OBSERVATIONS ON AZADIRACHTIN FOR THE MANAGEMENT OF CABBAGE CATERPILLAR INFESTATIONS IN THE FIELD

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ABSTRACT

Small scale field trials have been carried out involving an assessment of crop damage and insect toxicity at the individual level. Azadirachtin and Neemazal-F were demonstrated to give protection to brassicas against lepidopteran pests. No differences were found between azadirachtin and Neemazal-F preparations at the same concentration and dose-rate. Crop protection was demonstrated for *Mamestra brassicae*, *Pieris rapae* and *Plutella xylostella*, however the caterpillars did not die immediately and remained on the plants feeding very little or not at all. At the spray regime of 50 ppm at 400 l/ha caterpillars died either before pupation or pupated after a long delay. Of those which did pupate the majority died during diapause and before eclosion.

INTRODUCTION

Azadirachtin, from the neem tree *Azadirachta indica*, is a limonoid with marked antifeedant, insect growth regulatory and reproductive effects against insects (Schmutterer, 1990; Mordue (Luntz) & Blackwell, 1993). The feeding deterrency and growth disruptive effects of azadirachtin have been well described for numerous species and stages of insects of many orders (e.g. Mordue (Luntz) *et al.* 1985, 1986; Blaney *et al.*, 1990) and recent advances have been made in the field using both commercial and semi-commercial preparations of neem (Schmutterer, 1988; Locke & Lawson, 1990; Isman *et al.*, 1991).

Research into the mode of action and pest control potential of azadirachtin has been ongoing for some 30 years. However, whilst the effects of azadirachtin have been well documented in the laboratory, most field work has been carried out on a large scale using neem formulations rather than pure compound. In an effort to bridge the gap between laboratory and fieldwork small field experiments were set up to (i) compare the effectiveness of pure azadirachtin with a neem based formulation, Neemazal-F, (Trifolio-M, GmbH Lahnau, Germany) (ii) to measure crop damage at the individual plant level and (iii) to observe the feeding behaviour, growth and development of individual insects from the treated crop. To achieve these aims natural cabbage caterpillar infestations of brassicas were studied in (i) control ie. untreated, (ii) azadirachtin-, (iii) Neemazal-F- and (iv) cypermethrin-treated plots, the latter being a standard treatment for the control of lepidopteran pests of brassicas. Both crop damage and insect toxicity were observed at the individual level.

Table 1 Site details and design of field experiments to assess the biological efficacy of the azadirachtin treatments in Midlothian, Scotland, 1991 and 1992.

Site details/ experimental design	1991	1992
Site details		
Name	Goshen, Musselburgh	Bush Estate, Penicuick
British National Grid Ref.	NT367729	NT244638
Soil series	Dreghorn	Darvel
Soil type	Freely drained brown calc. and brown forest soil	Freely drained brown calc. and brown forest soil
Height above sea level	20m	190m
Aspect	Level	Level
Experimental design		
Treatments	1. Untreated Solvent (2% ethanol) + wetter (0.1% Triton-X-100) in water at 400 l/ha 2. Cypermethrin 'Ambush C': ICI Agrochem. 25g ai/ha in 400 l water 3. Azadirachtin 50 ppm at 233 l/ha (12g ai/ha) 4. 250 ppm at 233 l/ha (58g ai/ha) 5. 500 ppm at 2331/ha (117g ai/ha) 6. 750 ppm at 233 l/ha (175g ai/ha)	1. Untreated Solvent (2% ethanol) + water (0.1% Triton-X-100) in water at 400 l/ha 2. Cypermethrin 'Ambush C': ICI Agrochem. 25g ai/ha in 400 l water 3. Azadirachtin 50 ppm at 233 l/ha (12g ai/ha) 4. 50 ppm at 400 l/ha (20g ai/ha) 5. Neemazel-F 5% azadirachtin 50 ppm at 400 l/ha (20g ai/ha)
Layout	Randomised block	Randomised block
Replicates	4 (except azadirachtin treatments which were replicated once owing to scarcity of material)	4
Crop and cultivar	Calabrese (cv Marathon)	Summer cabbage (cv Pedrillo)
Planting date	31 May	15 May
Row width	56cm	56cm
Plant spacing	28cm	30cm
Fertiliser	N 148 kg/ha $P_2 0_5$ 74 kg/ha $K_2 0$ 74 kg/ha	N 225 kg/ha $P_2 0_5$ 75 kg/ha $K_2 0$ 175 kg/ha
Plot size	2.24 x 2.8 m	2.4 x 1.68 m

MATERIALS AND METHODS

The biological efficacy of the azadirachtin treatments was evaluated by field experimentation carried out according to EPPO Guidelines (Anon., 1984) in Midlothian, Scotland during July and August, 1991 and 1992. Site and experimental details are given in Table 1.

Using an Azo portable field sprayer, all treatments were applied twice in each year with a two week interval between applications. In both years, heavy rain following the first application rendered all treatments ineffective; the results reported are for the second application only. Plant damage by caterpillars was assessed in a mid-group of 16 (1991) or 8 (1992) plants in every plot by counting the number of holes in all leaves per plant (Chalfant *et al.*, 1979; Workman *et al.*, 1980) and, in 1992, also by a leaf damage index scale of 0-1 varying from least to most damaged plant per sampling occasion.

During 1992, caterpillars of *Mamestra brassicae* (L.) (cabbage moth), *Pieris rapae* (L.) (small white butterfly) and *Plutella xylostella* (L.) (diamond-back moth) were collected from unassessed plants in untreated and treated plots one day after treatment application, kept individually in the laboratory at ambient room temperature (22°C) and humidity and fed on leaves from original host plants. The area of leaves eaten per day was recorded until mortality or pupation occurred. Survival and eclosion of those caterpillars which had pupated was recorded during 1993.

RESULTS

Field Experiments

In both 1991 and 1992, damage to the crop was high in untreated and low in cypermethrin-treated plots. Azadirachtin and Neemazal-F treatments were intermediate in effect and gave relatively good plant protection (Fig. 1A & B). During 1991, there were no apparent differences in effect between 50, 250, 500 and 750 ppm azadirachtin at a spray rate of 233 l water/ha and hence these data were combined (Fig. 1A). Fifty ppm azadirachtin at a spray rate of 233 l/ha gave significantly less protection to the plants than at 400 l/ha by day 4 post treatment ($P = 0.05$) although protection was not significantly different by day 10 and in both cases was still greater than in controls ($P < 0.01$ at day 4 and day 10) (Fig. 1B). At a spray rate of 400 l/ha 50 ppm azadirachtin gave the same protection as 50 ppm Neemazal-F (Fig. 1B). There was no evidence of phytotoxicity in any of the treatments.

Assessment of crop damage in 1992 by using both the number of holes per plant and a leaf damage index scale demonstrated that both assessment methods were consistent and reliable in that very similar results were obtained in both cases. The results shown in Fig. 1 related to the increase in the number of holes per plant post-treatment.

Observations on individual larvae

An assessment of caterpillar numbers both before and after spraying in 1991 demonstrated significant differences ($P<0.01$) between cypermethrin and azadirachtin/Neemazal-F treatments. Caterpillars were significantly reduced ($P < 0.01$) in number after cypermethrin treatment (Table 2), however no such drop in numbers was found in azadirachtin treatments when compared with controls (Table 2).

Figure 1

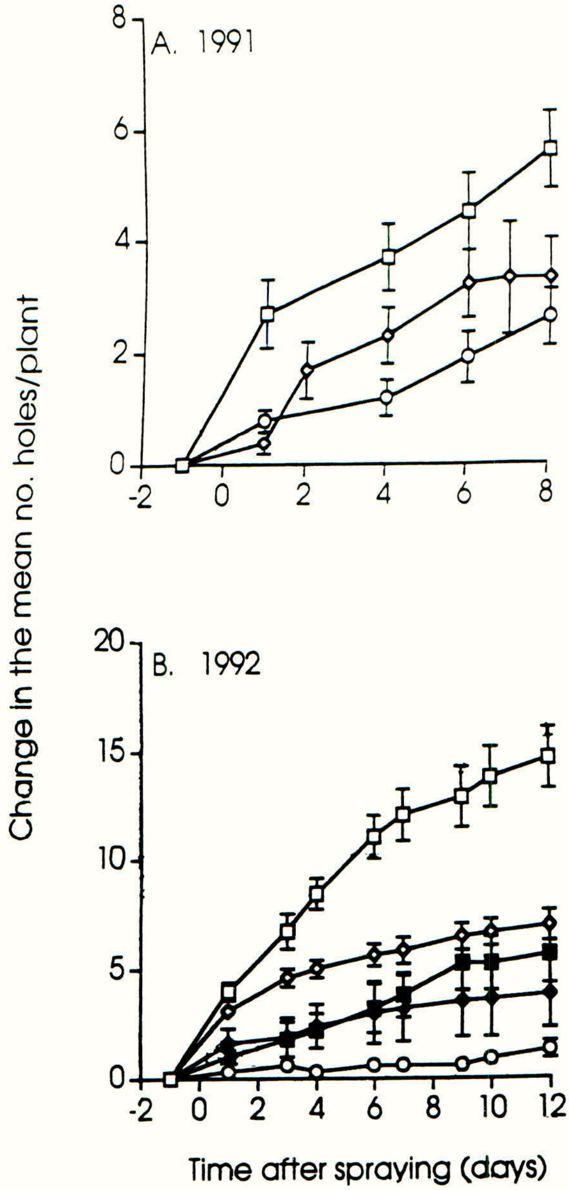

Fig. 1 The increase in damage to brassica crops, expressed as the number of holes per plant, by natural infestations of cabbage caterpillars after treatment of the plants with azadirachtin, Neemazal-F or cypermethrin (4 replicates of 16 (1991) or 8 (1992) plants).

A. 1991; □ control; ◊ azadirachtin from 50-750 ppm (at spray regime of 233 l/ha); O cypermethrin

B. 1992; □ control; ◊ azadirachtin (at 50 ppm and 233 l/ha); ♦ azadirachtin (at 50 ppm and 400 l/ha); ■ Neemazal-F (at 50 ppm and 400 l/ha); O cypermethrin

Table 2 The number of caterpillars observed per plant on day 8 after treatment of the crop with azadirachtin or cypermethrin on day 0; 1991 data (n=64 control and cypermethrin; n= 16 for azadirachtin)

Treatment (ppm)		Days post treatment		Significance (Student's t test)
		-1	+8	
Control		0.36 ± 0.08	0.41 ± 0.09	NSD
Azadirachtin	50	0.25 ± 0.11	0.30 ± 0.15	NSD
	250	0.12 ± 0.08	0.06 ± 0.06	NSD
	500	0.31 ± 0.15	0.19 ± 0.10	NSD
	750	0.31 ± 0.15	0.19 ± 0.10	NSD
Cypermethrin		0.17 ± 0.05	0.02 ± 0.02	P<0.01

Observations of feeding, growth and moulting were carried out during 1992 on insect larvae collected from crops treated one day previously. Overall numbers of insects available for collection was low, however by grouping together data from the azadirachtin treatments it was possible to gain some insight into the effects on cabbage caterpillar infestations in situations closely akin to that of the field. Experiments using larger numbers of reared insects are presently being carried out to confirm these preliminary results.

Mamestra brassicae

M. brassicae had been treated at the onset of the final instar. The larvae showed the classical effects of azadirachtin treatment; that is, a significantly reduced level of feeding and a delay in the time of pupation (Fig. 2). The average time of pupation was 25 days after spraying for controls and 30 days after spraying for azadirachtin-treated. Few mortalities occurred during the Vth instar and most individuals metamorphosed to diapausing pupae. However, whereas successful emergence occurred in May and June 1993 in 4 out of 5 controls, only 2 of 8 azadirachtin-treated *M. brassicae* emerged. Of these two, one appeared normal and the other died during eclosion in an unexpanded state. In both cases emergence was greatly delayed and occurred in August and September 1993 respectively. The remaining insects died as pharate pupae.

Pieris rapae

It was clear from five *P. rapae* larvae collected that treatment had also occurred towards the beginning of the final instar. The two control insects successfully pupated 20 days post-treatment after consuming an average of 2.9cm^2 leaf per day, peaking at 9.5 cm^2 at mid-instar on day 8. The three azadirachtin-treated insects showed a strong feeding inhibition with an average of 0.23±0.19 cm^2 leaf eaten per day throughout the period of the final instar. Two of the three treated insects died during the Vth instar whilst the third pupated after a long delay.

Plutella xyllostella

P. xyllostella larvae appeared to demonstrate a different pattern of response which was related to the production of a second summer generation of insects. Treated insects were nearing the end of the last larval instar at the time of treatment and the final stages of feeding and pupation were not affected (n=2). Controls (n=4) and one azadirachtin-treated insect emerged after 11 days, the other treated insect died in the pupal stage.

Figure 2

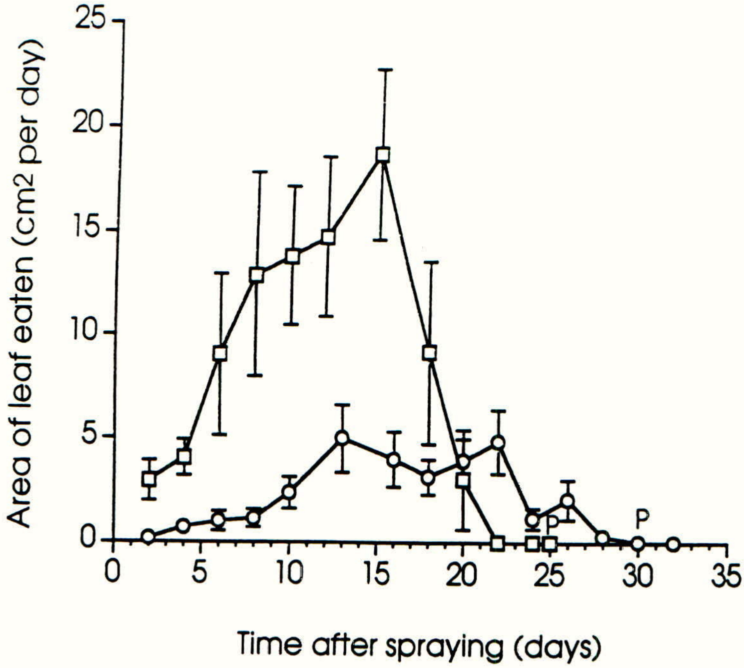

Fig. 2 Area of cabbage leaf eaten (cm^2/day) by *Mamestra brassicae* Vth instar larvae taken from crops sprayed with azadirachtin on day 0(1992). Insects were fed leaves from their original host plant. (n = 5 for controls; n = 8 for azadirachtin-treated. □ control; O azadirachtin.

DISCUSSION

In the field experiments, which covered a two year period, both pure azadirachtin and Neemazal-F preparations were shown to achieve good plant protection. At the recommended dose of 50 ppm and a spray regime of 400 l/ha such crop treatments achieved good protection which was almost as great as that achieved by cypermethrin treatment, a standard pyrethroid preparation for the control of lepidopteran pests. Effectiveness was lost in all cases, including cypermethrin, if rain immediately followed spraying supporting the argument for systemic treatment of the crop by azadirachtin. Such treatments have been shown to be effective in cabbage seedlings or leaves against *Pieris brassicae* (Osman & Port, 1990, Arpaia & van Loon, 1993) at doses of less than 10 ppm azadirachtin in the bathing medium (Arpaia & van Loon, 1993). Both azadirachtin and Neemazal-F gave similar results at the same dose, which reflects the importance of azadirachtin content in the overall activity of neem-based preparations (Isman *et al*., 1990). Also the lack of any protective formulation did not affect the efficacy of azadirachtin under the summer conditions of Midlothian, Scotland, in 1991 and 1992 when conditions were cool and temperate.

Although insect numbers were low for the observational experiments it was still apparent that crop treatments with azadirachtin at 50 ppm were sufficient to give good control of cabbage caterpillars. Further detailed studies of different lepidopterous species in the field are required to reveal any differences in the sensitivity of different species to azadirachtin and the importance of the time of spraying in relation to the insect's life cycle.

Interestingly, in spite of good plant protection in azadirachtin and Neemazal-F treatments, caterpillar numbers remained high. Both the detailed observations of individuals and the assessment of insect numbers in the field emphasised the apparency of caterpillars on the crop for extended periods of time, although they were not actively feeding. Such insects showed the classical azadirachtin poisoning symptoms of reduced feeding, delayed moults and increased mortalities both prior to and during pupation. Such effects together with unsuccessful emergence both that season and the following year suggested a good potential control of future generations of insects. The apparency of the immobilised larvae on the crop must however be taken into account when assessing the acceptability of a neem-based product by farmers.

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THE USE OF SPRAY ADJUVANTS IN WINTER CEREALS IN SCOTLAND

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ABSTRACT

A number of field trials were carried out at a range of sites to examine the effect of adjuvants (a soya phospholipid/proprionic acid blend, latex, an alkoxylated amine, and two organosilicones) on a range of fungicides (fenpropimorph, flusilazole, tebuconazole, prochloraz, and tridemorph) in winter wheat in Scotland. The target diseases were *Pseudocercosporella* (eyespot), *Erisyphe graminis* (mildew), *Septoria nodorum* and *Fusarium nivale*. In addition a trial in winter barley on manganese uptake is reported. Significant improvements in disease control, trace element uptake and yield were achieved by a number of the product/adjuvant combinations. The most effective results were achieved with organosilicone surfactants. Reductions in fungicide dose rates were achieved with improved efficacy, which led to increased sustainability of production systems.

INTRODUCTION

Cool, wet weather and difficult disease patterns in the arable areas of Scotland provide problems for the grower in achieving adequate uptake and efficacy of systemic fungicides in cereals. Previous work in Scotland (Dawson & Ballingall, 1990 and Dawson 1992) has shown that by using adjuvants in an integrated barley production system improvements in efficacy and gross margin can be achieved. The aim of the trials programme reported here was to extend this work to the wheat crop and investigate the scope for improved efficacy and fungicidal dose reduction. Much previous work has been carried out in the greenhouse and/or with formulation composition of fungicides. As greenhouse studies may differ markedly from field conditions, substantive evidence from field trials is required using commercial programmes and more complex tank mixes.

METHODS AND MATERIALS

A series of replicated small plot field trials were conducted on wheat (*Triticum aestivum*) from 1990-1994 to examine the control of powdery mildew (*Erisyphe graminis*), eyespot (*Pseudocercosporella herpotrichoides*), *Septoria nodorum* and *Fusarium nivale* in winter wheat; trial sites were located in Mintlaw (Grampian Region), Aberdour (Fife Region), and Kelso and Berwick (Borders Region). A trial was also carried out in winter barley to examine the effect of adjuvants on manganese uptake.

The trials were a randomised block design with four replicates. The seed rate was 500 seeds/m^2 and the main variety used was cv Riband and the plot size was 2m x 12m. The plots were sprayed with an Azo small plot sprayer using a Lurmark flat fan 80° EO2-80 nozzle at 2.5 bar delivering 200l/ha of water, producing a medium quality spray (BCPC classification). Grain yields were taken with a small plot combine equipped with a load cell. Disease control given in the data tables was measured as a visual assessment, using twenty leaves or stems per plot for each treatment. The days after application (DAA) and crop growth stage are given in the data tables. The assessment of eyespot was additionally measured using an ELISA technique (an immunoassay technique for disease confirmation and quantification) (Smith *et al*,1990). Apart from relevant experimental treatments, trace elements were applied to the plots in response to soil and tissue analysis. Soil pH was in the range of 5.9-6.3. Manganese tissue analysis was by the nitroperchloric acid digestion followed by atomic adsorption, after prewashing foliage with distilled water. The Zadocks growth stage key was used in defining growth stages. In one trial some treatments received a wetting treatment prior to application to simulate a crop with a heavy dew on the leaves.

The fungicides used in the programme were fenpropimorph (750g active ingredient (ai) per litre), a formulated mixture of fenpropimorph and tridemorph (BAS 464;500 + 250g ai/l), prochloraz (400g ai/l), flusilazole (160g ai/l), tebuconazole (250g ai/l). These products contain an adequate adjuvant system in their formulation according to manufacturers. The adjuvants used were soya phospholipid and proprionic acid (750g/ha LI700; Loveland Industries) at 0.5% v/v of spray solution, synthetic latex (63g/ha Bond;Loveland Industries) at 0.08% v/v of spray solution. An alkoxylated amine (Arma blend;International Speciality Products) at 0.1% v/v of spray solution, and two organosilicone surfactants (Silwett L77 and Slippa, a blend of Silwett L77 and a linear alcohol;OSi Specialities) at 0.15% v/v of spray solution.

A. Stem base disease control

In the first trial the effect of an organosilicone adjuvant (Silwett L77) on the control of eyespot and *Fusarium* achieved with recommended and lower than recommended rates of prochloraz and flusilazole was investigated. The treatments were applied at first node and a standard fungicide (triadimenol) was applied to all treatments at flag leaf emergence and at full ear emergence, in order to remove the late season effects of foliar pathogens. The variety in the trial was Riband grown as a second wheat crop in the Borders.

B. Mildew control

A series of trials examined the effect of adjuvants on control of mildew in wheat with recommended and lower than recommended rates of fenpropimorph and fenpropimorph/tridemorph in combination. The treatments were applied at first node and a standard commercial fungicide (flusilazole) was applied to all treatments at flag leaf emergence and at ear fully emerged, in order to remove the late season effects of other foliar pathogens. In one trial (Table 3) plots were artificially wetted to the point of run off, prior to a spray application including synthetic latex, these are denoted as wet (W) and dry (D) in tables 2 and 3. The variety in all trials was Riband.

C. Septoria control

A trial in wheat examined the effect of adjuvants on *Septoria* control with tebuconazole at half the recommended rate at ear emergence. The predominant disease was *Septoria nodorum* and this was confirmed by an ELISA test. A standard programme of fungicides was applied to all treatments at Zadocks 31 and 37 and treatments were applied at ear emergence.

D. Manganese Uptake

The trial on winter barley examined the effect of an organosilicone and a phospholipid adjuvant on the uptake of manganese and grain yield.

ANOVA statistical analysis was conducted on the data and the values given in the tables which differ significantly from each other at a 95% confidence interval are denoted by a different letter.

RESULTS AND DISCUSSION

A. Stem base disease control

The control of stem base disease was examined in a second year wheat. The incidence of both eyespot and Fusarium were measured at several stages during the season by visual assessment (data are reported for GS75 assessments). The data for yield and the assessments are shown in Table 1. The table shows the data for eyespot control with both flusilazole and prochloraz, best control was achieved by the lower rate of each product in combination with Silwett L77. This result was confirmed by ELISA data. Prochloraz did not give similar control of eyespot to flusilazole. Only the combination of flusilazole and Silwett L77 gave significant control of stem base browning caused by *Fusarium*, which was a very visual effect in the field.

There was no lodging in any treatment due to the good seasonal conditions. In a normal Scottish harvest the effects of stem base *Fusarium* are a significant factor in lodging in many crops. In the absence of lodging yield differences between treatments showed few significant differences apart from comparison with the untreated control. The best treatments for *Fusarium* control was the lower rate of flusilazole with Silwett L77.

Table 1 Effect of fungicide and adjuvant combinations on control of Eyespot and *Fusarium* in winter wheat variety Riband (Borders 1990)

TREATMENT	Eyespot Control GS75 (%)	Fusarium Control GS75 (%)	Yield (t/ha)
UNTREATED (% mainstems infected)	35a	44a	9.70a
Flusilazole 200g/ha	45b	0a	10.65bc
Flusilazole 100g/ha	40ab	0a	10.35b
Prochloraz 400g/ha	55b	0a	10.96c
Prochloraz 200g/ha	40ab	0a	10.37b
Flusilazole 100g/ha + Silwett L77 0.15%(v/v)	60bc	56b	10.69bc
Prochloraz 200g/ha + Silwett L77 0.15%(v/v)	65c	0a	10.31b

B. Mildew Control

Control of mildew on the stem base in thick wheat crops is important if long term control is to be achieved. It also gives a useful measure of physical targetting of fungicide, as basipetal movement of fungicide down the plant post application is limited. Tables 2,3 and 4 show data from three trials which were carried out to examine the effect of adjuvants on mildew control in winter wheat. Adjuvant effect on fenpropimorph for leaf and stem mildew and yield increase was greatest from Silwett L77, and was significantly more effective than doubling the rate of fenpropimorph. The addition of soya phospholipid or synthetic latex applied either to wet or dry leaves gave similar increased mildew control to each other, but less than Silwett L77 and generally no better than doubling the rate of fenpropimorph. Artificially wetting the plots (W) prior to spray application also improved mildew control significantly on leaf 3 in the synthetic latex treatments 14 DAA (Table 2).

Table 2 Effect of fungicide and adjuvant combinations on severity of mildew in winter wheat variety Riband (Borders 1990)

TREATMENT	Mildew% Leaf 3 14DAA	Mildew% Leaf 3 23DAA	Mildew% Stem base 23DAA	Yield (t/ha)
UNTREATED	7.2a	9.0a	32.5a	8.51a
Fenpropimorph375g/ha	2.5b	1.0b	18.5b	8.88ab
Fenpropimorph 187.5g/ha	3.5b	1.5b	21.5b	8.67a
Fenpropimorph 93.8g/ha	3.5b	2.5b	26.5ab	8.63a
Fenpropimorph 187.5g/ha + Silwett L77 (0.15%v/v)	0.2c	0.4c	0.5c	9.49c
Fenpropimorph 187.5g/ha + Soya phospholipid (0.5%v/v)	1.5b	1.0b	15.5b	9.01bc
Fenpropimorph 187.5g/ha + Synthetic Latex (0.08%v/v) D	1.0b	1.5b	15.0b	8.76ab
Fenpropimorph 187.5g/ha + Synthetic Latex (0.08%v/v) W	0.2c	1.0b	12.0b	9.21b

The use of synthetic latex on wet leaf (W) resulted in a significant yield increase over fenpropimorph alone in one trial. Addition of soya phospholipid to fenpropimorph gave variable results, significantly improving leaf mildew control in one of two trials, although no improvement in stem base mildew was achieved. However, despite this variable performance in mildew control, significant yield increases occurred. Grain yield generally followed the level of mildew control.

Table 3 Effect of fungicide and adjuvant combinations on severity of mildew in winter wheat variety Riband.(Aberdeenshire 1990)

TREATMENT	Mildew% Leaf 3 32DAA	Mildew% Stem Base 32DAA	Yield (t/ha)
UNTREATED	7.0a	20.5a	7.45a
Fenpropimorph 375g/ha	5.0a	12.5b	7.72a
Fenpropimorph 187.5g/ha	7.0a	15.0ab	7.65a
Fenpropimorph 187.5g/ha + Silwett L77 (0.15%v/v)	2.0b	1.5c	8.35b
Fenpropimorph 187.5g/ha + Soya phospholipid 0.5%(v/v)	5.0a	11.5b	8.15b
Fenpropimorph 187.5g/ha + Synthetic Latex (0.08%v/v) D	4.0ab	15.0ab	8.01ab
Fenpropimorph 187.5g/ha + Synthetic Latex (0.08%v/v) W	2.0b	7.5b	8.15b

A comparison of the two organosilicone surfactants in Table 4 shows the Silwett L77 blend to be superior in mildew control to Silwett L77 alone in this trial. The mildew control from the use of the organosilicone surfactants was more pronounced on the stem base, which should reduce reinfection.

Table 4 Effect of fungicide and adjuvant combinations on severity of mildew in winter wheat variety Riband (Fife 1993)

TREATMENT	Mildew% Leaf 3 32DAA	Mildew% Stem Base 32DAA	Yield (t/ha)
UNTREATED	5.0a	12.5a	9.51a
BAS464 (150 + 75g/ha)	1.5b	8.5a	10.28b
BAS464 (150 + 75g/ha) + Silwett L77 (0.15%v/v)	0.8b	1.5b	10.04ab
BAS464 (150 + 75g/ha) + Silwett L77 blend (0.15%v/v)	0.0c	0.0c	10.80c

C. Septoria Control

Further work was carried out to examine the effect of adjuvants added to tebuconazole on the control of *Septoria nodorum* at ear emergence. The data (table 5) show the disease control and yield benefits from a fungicide applied at ear emergence which was further enhanced by both adjuvants. The data show that the organosilicone surfactant has improved disease control in the lower leaf canopy, but has reduced control on the flag leaf (L1). It is believed that the fungicide has been washed down the plant at application and not redistributed into upper leaves, due to high soil moisture deficits. In contrast the alkoxylated amine improved disease control on the upper flag leaf and increased grain yield significantly. This affords the possibility of targetting sprays in the canopy using ELISA diagnostic techniques to determine the site of disease.

Table 5 Effect of fungicide and adjuvant combinations on control of *Septoria nodorum* in winter wheat variety Brigadier (Fife 1994)

TREATMENT	%*Septoria nodorum* Leaf 3 32DAA	%*Septoria nodorum* Leaf 1 32DAA	Yield (t/ha)
Untreated	65.4a	30.5a	12.95a
Tebuconazole (125g/ha)	18.5b	9.5c	13.62bc
Tebuconazole (125g/ha) +Silwett L77 (0.15%v/v)	5.5c	20.0b	13.50b
Tebuconazole (125g/ha) +Arma blend (0.1%v/v)	12.4b	2.5d	14.11c

D. Manganese Uptake in Winter barley

The addition of either a soya phospholipid adjuvant or an organosilicone surfactant increased both manganese uptake and grain yield in the barley variety Princess (Table 6).

Table 6 Effect of manganese and adjuvant combinations on uptake and grain yield of winter barley (Fife)

TREATMENT	Manganese (ppm) 21DAA	Yield (t/ha)
Manganese (620g/ha)	23a	10.64a
Manganese (620g/ha) + Soya phospholipid (0.5%v/v)	48b	11.02a
Manganese (620g/ha) + Silwett L77 blend (0.15%v/v)	59b	11.68b

The Silwett L77 blend was more effective than the soya phospholipid adjuvant in increasing yield on this manganese deficient soil. The variety used in this trial was Princess.

CONCLUSIONS

The evidence from the field trials data in this paper would suggest that adjuvants have an important part to play in increasing the efficiency of fungicides in winter wheat in Scotland, and increasing sustainability of production. The organosilicone surfactants,and in one trial, the alkoxylated tallow amine gave the best results with the fungicide and disease targets specified. There are possibilities for exploiting this potential either by maintaining efficacy and reducing fungicide dose or by maintaining the fungicide dose and increasing the effect. Both of these strategies may reduce cost of production per tonne and increase profitability, but only the former will reduce environmental load. It is clear from the data that fungicide/adjuvant/target interactions are specific and care must be taken in selecting the correct combinations for effective field use. A full understanding of product and adjuvant modes of action and disease epidemiology will be needed by the field adviser in order to exploit the potential of these management tools and improve the sustainability of inputs, from both economic and environmental standpoints.

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