
Septoria nodorum (on Ear)	37	3.3	44*
Brown Rust	56	2.3	42
Yellow Rust	30	2.0	13
Sharp Eyespot	5	2.9	65
Ear Diseases: Sooty Moulds, Fusarium, etc.	17	1.9	N/A

* 1980 only

The results should be regarded with caution as a comparison is made between regional averages and observations at particular locations, whilst disease levels vary considerably within an area.

Eyespot was observed by 69% of farmers during 4 years in the last 5, compared to only 49% of the MAFF sample. Sharp eyespot was observed by only 5% of farmers whereas 65% of the MAFF sample was affected. 72% of farmers had observed Septoria leaf spot during 3 or 4 years out of the last 5, whereas on average 92% of the MAFF sample was affected. Septoria glume blotch and rust appeared infrequently and were observed infrequently by the farmers.

The sample farmers appeared to be over-estimating the frequency of observing eyespot and mildew and under-estimating the frequency of observing sharp eyespot and septoria leaf spot. There may have been some confusion between sharp eyespot and eyespot since the former had only recently become important. Septoria frequency may be underestimated because farmers have difficulty recognising the disease.

DESIGN CONSIDERATIONS FOR COMPUTERISED ADVISORY PACKAGES

An interactive advisory package may be regarded as consisting of three distinct segments. The observational part of the system deals with the input by the user of observations from the outside world. The predictional part of the system takes the observations and makes calculated or conceptual predictions about losses which are then used in the presentation of recommendations. The survey has implications for the design of all three segments.

The survey showed wide variation in the ability to recognize symptoms. Mildew, Eyespot and Brown Rust were recognized but other diseases were often confused. No data was recorded on the ability to distinguish between different levels of infection rather than simple presence or absence, but it seems likely that difficulties would also occur. The design of the observational part of the system would therefore have to be carried out with great care. There may be as much danger in symptoms being 'seen' when not actually present, as there is in symptoms being not recognised. Whilst the good colour displays available with high resolution graphics could allow a detailed disease recognition component of a computer package, the extra hardware costs would add significantly to the total cost of providing remote terminals close to where the decision has to be made. Experience with EPIPRE has already shown that an important input is in the training of the observers (Rijsdijk, 1982). It is difficult to see how any reasonably sophisticated package could be successful without a considerable element of user-training.

The survey also showed that farmers varied in their understanding of the influence of factors affecting disease development and hence losses. But this is perhaps less of a problem from the designer's point of view since he should be building into the predictional part of the system a mechanism by which questions are automatically asked about those factors regarded as important by the specialists who would also provide data about the relative importance of the factors. For some of the more rapidly developing diseases it may be less important to recognize the symptoms correctly (because, if they are easily visible, the damage has already been done) than to identify correctly the factors affecting disease development.

Factors affecting the presentation of recommendations

The presentation of recommendations is important since it is by the communication of this knowledge that a package hopes to influence a farmer's decision. However well a package may perform in its earlier functions, it will fail unless adequate effort is made to fit in with the farmer's decision-making environment. Some of the major issues are enunciated below.

Farmer's objectives

An elementary point relates to the distinction between maximising income and maximising yield. For many advisers and researchers, the achievement of maximum yield may become an end in itself. But the advice provided to farmers must recognize that they maximise net farm income rather than yield. Advice should be presented in terms of the increase (or decrease) in gross margin resulting from the proposed treatment. Furthermore, because the gross margin calculation depends upon assumptions about costs, prices and losses, the package should be designed so as to allow the user to alter the assumptions at will.

Money values should be used so that the proposed control measures can be compared with other opportunities for the use of the fixed resources. Labour required for spraying may have some other more profitable occupation. Likewise, if environmental considerations are important, the opportunity cost of not spraying is made obvious.

A range of alternatives

The evaluation of a range of alternatives provides the manager with more information about his situation than a single supposedly optimal choice. Often in disease control packages the comparison is with a 'do-nothing' alternative and the results are presented as a forecast of 'addition to gross margin'. But even for a single application there may be a choice of materials which have different effects. If a complete spray programme is being evaluated, the range of options (1 spray, 2 spray etc.) should be compared in terms of addition to gross margin, plus the requirements of fixed resources, e.g. hours of regular labour, specialised machinery, etc.

When the package provides an automatic search amongst a series of possible alternatives, the criterion of choice should, as above, be income rather than yield maximisation. The best few alternatives should be displayed rather than a single choice which the package regards as the 'best'.

Terminology used

Since the written (or dsiplayed) word is the medium of communication, it becomes more important to use standard terminology to describe costs, revenues and other concepts. There is often confusion between 'income', 'revenue', and 'margin'. The UK is fortunate to have Anon. (1977) as a source of agreed definitions of terms. This document should be followed wherever possible.

Risk

Risk is a notoriously difficult concept to communicate but is nevertheless widely used in relation to disease loss. An attractive definition of risk is "the likelihood of something bad happening". Note that there are two dimensions to risk, namely degree of "likelihood" and degree of "badness".

Statisticians tend to use probability to measure likelihood, but the difficulties of getting untrained people to interpret probabilities correctly are well known. Weather forecasters often report that people's actions depend on whether "an 80% chance of fine weather" is forecast, or whether the same conditions are put as "a 20% chance of rain".

Furthermore, a particular probability level must be associated with a given degree of "badness" (or loss, environmental impact, or whatever). Thus, when told that there is a 30% chance of disease loss, one must also ask what level of loss that chance refers to. Does it mean any loss (e.g. 0.0001 t/ha) or does it mean some particular threshold level of loss (e.g. 0.5 t/ha) for example? Without a stated level of loss, the probability of that loss is meaningless. Conversely a stated level of loss without a probability attached to it is also difficult to interpret. When told, for example, that there is a possible yield loss of up to, say, 0.5 t/ha, we also need to know the chance of that loss. Is it a 1% chance only or is it a 50% chance? It makes an important difference.

In fact, as far as cereal disease losses go, there is evidence (Smith 1986, Thornton 1985) that recommendations need only be based on the expected or mean loss (implying an equal, 50%, chance of the actual loss being greater than or less than the specified mean level). If this is the case then other parameters of the distribution of losses, such as variance and probability of particular losses, can safely be ignored.

CONCLUSION

The survey has shown a wide range of ability to understand and recognise factors affecting disease development amongst farmers. Designers of computerised advisory systems for disease control must take account of this varying ability. Presentation of recommendations should also take into account the decision environment of the farmer.

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REFERENCES

Anon., (1977) Definitions of Terms used in Agricultural Business Management, London, HMSO p.39.

Anon., (1984a) Use of fungicides and insecticides on cereals, MAFF Booklet 2257; London, HMSO pp.103.

Anon., (1984b) Pesticides; the case of an industry out of control. London; Friends of the Earth.

Dekker, J. (1972) Resistance; in, Marsh, J. R. ed. Systemic Fungicides, London; Longmans Ltd.

Mumford, J. D. (1978) Decision-making in the Control of Sugar Beet Pests; Unpublished Ph.D. thesis, University of London.

Rijsdijk, F. H. (1982) "The Epipre System" in Decision-making in the practice of crop protection; in, British Crop Protection Council Monograph No. 25 pp. 65-76.

Smith, P. J. (1986) Economics of Disease Control in Cereals; unpublished Ph.D. thesis, University of London; p.240.

Thornton, P. K. (1985) "Treatment of Risk in a Crop Protection Information System" Journal of Agricultural Economics, 34, 201-210.