POSTER SESSION 8E

ADVANCES IN FORMULATION AND APPLICATION TECHNOLOGY

Session Organisers: Dr D Stock

Syngenta, Bracknell, UK

and

Professor M G Ford

Portsmouth University, UK

Poster Papers: 8E-1 to 8E3

Technical advances in fumigant application for soil disinfestation

M L Gullino, A Minuto, A Garibaldi
Di.Va.P.R.A. Patologia Vegetale Univ. Torino, Grugliasco, Italy
Email: gullino@agraria.unito.it

H A Ajwa
University of California, Davis, California, USA

ABSTRACT

Results from several experiments in Italy on alternative fumigants to methyl bromide for soil disinfestation are presented. The importance of application methods of dazomet, metham sodium, chloropicrin alone or combined with 1,3 dichloropropene is reported. Drip fumigation and soil solarization along with the use of mulching film, including virtually impermeable film (VIF), are beneficial factors to improve the efficacy and safety of alternative fumigants.

INTRODUCTION

Since the nineteen-seventies, many crops including vegetables, cut flowers and perennials relied on methyl bromide (MB) to control soil-borne pests, diseases, and weeds. Its inclusion among substances controlled by the Montreal Protocol, stimulated investigations to find reliable short-term alternatives. Metham sodium (MS) and dazomet (DZ), methylisotiocyanate (MITC) generators, are registered in Italy and effective for controlling weeds and soil-borne pathogens, principally fungi, and several parasitic nematodes, but must be applied when soil temperatures are above 12-15°C (Bell *et al.*, 1996). Chloropicrin (CP) (trichloronitromethane, CCl_3NO_2), not yet registered in Italy, is one of the most effective soil fumigants against plant diseases, being easily combined with MB or 1,3 dichloropropene (1,3 D) to broaden its activity against nematodes (Bell *et al.*, 1996). This paper summarizes results obtained from testing alternative fumigants, alone and in combination with soil solarization (SS), and innovative techniques to improve fumigant distribution in soil, including virtually impermeable plastic films (VIF) and drip fumigation.

MATERIALS AND METHODS

The experiments were carried out in Northern (sandy-loam soils, pH 8.1, organic matter 2.5 %) and Southern (sandy soils, pH 8.3, organic matter 0.7 %) Italy in open fields and protected crops, testing DZ, MS, CP and mixtures of 1,3 D and CP. MB was applied using the hot gas method (Bell *et al.*, 1996) by adopting the mixture of MB + CP (98 % + 2 % w/w). DZ granular formulation (Basamid, ex BASF, 99 % w/w a.i.) was mechanically rototilled into dry soil to a depth of 20 cm. The mulched soil was subsequently irrigated, distributing water to a volume of 30–40 l/m^2 through the drip irrigation system (drip lines spaced 30 cm apart, water emitters spaced 30 cm apart with water flow rate of 1-3 l/h). A liquid formulation of MS (Vapam, ex Sipcam, 32.7 % w/w a.i.) was applied through the drip irrigation system (see above) on mulched dry soil, diluting the formulation rate to a water volume of 30–40 l/m^2. A liquid CP formulation (Tripicrin, ex Trical, 99 % w/w a.i.) was applied by soil shank injection or by drip irrigation into a mulched soil. Shank-injected CP was applied with the same equipment used for MB cold fumigation. In each bed, CP was injected at a 30-cm depth with two shanks placed 20 cm from the bed edge and 40 cm apart. Chloropicrin, applied through drip irrigation, was applied on beds made with the same equipment used for injection. Each bed was provided with two drip lines, placed on the soil surface, 20 cm from the bed edge and 40 cm from each other. The drip lines were equipped with water emitters (flow rate 2.4 l/h) spaced 30 cm apart. The formulation of CP, combined with an emulsifier (5% w/w, TS101, ex Trical, Hollister, CA, USA) to ensure uniform distribution of CP in the irrigation water, was injected into the irrigation line by a peristaltic pump that was pre-calibrated to obtain a desired final concentration. The application of Telone C-35 (ex Dow AgroSciences, CP 35 % + 1,3D 61 % w/w,) was carried out only by soil injection using the same method described for CP. The experiments were carried out in a randomized complete block design with three or four replicates and, depending on the trial purpose, different crops were transplanted (tomato, melon, lettuce, gerbera) or seeded (sweet basil). During the cropping season, to evaluate the effect of soil treatments on disease incidence and crop yield, data were collected weekly and statistically analyzed according to Duncan's Multiple Range Test.

RESULTS

Table 1 shows the effectiveness of soil mulching and DZ to control fungi for tomato and basil production in Italy, particularly when combined with soil solarization (Minuto *et al.* 2000a).

Table 1. Effect of different treatments on the incidence of Fusarium wilt on basil, cv Genovese gigante (Gg) and Fine verde (Fv), on the incidence of *Fusarium oxysporum* f.sp *lycopersici*, *Verticillium dahliae* and *F. oxysporum* f.sp.*radicis-lycopersici* (Forl) on tomato cv Principe Borghese and on the incidence of *Sclerotinia sclerotiorum* on lettuce (Minuto *et al.*, 2000a)

Treatment, g/m^2, film	SS (dd)	% infected plants: basil – 06/10/99, cv Gg	basil – 06/10/99, cv Fv	tomato – 08/10/99, Wilt pathogens°	tomato – 08/10/99, Forl	tomato – 08/10/99, Combined	lettuce 17/12/99
DZ, 99, -	-	7.8 b*	32.0 bc	16.7 b	8.3 a	25.0 abc	37.4 b
DZ, 49.5, PE+	-	5.0 b	19.4 ab	0.0 a	8.3 a	8.3 ab	22.8 ab
DZ, 49.5, VIF++	-	5.1 b	21.2 ab	n.t.^	n.t.	n.t.	33.9 b
DZ, 49.5,VIF	21	0.2 a	0.3 a	0.0 a	0.0 a	0.0 a	5.6 a
Control	-	16.6 c	50.4 c	16.7 b	25.0 a	41.7 bc	39.0 b

° The value includes the percent of plants infected by *V. dahliae* and by *F. oxysporum* f.sp. *lycopersici*; *Means of the same column, followed by the same letter, do not significantly differ following Duncan's Multiple Range Test (P=0.05). + PE: polyethylene 0.05 mm thick; ++ VIF (IPM - Italy) 0.035 mm thick, permeability coefficient to MB 0.02 g/m^{2}xh NFT54-195; ^ not tested.

On gerbera against root rot, caused by *Phytophthora cryptogea* under greenhouse conditions, MS did not provide satisfactory disease control when drip applied with 35 mm of water at 192 g/m^2 without plastic mulch. MB, applied at 60 g/m^2 or at 40 g/m^2 under VIF, gave satisfactory results, but MS provided similar disease control when drip applied at 96 g/m^2 under plastic mulch (Table 2) (Minuto *et al.*, 2000b). In Northern and Southern Italy, CP applied by shank bed injection at 30-40 g/m^2 under PE film provided satisfactory and consistent control of *Fusarium oxysporum* f. sp. *melonis* on melon, *Verticillium dahliae* on eggplant and *V. dahliae*, *F. oxysporum* f. sp. *lycopersici* and *F. oxysporum* f. sp. *radicis-lycopersici* on tomato, particularly in sandy soils (Table 3) (Gullino *et al.*, 2002a,b). CP at 40 or 60 g/m^2 under PE film drip-applied at the concentration of 700 to 1,200 µl/l provided the best results against Fusarium wilt on melon and against Fusarium and Verticillium wilts on tomato (Table 4). These results are consistent with those of Gullino *et al.* (2002a,b). Comparing CP drip application under PE and under VIF, CP efficacy was greater under VIF, reducing the dosages below 40 or 30 g/m^2 against soil-buried inoculum of *R. solani* (Gullino *et al.*, 2002b). Previous open-field experiments using shank-injected Telone C-35 showed great efficacy against soil-buried pathogens as well as *P. capsici* and *R. solani* at CP+1,3D rates of 14+24.4 and 17.5+30.5 g/m^2 under PE, and against *F. lycopersici* at a rate of 10.5+18.3 g/ m^2 under VIF.

Table 2. Effectiveness of different treatments against *Phytophthora cryptogea* on gerbera (Albenga, 1997 - 1998) (Minuto *et al.*, 2000b)

Treatment, g/m^2, film	% dead plants at days after transplant				n° flowers/plant
	106	213	310	386	
Control	7.9 b*	11.2 c	26.1 b	44.5 b	22.1 a
MB, 60, PE$^+$	3.0 a	3.1 a	11.4 a	17.2 a	19.0 b
MB,40, VIF^{++}	2.1 a	3.0 a	12.0 a	19.9 a	20.1 ab
MS, 192, -	5.4 ab	6.1 b	15.5 a	30.2 b	19.6 ab
MS, 96, PE	4.8 ab	3.3 a	13.1 a	26.2 ab	18.6 b
MS, 96, VIF	5.7 ab	5.0 ab	13.2 a	26.5 ab	22.4 a

*, $^+$, $^{++}$ see table 1

Table 3. Effect of CP soil injected and MB fumigation under PE$^+$ on tomato plants (cv Principe Borghese) infested with *P. lycopersici, F. oxysporum* f.sp. *radicis lycopersici* (Forl), *F. oxysporum* f.sp. *lycopersici* and *V. dahliae* in sandy soils (SS) and in sandy-loam soils (SLS) (Gullino *et al.*, 2002a)

Treatment, g/m^2	Percentage of plants infected							
	P. lycopersici		Wilt pathogens°		Forl		Combined	
	SS	SLS	SS	SLS	SS	SLS	SS	SLS
Control, -	9.9 b*	-	4.3 b	25.6 b	22.5 b	29.6 b	36.7 b	55.2 c
CP, 20	0.0 a	-	0.5 a	19.5 ab	5.9 a	27.2 a	6.4 a	46.7 b
CP, 30	1.6 a	n.t.^	0.5 a	n.t.	5.2 a	n.t.	7.3 a	n.t.
CP, 40	4.3 ab	-	0.0 a	17.1 ab	3.2 a	30.7 b	7.5 a	47.8 b
MB, 60	1.1 a	-	0.0 a	11.7 a	0.5 a	27.5 a	1.6 a	39.2 a

°, *, $^+$, ^ see table 1.

The effect of the fumigant mixture against soil-buried *V. dahliae* was only moderate at 17.5+30.5 g/m^2 under PE and at 10.5+18.3 g/ m^2 under VIF, suggesting that the efficacy of PIC+1,3D could be improved by applying the mixture under VIF films (Minuto *et al.*, 2000c). Repeating the same experiment on tomato and eggplant, respectively infected by *V. dahliae*, *F. oxysporum* f.sp. *lycopersici*, *F. oxysporum* f.sp. *radicis lycopersici* and by *V. dahliae*, showed a general increase in fumigant effectiveness with VIF (Table 5). More recently the application of CP+1,3D against soil-buried pathogens (*P. capsici, F. oxysporum f.sp. melonis, R. solani*) showed statistically similar efficacy of 14+24.4 g/m^2 under VIF and 17.5+30.5 g/m^2 under PE (Table 6).

Table 4. Effect of CP drip applied and MB fumigation under PE[+] on tomato plants (cv Principe Borghese) infested with *V. dahliae*, *F. oxysporum* f.sp. *lycopersici* and *F. oxysporum* f.sp. *radicis lycopersici* (Forl) in sandy-loam soils in open field (OF) and under protected crop (PC) (Gullino *et al.*, 2002a)

Treatment, g/m², mm water (CP µl/l)	Percentage of plants infected					
	Wilt pathogens°		Forl		Combined	
	OF	PC	OF	PC	OF	PC
Control, -, -	25.1 b*	22.9 b	41.0 b	43.0 a	66.1 c	65.9 b
CP, 20, 17 (700)	12.2 a	n.t.	38.1 ab	n.t.	50.3 b	n.t.
CP, 20, 20 (600)	n.t.^	12.9 ab	n.t.	25.7 a	n.t.	38.6 ab
CP, 40, 20 (1,200)	10.3 a	n.t.	29.4 ab	n.t.	39.7 ab	n.t.
CP, 40, 35 (700)	n.t.	5.9 a	n.t.	21.4 a	n.t.	27.3 a
MB, 60, -	8.5 a	8.6 a	28.5 a	18.6 a	37.0 a	27.2 a

°, *, +, ^ see table 1.

Table 5. Effect of fumigation with CP+1,3D soil injected and MB fumigation on tomato (cv Cuore di bue) infested with *V. dahliae*, *F. oxysporum* f.sp. *lycopersici* and *F. oxysporum* f.sp. *radicis lycopersici* (Forl) and on eggplant (cv Prospera) infested with *V. dahliae* in sandy-loam soils in open field (Albenga, Northern Italy, 1999)

Treatment, g/m² plastic mulch	Percentage of plants infected			
	Tomato			Eggplant
	Wilt pathogens°	Forl	Combined	*V. dahliae*
Control,-, -	19.9 a*	18.7 b	38.6 b	36.1 c
CP+1,3D, 7+12.2, PE[+]	14.3 a	3.8 a	18.1 a	33.3 bc
CP+1,3D, 7+12.2, VIF[++]	9.4 a	3.0 a	12.4 a	11.4 ab
CP+1,3D, 10.5+18.3, PE	16.2 a	8.1 a	24.3 ab	22.2 abc
CP+1,3D, 10.5+18.3, VIF	11.2 a	1.9 a	13.1 a	9.7 ab
PIC+1,3D, 14+24.4, PE	16.1 a	3.9 a	20.0 ab	12.6 abc
PIC+1,3D, 14+24.4, VIF	7.2 a	3.7 a	10.9 a	19.4 abc
PIC+1,3D, 17.5+30.5, PE	10.0 a	1.5 a	11.5 a	5.8 a
BM, 60, PE	18.3 a	2.6 a	20.8 ab	16.7 abc
BM, 40, VIF	6.1 a	0.0 a	6.1 a	8.3 a

°, *, +, ++, ^ see table 1.

CONCLUSIONS

Determining improved application methods for DZ, MS, and CP alone or mixed with 1,3D is critical to maintain the economical competitiveness of Italian horticulture and to adopt viable and environmentally-friendly application methods. Under typical field practices, several alternative fumigants can be also applied to soil by shank injection at 20 to 30 cm depth. However, the available alternatives, particularly CP, 1,3 D, and MS have low vapor pressures and high boiling points compared to MB and their efficacy against soilborne pests is more dependent on the method of delivery into the soil type and on meteorological conditions (Ajwa *et al*, 2002; Ben-Yephet *et al.* 1985; McGovern *et al.*, 1988). Shank-applied MS moves only a short distance from the injection points (Smelt & Leistra, 1974), but when MS is applied with water, its distribution in the soil improves so efficacy increases, even against nematodes (Roberts *et al.*, 1988). Based on these considerations, on our reported data and on field evaluations carried out under different conditions (Ajwa *et al.*, 2002), drip irrigation systems could be considered as a vehicle to deliver water-emulsifiable fumigant formulations, providing a more uniform soil distribution of chemicals than shank injection. Several considerations arise: the integrity of the delivery system could influence both fumigant distribution and worker safety; the uniformity of water distribution in the field should be at least 80% and emission uniformity along the drip tape should be 90% or more (Ajwa *et al.*, 2002); the drip system components should be compatible with the applied fumigant, which limits the use of polyvinyl chloride (PVC) in favor of more polyethylene adoption because it is compatible with most fumigants (Ajwa *et al.*, 2002). Moreover, using drip fumigation under standard PE film led to more uniform fumigant distribution in soils than shank injection, improving the fumigant distribution across the soil profile and preventing its volatilization through the soil surface into the atmosphere (Ajwa *et al.*, 2002, Gan *et al.*, 1998). Several factors can affect water distribution around the drip line: soil hydraulic properties, water application rate, drip system configuration, bed or broadcast application and the initial soil water content. Initial soil water content negatively affects water distribution: water tends to move more horizontally in a dry soil than in a wet soil, and the ability of a soil to hold water decreases with increasing water content (Ajwa *et al.*, 2002). As a result, 30-40 mm of water should be considered as the minimum volume needed to deliver sufficient fumigant horizontally 30 cm in a sandy loam soil, with drip lines spaced up to 50-60 cm apart; moreover the effectiveness of alternative fumigants can be improved by the use of VIF to reduce emissions following drip fumigation (Gullino *et al.*, 2002b).

Table 6 - Effect of fumigation with CP+1,3 D mixture soil injected and MB fumigation on the survival of soil-buried pathogens (Albenga, Northern Italy, 2000).

Treatment, g /m^2, plastic mulch	% of kernels infected with *Phytophthora capsici* at depth of		*F oxysporum* f.sp. *melonis*		*Rhizoctonia solan*	
	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm
Testimone	50.0 c*	55.3 d	82.7 c	78.3 d	33.0 b	29.5 bc
CP+1,3D, 9.5+16.5, PE$^+$	47.0 bc	48.3 bcd	87.5 c	67.8 cd	28.0 ab	16.8 ab
CP+1,3D, 14+24.4, PE	64.0 bc	32.8 bc	39.5 b	38.0 ab	23.0 ab	35.0 c
CP+1,3D, 18.9+32.9, PE	15.0 ab	27.3 b	43.0 b	51.0 bc	8.0 a	9.7 a
CP+1,3D, 18.9+32.9, VIF^{++}	8.0 ab	1.3 a	18.3 ab	22.0 ab	15.0 ab	1.0 a
CP+1,3D, 23.5+40.9, PE	6.0 ab	17.3 a	37.3 ab	20.0 a	9.0 a	2.3 a
BM, PE, 60	4.0 a	3.3 a	16.8 ab	12.5 a	8.8 a	11.0 a
BM, VIF, 40	9.0 ab	7.7 a	6.0 a	32.5 ab	72.3 c	88.3 d

*, $^+$, $^{++}$ see table 1.

Recently, it has been demonstrated that an emulsified fumigant formulation of 61 % 1,3-D + 35% CP at 236 l/ha throughout 43 mm water resulted in higher concentrations of 1,3-D under VIF than under HDPE film, achieving in the soil air space a greater concentration of 1,3-D and CP under VIF than HDPE film over a 14-day sampling period (Ajwa *et al.*, 2002). Finally drip fumigation, combining soil irrigation and chemical fumigation will increase the integrated adoption of short periods of soil solarization (2-3 weeks), when climatically possible (Katan, 2000). As a result, a further reduction of chemical rates and negative side effects can be expected and further investigated.

AKNOWLEDGEMENTS

Work supported by a grant from Italian Ministry for Environment and Territory – Rome, Italy.

REFERENCES

Ajwa H; Trout T; Mueller J; Wilhelm S; Nelson S; Soppe R; Shatley D (2002). Application of alternative fumigants through drip irrigation systems. *Journal of Phytopathology*, in press.

Bell C H; Price N; Chakrabarti B (1996). *The methyl bromide issue. John Wiley and Sons*: New York.

Ben-Yephet Y; Frank Z R (1985). Effect of soil structure on penetration by metham-sodium and of temperature on concentrations required to kill soilborne pathogens. *Phytopathology*, **75**, 403-406.

Gan J; Yates S R; Wang D; Ernst F F (1998). Effect of application methods on 1,3-dichloropropene volatilization from soil under controlled conditions. *J. Environ. Quality* **27**, 432-438.

Gullino M L; Minuto A; Gilardi G; Garibaldi A; Ajwa H; Duafala T (2002a). Efficacy of preplant soil fumigation with chloropicrin for tomato production in Italy. *Crop Protection*, in press.

Gullino M L; Minuto A; Garibaldi A (2002b). Soil fumigation with chloropicrin in Italy: experimental results on melon, eggplant and tomato. *Med. Fac. Landbouww. Rijksuniv. Gent*, in press.

Katan J (2000). Soil and substrate disinfestation as influenced by new technologies and constraints. *Acta Horticulturae*, **532**, 29-35.

McGovern R J; Vavrina C S; Noling J W; Datnoff L A; Yonce H D (1998). Evaluation of application methods of metham sodium for management of fusarium crown and root rot in tomato in southwest Florida. *Plant Disease*, **82**, 919-923.

Minuto A; Gilardi G; Gullino M L; Garibaldi A (2000a). Combination of soil solarization and dazomet against soilborne pathogens of glasshouse-grown basil, tomato and lettuce. *Acta Horticulturae*, **532**, 165-170.

Minuto A; Pome' A; Gullino M L; Garibaldi A (2000b). Lotta al marciume basale su gerbera con l'uso di fumiganti. *Colture Protette*, **29** (2), 109-112.

Minuto A; Gilardi G; Bacci L; Titone P; Gullino M L (2000c). Application of chloropicrin + 1,3 dichloropropene through soil injection in Northern Italy. In: *Proc. Ann. Int. Conf. Methyl Bromide Alternatives and Emission Reduction (Orlando - Fl)*, 43-1, 43-3.

Roberts P A; Magyuarosy A C; Matthews W C; May D M (1988). Effects of metham-sodium applied by drip irrigation on root-knot nematodes, *Pythium ultimum* and *Fusarium* spp. in soil and on carrot and tomato roots. Plant Disease, **72**, 213-221.

Smelt J H; Leistra M (1974). Soil fumigation with dichloropropene and metham-sodium: Effect of soil cultivations on dose patterns. *Pesticide Science*, **30**, 419-428.

Novel pesticides for slug and snail control in horticulture

I Schüder, G Port
University of Newcastle, School of Biology, Ridley Building, Newcastle upon Tyne, NE1 7RU, UK
Email: Ingo.Schueder@ncl.ac.uk

J Bennison
ADAS Boxworth, Cambridge, CB3 8NN, UK

ABSTRACT

Slugs and snails cause costly damage to ornamental plants. We are investigating ways to: (1) Reduce the plant damage on commercial nurseries growing hardy ornamentals; (2) Improve plant quality, and (3) Use ecologically more sustainable products to meet customer demands. Ten products were screened in the laboratory, using the most abundant slug and snail species occurring on ornamental nurseries, *Deroceras panormitanum* and *Oxyloma pfeifferi* respectively. The bioassays included horticultural mattings, metal foils, mulches, minerals and fertilisers. Five products were then tested in a small-scale field trial and finally one copper-impregnated matting was evaluated under commercial conditions. Copper-impregnated mattings, copper foil, ureaformaldehyde, cinnamamide and garlic concentrates proved to be most effective at reducing mollusc damage. However, practicality of application, cost:benefit ratio of the products, customer acceptance and costs for registration will determine the products' success in the horticultural industry. Future research on the life cycle of the slug and snail species and their behaviour will help to optimise the integrated control strategy.

INTRODUCTION

Slugs and snails are common pests in UK horticulture and agriculture. Growers and farmers are experiencing difficulties in controlling these pests on a wide range of crops with conventional molluscicide pellets.

The development of alternative, integrated, more effective control measures would reduce plant losses and the use of chemical molluscicides, improve plant quality and offer a sustainable strategy for controlling slug and snail pests. As more growers and farmers are now adopting Integrated Pest Management (IPM) techniques, the development of an IPM strategy will satisfy increasing market demands for plants and crops grown with environmentally-responsible production methods.

Investigations carried out by ADAS in 2000 established two mollusc species as the most common on hardy ornamental nurseries, the snail *Oxyloma pfeifferi* and the slug *Deroceras panormitanum*.

METHODS

Slugs and snails were collected from the field and from nurseries respectively. Ten products were investigated as barriers against *D. panormitanum* and *O. pfeifferi*. Replicated laboratory bioassays were carried out at 15°C and a 16:8 Light:Dark cycle.

The treatments included:

- Mypex ® matting (MYP), which will be referred to as 'conventional matting'
- Tex-R (SpinOut) ® matting (TEX) which is currently used for landscaping and will be referred to as 'copper-impregnated matting'
- aluminium (AL) and copper (CU) foils
- solutions or dispersions of cinnamamide (CIN) (1% w/w with 1% non-ionic surfactant), Croptex Fungex ® (CF) (copper ammonium carbonate, 0.625%), garlic concentrate (GA) (2.5 and 5%), ureaformaldehyde (UF) (10% dilution of resin containing 60-75% ureaformaldehyde and 1-3% formaldehyde)
- SnailBan ® minerals (SB)
- mulch (MU)

Damp compost was used as a control (CT).

The above abbreviations (in brackets) will be used in the graphs.

Barrier against horizontal movement by snails

The snails weighed 60-130 mg and were starved for 24h prior to the experiment. The products were applied to a 3 cm wide strip in the middle of a circular dish (16 cm diameter). Thirty ml of solutions were applied; mulch and mineral were applied to a depth of ca. 5 mm. One snail was placed on one side of the barrier, a 4 cm^2 piece of Chinese Cabbage leaf on the other. The percentage of leaf area damaged was recorded daily for seven days. There were 20 replicates.

Barrier against vertical movement by slugs

One slug was buried in a transparent plastic beaker (300 ml, 6 cm diameter) under a 2 cm layer of damp compost. Eight ml of the solutions and approximately 5mm of mulch and mineral products were applied to the surface of the compost. Four cm^2 pieces of Chinese cabbage were placed on the surface. The percentage of leaf damaged was recorded for seven days. There were 20 replicates.

Small-scale field trial

The experiment took place in a polythene tunnel. Each circular plot (40 cm diameter) had four small potted Chinese cabbage plants in the centre and was infested with five adult slugs at the edge of the plot. The plots were covered with the conventional matting and surrounded by a vertical barrier painted with Fluon ® to prevent slugs escaping. Products were applied to the surface of pots (cinnamamide, copper ammonium carbonate, garlic and ureaformaldehyde) or the whole plot surface was covered with the copper-impregnated instead of the conventional matting. The number of damaged leaves was recorded for four weeks. Plants were watered by sub-irrigation. There were 10 replicates.

Large-scale field trial

An area planted with clover with a very large slug population was used. Square pieces of horticultural matting (1.4 m^2) were placed on the ground. The copper-impregnated matting was compared with the conventional matting. Thirty six potted plants, six plants each of Hosta, Choisya, Impatiens, Geranium, Marigold and Chinese cabbage were placed on the matting. The number of slugs on the plot and the damage caused to the plants was assessed every 14 days for eight weeks. There were 10 replicates.

RESULTS AND DISCUSSION

Barrier against horizontal movement

The two most effective products for repelling snails were ureaformaldehyde and copper foil, with 90 and 80% barrier efficacy respectively. Garlic caused the highest mortality rate (30%) of *O. pfeifferi.*

All products except the conventional matting and aluminium foil reduced the damage significantly (N = 20, Kruskal-Wallis-Test: $P < 0.001$, Wilcoxon & Wilcox statistics for posthoc), ranging from between 66% reduction with the copper-impregnated matting and nearly 100% with ureaformaldehyde (Fig. 1).

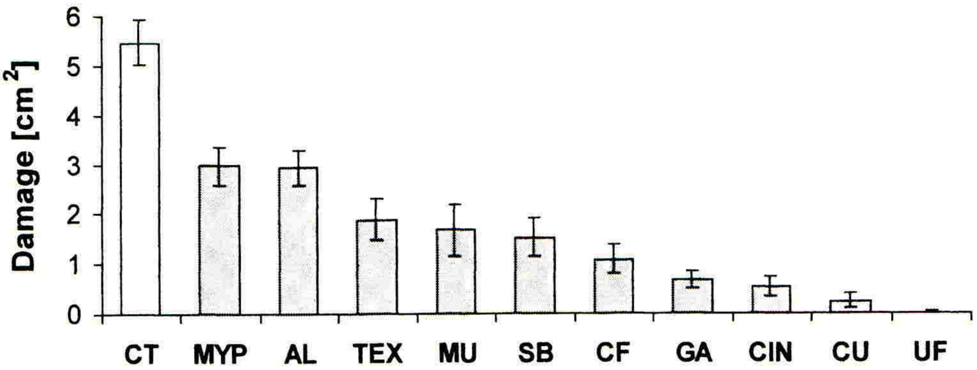


Fig. 1: Accumulated leaf damage (± SE) by *O. pfeifferi* after seven days
Abbreviations of treatment names as stated in Methods.

Barrier against vertical movement

All products had significant effects as barriers against vertical movements of *D. panormitanum*. The garlic concentrate caused the highest mortality rate (95%).

All products significantly reduced the damage (N = 20, Kruskal-Wallis-Test: $P < 0.001$, Wilcoxon & Wilcox statistics for posthoc, Fig. 2). The success varied between 62 % reduction of damage with the copper-impregnated matting and 100% reduction with garlic and ureaformaldehyde.

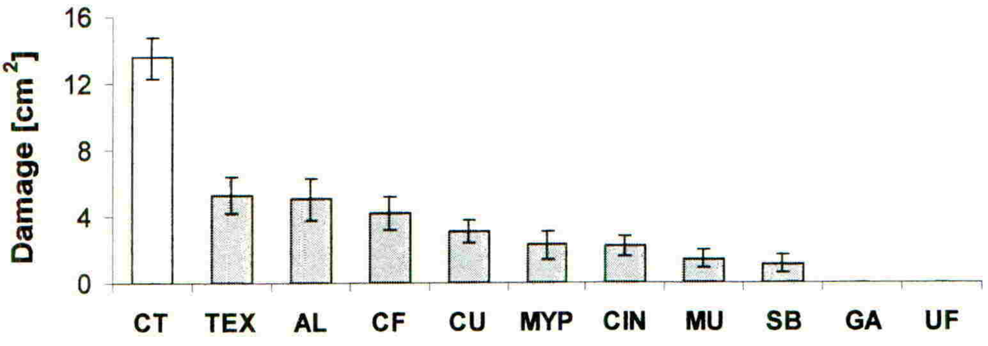


Fig. 2: Accumulated leaf damage by *D. panormitanum* (± SE) after 7 days
Abbreviations of treatment names as stated in Methods.

From the laboratory bioassays it can be concluded that a combination of effects lead to the reduction in damage. Effects can be:

- Repellency, causing a chemical barrier effect
- Physical barrier effect
- Irritation
- Mortality
- Antifeedant effect
- Any combination of the five

The effectiveness of repellents depends on the width of the barrier, i.e. on the barrier width:body size ratio. For smaller species, such as *O. pfeifferi,* treating a pot surface and thereby creating a barrier only a few cm wide should be sufficient. For larger species this might not be sufficient and products with antifeedant or irritating effects or treating larger areas might be more effective.

Irritation can cause a reduction in activity, for example by intense mucus production, which will lead to dehydration and may finally cause the death of the animal. The general effect of copper, component of the copper ammonium carbonate and the copper-impregnated mattings, on slugs and snails is well known, e.g. Miles *et al.* (1931) showed that solid copper sulphate kills slugs such as *Tandonia* (*Milax*) *sowerbyi*. The effect of the matting is very specific. The copper is bound to a latex matrix and only released at a pH of 5 or below. We presume that small amounts of copper are released from the matrix when it is in direct contact with the foot of the slug or snail. The foot of the slug has already been described as the site of copper uptake (Ryder & Bowen 1977).

Cinnamamide has already been described as a potential seed coating to protect against feeding damage of the field slug *Deroceras reticulatum* on wheat seeds (Watkins *et al.*, 1996). However, the results presented here show that the product has the potential for other methods of application.

Small-scale field trial

The plots treated with the five products had significantly less damage than the control (N =10, Anova: F= 7.62, P < 0.001, see fig. 3). The copper-impregnated matting was the most successful product with 94% fewer damaged leaves than the control. This indicates that treating larger areas might be more effective than treating small areas such as just the surface of pots. This is particularly true where sub-irrigation is not possible and overhead irrigation may leach out any pesticide solution from the pots.

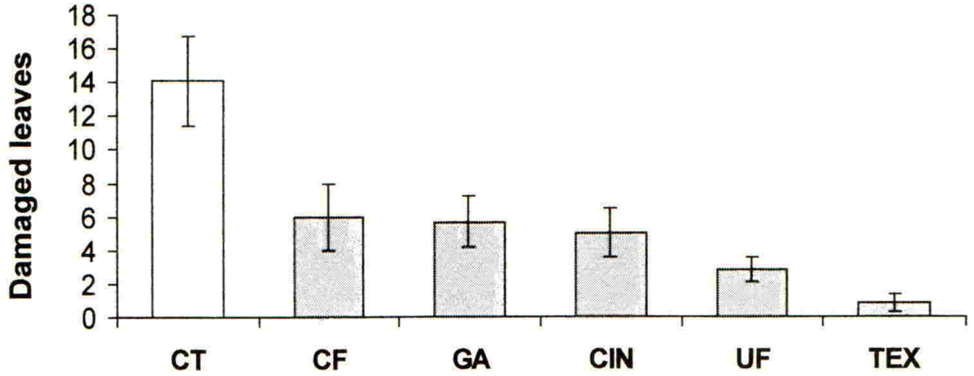


Fig. 3: Leaf damage caused by five *D. panormitanum* to four Chinese Cabbage plants in four weeks
Abbreviations of treatment names as stated in Methods.

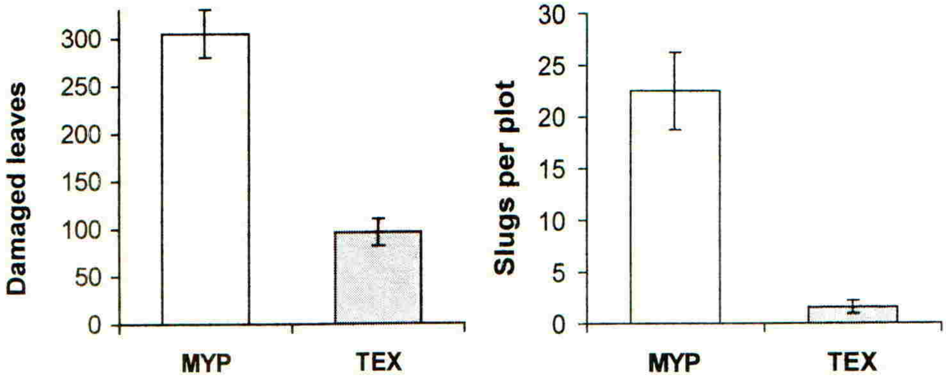
In this trial the soluble products were used at very high concentrations, which might not be commercially viable.

Large-scale field trial

On a commercial scale the copper-impregnated matting seems to be the best option at present.

In comparison with the conventional matting the slug abundance on the plots with copper-impregnated matting was reduced significantly (N =10, T-Test: P< 0.01, fig 4A.). Slug numbers were reduced by 93 %.

As slugs are nocturnal, the numbers found by searching during the day were relatively low. However, the sampling technique provides a fair comparison between the two products. It is very likely that at night the slugs migrated onto the plots from the surrounding clover. Another indication of slug abundance is the number of eggs, which were mostly found under pots on the conventional matting.



A B

Fig. 4: A. Number of slugs and B. damaged leaves found per plot on conventional (MYP) and copper-impregnated (TEX) matting after eight weeks.

Plant damage was also significantly reduced (N =10, U-Test: $P < 0.001$, fig 4 B). The number of damaged leaves on the copper-impregnated matting was reduced by 68 % compared with that on the conventional matting.

Future work with selected products will evaluate their efficacy at lower concentrations, against both adults and eggs. This will help to find the optimum cost:benefit ratio for each product.

The copper-impregnated matting will be also evaluated against *O. pfeifferi,* using similar methods to those described for slugs.

Aspects of population dynamics, data on the behavioural response of the animals to products, the use of parasitic nematodes as biological control agents and changes in horticultural practice, especially irrigation regimes, will be incorporated in the final integrated control strategy.

ACKNOWLEDGEMENTS

This work was funded by the Horticultural Development Council (HDC) and the Department for Environment, Food & Rural Affairs (DEFRA). We thank Fargro Ltd. and Ecospray Ltd. for supplying us with horticultural mattings and the garlic concentrate respectively.

REFERENCES

Miles H W; Wood J; Thomas I (1931). On the ecology and control of slugs. *Annals of Applied Biology* **18**, 370-400.

Ryder T A; Bowen I D (1977). The slug foot as a site of uptake of copper molluscicide. *Journal of Invertebrate Pathology* **30**, 381-386.

Watkins R W; Mosson H J; Gurney J E; Cowan D P; Edwards J P (1996). Cinnamic acid derivatives: Novel repellent seed dressings for the protection of wheat seed against damage by the field slug, *Deroceras reticulatum*. *Crop-Protection* **15 (1)**, 77-83.

A comparison of a chemical injection field sprayer with a conventional one

A G Hodgekiss
Syngenta, Hampstead Lane, Yalding, Maidstone, Kent, ME18 6HN, UK
Email; *tony.hodgekiss@syngenta.com*

ABSTRACT

A two-year comparison study with a conventional field sprayer showed that a chemical injection sprayer was capable of giving reliable and accurate application, with a number of confirmed advantages over the conventional sprayer. Some unattractive features of proprietary chemical injection sprayers were shown possible to overcome by the modifications made to the test sprayer. The sprayer showed potential benefits in both crop and environmental management. This study indicated the areas in which agrochemical and sprayer manufacturers would need to cooperate, if this type of sprayer was to become more widely used.

INTRODUCTION

Conventional sprayers require the correct amount of chemical to be added to the water in the tank and mixed before spraying commences. Chemical injection (CI) sprayers have only water in the tank and the chemical is metered into the water flow as it passes to the spray nozzles. This type of sprayer is available as a commercially produced item, but is not commonly used for field crop spraying in Europe. The concept offers a number of distinct advantages to users and the environment, but also apparent disadvantages, which currently deter potential buyers.

Potential advantages include; much-reduced rinsings, better environmental controls, more accurate application, no tank residues/ foam/ a.i.-hydrolysis, less chemical wastage, faster and more flexible field operation. Apparent disadvantages include; the need for 'secondary packaging' on the sprayer (Figures 1 & 2), a pack-cleaning method is not clear to users, extra purchase costs (where the added value is not clear) and the perception of complexity.

This project compared the performance of tractor-mounted field sprayers, both of 1000 litre tank capacity and 12metre boom width. One sprayer was conventional, whilst the other was fitted with a chemical injection system. The project purpose was primarily to gain information, not for sprayer development.

Objectives of the project

- To check if the advantages are real and can be quantified
- To learn if any disadvantages can be overcome
- To check the financial value of any advantages (Where do the extra costs of the chemical injection system become viable?)

- To understand what response may be needed from the agrochemical industry, especially for packs and formulations

Factors for and against the chemical injection concept for different interest groups

The range of advantages and apparent disadvantages of the chemical injection concept, as various interest groups may perceive it are outlined in the following table.

Table 1. Summary of apparent advantages (+) and disadvantages (-) of chemical injection

Feature	User	Environ	Ag. Chem. Manufact.	Ag.Chem. Distrib.
No tank residues or washings for disposal	+	+		
Tank mixing unnecessary	+	+?		
No tank settlement risk	+		+	
Difficult mixes possible	+	+?	+?	+
No foaming risk	+	+	+	
No hydrolysis in tank if delayed	+		+	
"Overfill" not needed for unknown area	+	+		
No chemical spillage from tank overfilling	+	+		
Chemical transfer via closed couplings	+	+		
Less danger than tank full of dilute spray?	+	+		
Empty containers rinsed cleaner for disposal	+	+		
Bigger spray windows as less delay	+	+	+	+
More flexible application rate & volume	+	+	+	+
Application rate change-on-move with no nozzle changes (=less sizes?)	+	+	+?	
Faster more flexible field operations	+	+	+	+?
Higher work rate (x1.5?)	+			
Saves money on tank cleaners	+	+	-	-
Basis of full easy data recording; e.g. barcodes on containers	+	+	+	+
Basis of full precision agriculture/GPS	+	+	+	
No measurement of area or mixing calculation needed	+	+	+?	+?
Supports against pesticide tax?	+	?	+	+
Present "secondary containers" not good	-	-		
Present pack disposal route unclear	-		-	-
Special pack development necessary?		-	-	
Some formulations may not be usable?	-	?	-	-
CI adds cost to basic sprayer	-	-?		
Basic sprayer costs can be reduced	+			
CI items can be moved to a new sprayer	+	+		
Perception of complexity and "high-tech"	-	-	-	-

It is possible to overcome some of these disadvantages by modification of typical CI components. Rather than using secondary containers, standard agrochemical containers can be incorporated directly, via suitable couplings (Figures 3 & 4). The issues of rinsing and disposal can also be addressed (Figure 5).

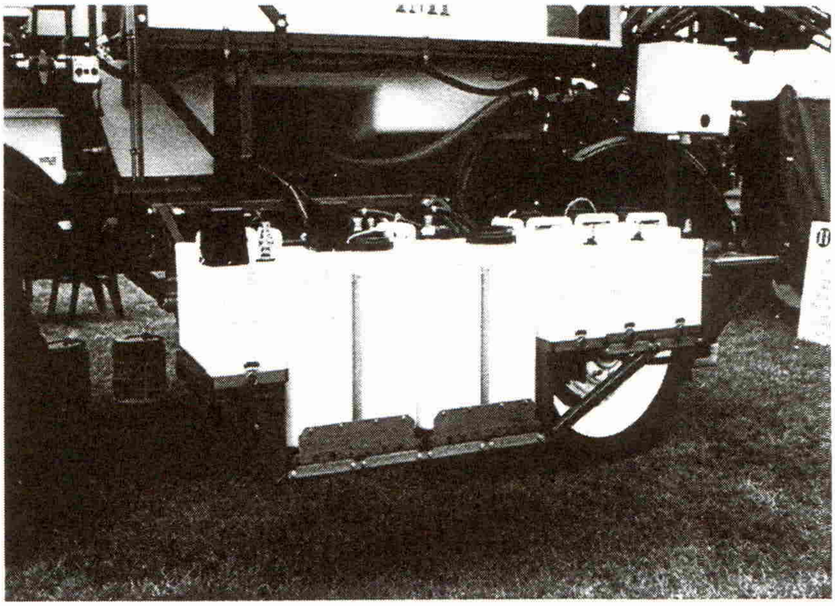


Figure 1. Typical chemical injection sprayer with secondary containers, lowered to the filling position, each for a different chemical.

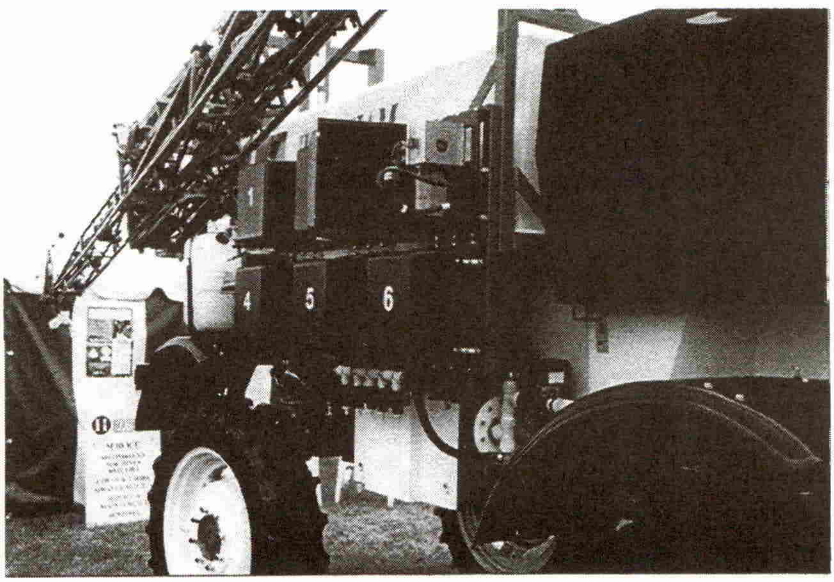


Figure 2. Metering pumps, each one coupled to a secondary container.

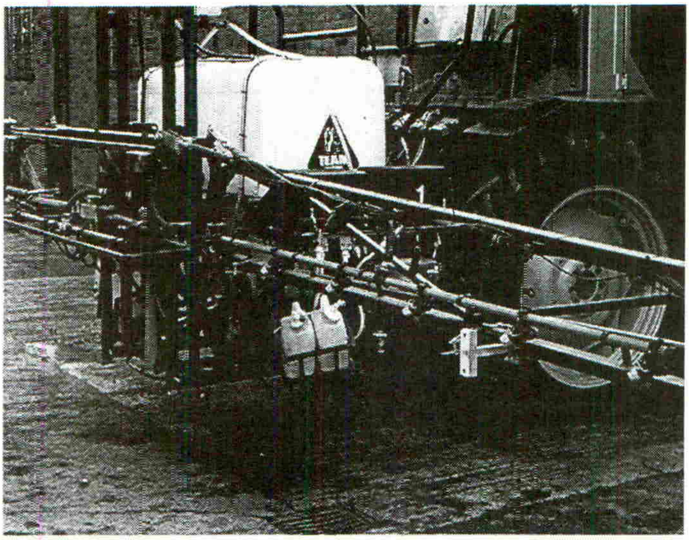


Figure 3. A general view showing the use of standard agrochemical containers on an experimental Syngenta CI sprayer.

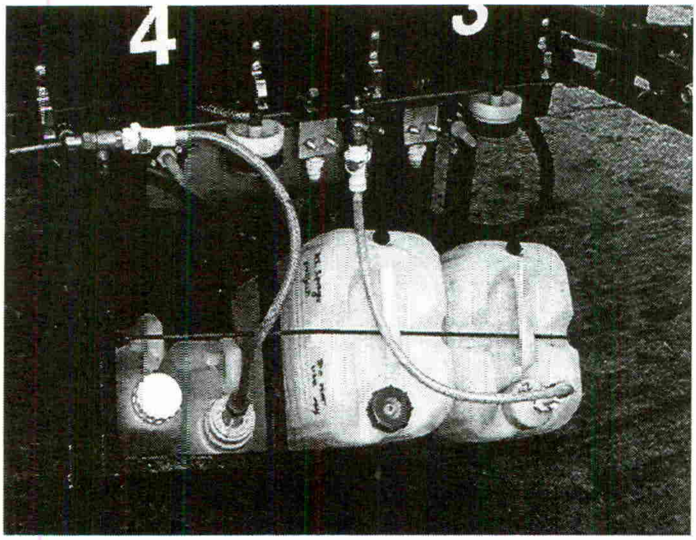


Figure 4. Detail showing two types of standard containers in use and couplings to the pumps

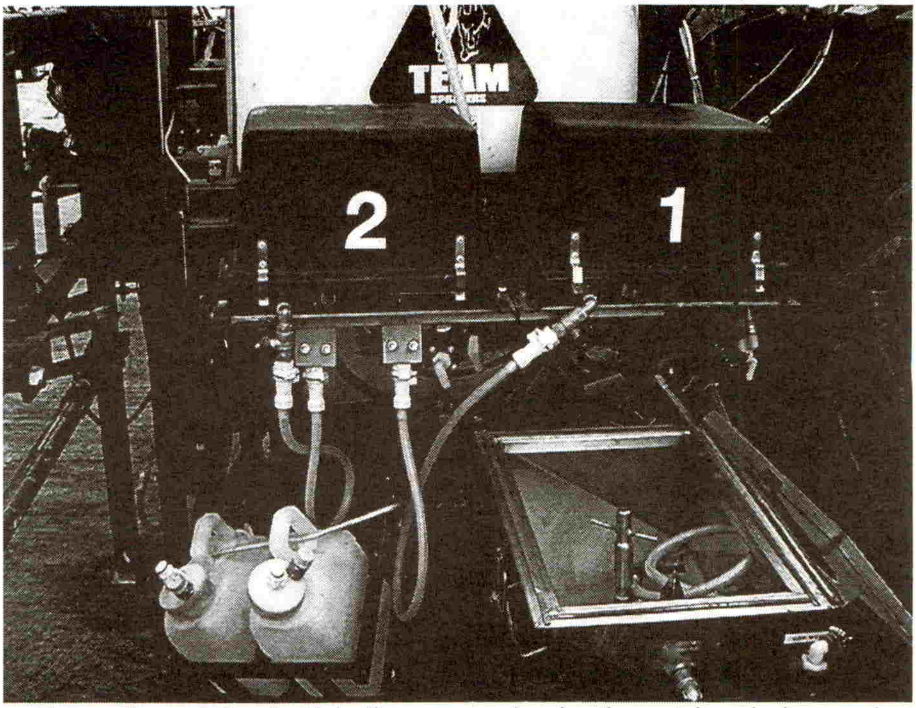


Figure 5. Experimental chemical injection sprayer, showing the container rinsing nozzle and rinsings disposal hopper

RESULTS AND CONCLUSIONS

In use, the following was noted for the chemical injection sprayer;

- Reliable and accurate with liquids (Note. WG's have not been tested yet).
- Not over-complex for the operator to use.
- Significant advantages were confirmed, e.g. 7 –10 times faster rinsing and requiring 2 – 4 times less water.
- Some 'disadvantages' were overcome – e.g. by the use of standard packs and a rinsing system.
- Standard 'single use' containers can be used.
- Simple low-cost container couplings are acceptable, but could be improved.
- There is a low understanding of the chemical injection concept and possible benefits by farmers, the agricultural trade and the agrochemical industry.

Financial value comparisons were not achieved in this project, owing to the type of farm on which the trial was carried out. Better ways need to be devised for this in any future trials. The metering principle was found likely to meet farmer's future needs in terms of:

- Increased workrate and safer handling
- Reduced costs

- Better environmental responsibility and safety

Feedback from a presentation and survey with farmers and the agricultural trade, indicate that they would consider the features of a chemical injection sprayer important to their businesses within 5 years.

From the results obtained above, it can be concluded that the likely responses needed by agrochemical and sprayer manufacturers will be closer cooperation leading to;

- Joint projects to better understand the value and benefits of chemical injection sprayers in farming.
- The development of an industry-standard container range/size/shape
- The agreement on standard couplings for the container – to - sprayer connection
- The agreement on the chemical property limits of formulations, e.g. liquid viscosity limits, WG's dispersibility times
- A possible agreement on alternative manufacturing specifications for chemical injection sprayers? For example, no induction bowl, smaller pumps and tank cleaning parts omitted. These should lead to some injection sprayer costs being reduced?
- New 'legislation' for operator training and annual sprayer testing to suit chemical injection sprayers.

ACKNOWLEDGEMENTS

This project owes thanks to Team Sprayers, Ely, UK and John Handbury of LH Technologies, Aalborg, Denmark, for supply and assistance with the sprayer equipment. Also to Colin Peters, Mark Gardner and Andrew Hunt of IACR Rothamstead who used the sprayers on their farms and provided the comparative data.