Evaluation of mandipropamid for the control of potato late blight in Northern Ireland

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SUMMARY
Field trials in Northern Ireland over the years 2005-2009 compared potato late blight control by a standard fungicide programme consisting of two applications of metalaxyl-M + mancozeb followed by eight applications of fluazinam with programmes which included mandipropamid used either alone or tank-mixed with fluazinam. In 2005-2008, mandipropamid was applied after two applications of metalaxyl-M + mancozeb at various positions within the spray programmes. In 2009, mandipropamid was used early season in place of metalaxyl-M + mancozeb (sprays 1 and 2) and then again, after fluazinam, for sprays 4 and 5. Treatments were applied to the susceptible maincrop cultivar Up-to-Date at 7-day intervals. A severe, uniform infection pressure was provided by inoculating unsprayed spreader rows with recent Northern Ireland isolates of *Phytophthora infestans* (50/50 phenylamide-resistant/-sensitive), which included isolates of phenylamide-resistant A2 genotypes in 2008 and 2009.

Programmes including mandipropamid gave excellent foliage blight control which was consistently better than that achieved by the standard programme. In most years, plots receiving programmes including mandipropamid tank-mixed with fluazinam had less foliage blight than those receiving mandipropamid alone, although differences were not significant. Programmes containing mandipropamid tank-mixed with fluazinam tended to result in less tuber blight than both the standard programme and those containing mandipropamid alone and also achieved the greatest marketable yields. Used early season, mandipropamid proved an effective alternative to metalaxyl-M + mancozeb, suitable for use where phenylamide-resistant strains of *P. infestans* predominate. In regions such as Northern Ireland, where there is a high risk of tuber blight, mandipropamid should be used tank-mixed with fluazinam.

KEYWORDS
Phytophthora infestans, late blight control

INTRODUCTION
In Northern Ireland, weather conditions favour late blight, caused by the oomycete pathogen

Phytophthora infestans, in most years and the vast majority of potato cultivars planted have little or no blight resistance and therefore depend on fungicidal protection to survive blight attack. Crops generally receive about 10 fungicide applications, but may receive 15 or more in some years. Phenylamide-resistant strains of *P. infestans* were first identified in Northern Ireland in 1981 (Cooke, 1981). Their incidence increased during the 1980s and by 1988 they were detected in 90% of isolates, but in the early 1990s anti-resistance strategies were adopted and these proved effective up to 2006 (Cooke & Little, 2006). However, since 2007, new, aggressive phenylamide-resistant genotypes of *P. infestans*, notably 'Blue 13' (13_A2), have appeared and come to dominate the population (Kildea *et al.*, 2010), apparently as a consequence of their fitness rather than of selection by usage of phenylamide fungicides. This has increased the need for non-phenylamide fungicides with either systemic or translaminar activity.

The Syngenta fungicide, mandipropamid (Huggenberger & Knaufbeiter, 2007, 2008) belongs to the CAA (Carboxylic Acid Amide) fungicide group and was first registered in the UK in 2007 as 'Revus' for the control of potato late blight. It is specifically active against Oomycete pathogens and has a high affinity for the wax layer on leaf surfaces. After absorption into the wax layer, it gradually moves into the plant tissues so that it exhibits translaminar activity. To date, no strains of *P. infestans* resistant to CAA fungicides have been identified and mandipropamid is equally active against phenylamide-resistant and -sensitive strains of the pathogen.

As described previously (Cooke & Little, 2007), fungicide evaluation trials are conducted annually in Belfast, Northern Ireland under conditions of extreme blight pressure. The trials are planted with the maincrop cultivar Up-to-Date, which is very susceptible to both foliar and tuber blight, and are inoculated with recent Northern Ireland *P. infestans* isolates, collected for fungicide resistance and population studies. Here results of trials with mandipropamid formulations conducted between 2005 and 2009 are reported.

MATERIALS AND METHODS

Tubers cv. Up-to-Date were planted in May (or June in 2009) of each year (Table 1) at AFBI Headquarters, Newforge, Belfast, Northern Ireland in fully randomised blocks with five replicate plots per treatment. Each plot (2.8 x 3.0 m^2) contained four rows of ten tubers. Pairs of rows of unsprayed plants adjacent to each treated plot served as an infection source and were inoculated in July of each year (Table 1). In these rows, two leaves on every fourth plant were inoculated with phenylamide-resistant and phenylamide-sensitive isolates of *P. infestans*, 50% of leaves being inoculated with a mixture of three or more phenylamide-resistant isolates and 50% with a mixture of three or more phenylamide-sensitive isolates. In 2005-2007, the isolates used were all of the A1 mating type, but in 2008 and 2009, 25% of leaves were inoculated with phenylamide-resistant A2 genotypes including Blue 13. All isolates originated from Northern Ireland potato crops and were obtained within the last three years. When required, plots were misted after inoculation, usually for 2-3 h daily at dawn and dusk to encourage spread of blight.

Table 1. *Field trials for the control of potato blight, 2005-2009: dates of field operations*

Year	Planting date	Fungicide application dates		Inoculation	Desiccation	Harvest
		First	Last			
2005	13 May	23 June	26 August	7 July	1 September	27 September
2006	25 May	28 June	30 August	10 July	5 September	9 October
2007	2 May	20 June	21 August	3 July	28 August	12 September
2008	6 May	25 June	27 August	8, 21 July	29 August	29 September
2009	6 June	30 June	1 September	16 July	4, 9 September	30 September

Fungicide formulations were applied at manufacturers' recommended rates in *c.* 300 litres water/ha using a Cooper Pegler CP15 knapsack sprayer. The first applications were made before inoculation in the third or fourth week of June of each year (Table 1) and ten treatments were applied at 7-day intervals (as far as possible) until the end of August. In each year, the standard programme comprised two sprays of metalaxyl-M + mancozeb ('Fubol Gold WG', Syngenta) followed by eight sprays of fluazinam ('Shirlan', Syngenta, applied at 300 ml/ha, 2005-6 and 400 ml/ha, 2007-9), while the comparison programmes included mandipropamid (subsequently registered as 'Revus', Syngenta) either alone or tank-mixed with fluazinam. In 2009, fluopicolide + propamocarb HCl ('Infinito', Bayer) was included in one of the comparison programmes. Details of programmes and rates are shown in Table 2.

Table 2. *Fungicide programmes evaluated for the control of potato blight, 2005-2009*

Number of applications of active ingredients (g a.i./ha)[a]			Abbreviation[b]	Year				
Early season	Mid-season	Late season		'05	'06	'07	'08	'09
2 x metalaxyl-M + mancozeb (76 + 1216)	5 x fluazinam (150)	3 x fluazinam (150)	F/S_L	√	√			
2 x metalaxyl-M + mancozeb (76 + 1216)	5 x fluazinam (200)	3 x fluazinam (200)	F/S			√	√	√
2 x metalaxyl-M + mancozeb (76 + 1216)	5 x mandipropamid (150)	3 x fluazinam (150)	F/R/S	√				
2 x metalaxyl-M + mancozeb (76 + 1216)	5 x mandipropamid (150)	3 x mandipropamid (150)	F/R		√			
2 x metalaxyl-M + mancozeb (76 + 1216)	2 x mandipropamid (150) 1 x fluazinam (200) 2 x mandipropamid (150)	3 x fluazinam (200)	F/R/S/R/S			√	√	
2 x metalaxyl-M + mancozeb (76 + 1216)	2 x mandipropamid + fluazinam (125 + 100) 1 x fluazinam (200) 2 x mandipropamid + fluazinam (125 + 100)	3 x fluazinam (200)	F/R+S/S			√	√	
2 x mandipropamid (150)	1 x fluazinam (200) 2 x mandipropamid (150) 2 x fluazinam (200)	3 x fluazinam (200)	R/S/R/S					√
2 x mandipropamid + fluazinam (125 + 100)	1 x fluazinam (200) 2 x mandipropamid + fluazinam (125 + 100) 2 x fluazinam (200)	3 x fluazinam (200)	R+S/S/R+S/S					√
2 x fluopicolide + propamocarb HCl (100 + 1000)	1 x fluazinam (200) 2 x fluopicolide + propamocarb HCl (100 + 1000) 2 x fluazinam (200)	3 x fluazinam (200)	I/S/I/S					√

[a] *all applications were made at approx. 7-d intervals;* [b] *used in Figures 1 and 2, F = 'Fubol Gold WG'; S = 'Shirlan'; R = 'Revus'; I = 'Infinito'*

Foliage blight was assessed on each drill of each sprayed plot twice weekly from the time that blight was first seen in them until haulm destruction, using the ADAS key (Anonymous, 1976) with added 0.01% and 10% categories. Plots were desiccated with diquat dibromide ('Reglone', Syngenta) in late August or early September within 7 days of the final fungicide application and tubers harvested

Presentation

in September or October, at least two (and usually three) weeks after desiccation. The yield from each plot was graded and recorded; the number and weight of blighted, soft-rotted tubers was recorded and they were then discarded. The number and weight of firm blighted tubers >35 mm was assessed (and diseased tubers discarded) in November-December in each year. The remaining healthy tubers were stored and re-assessed in late January-February, after which the final marketable yield was determined.

All data were subjected to analyses of variance with angular transformations of means used for percentage data. In each trial, the Area Under the Disease Progress Curve (AUDPC) was calculated from the untransformed percentage foliage blight for each plot and compared by analysis of variance.

RESULTS

Foliage blight development is shown in Figures 1 and 2. The data in Table 3 should be used for statistical comparisons.

Table 3. *Field trials for the control of potato blight, 2005-2009: final foliage blight, area under the foliar disease progress curve, tuber blight and yield assessments*

Year/Treatment[a]	Final foliar blight (% ang. trans.[b])	AUDPC[c]	Tuber blight (% ang. trans.[b] by number)	Total yield >35 mm (kg/plot)	Marketable yield (kg/plot)
2005					
F/S_L	25.9	254	7.1	59.4	53.8
F/R/S	11.1	40	7.9	62.5	56.1
L.S.D. (*P*<0.05)	7.52	135.7	2.90	n/a	n/a
2006					
F/S_L	32.2	236	21.7	44.6	35.7
F/R	24.1	143	31.3	42.0	27.4
L.S.D. (*P*<0.05)	5.65	95.5	n/a	3.16	6.41
2007					
F/S	32.8	471	8.0	52.3	49.2
F/R/S/R/S	14.2	120	13.8	53.4	47.6
F/R+S/S	10.6	57	9.4	55.2	51.7
L.S.D. (*P*<0.05)	9.71	292.1	4.37	n/a	n/a
2008					
F/S	27.6	130	27.1	46.6	33.2
F/R/S/R/S	12.7	30	26.6	47.5	34.2
F/R+S/S	10.5	19	24.5	47.1	35.4
L.S.D. (*P*<0.05)	10.82	102.0	n/a	n/a	n/a
2009					
F/S	20.1	45	7.6	35.5	33.0
R/S/R/S	14.0	18	4.5	35.9	34.0
R+S/S/R+S/S	10.2	4	7.6	41.0	38.4
I/S/I/S	20.7	120	6.7	38.2	35.8
L.S.D. (*P*<0.05)	4.60	58.0	n/a	n/a	n/a

[a] *treatments as defined in Table 1; F = 'Fubol Gold WG'; S = 'Shirlan'; R = 'Revus'; I = 'Infinito'*

[b] *% ang. trans. = angular transformed percentage data;* [c] *Area Under the Disease Progress Curve for foliage blight development*

n/a = not applicable; no significant effect of treatment (P>0.05)

2005 – 2006 TRIALS

In 2005 and 2006, the programmes in which metalaxyl-M + mancozeb was followed by mandipropamid (5 mandipropamid applications followed by 3 x fluazinam in 2005 and 8 mandipropamid applications in 2006) had significantly less foliage blight at the end of the season and lower AUDPC values than the standard programme (Table 3). In 2005, little tuber blight developed and there were no significant differences in terms of either total or marketable yield. In 2006, much more tuber blight developed and although differences in percentage tuber blight were not significant, the marketable yield from plots receiving the programme including mandipropamid was significantly lower than that from the standard; this was associated with losses from tuber blight.

2007 – 2008 TRIALS

In 2007 and 2008, programmes in which applications 3 and 4 and 6 and 7 of the standard programme were substituted with mandipropamid alone or mandipropamid tank-mixed with fluazinam were evaluated (Table 2). In both years, the two programmes including mandipropamid had significantly less foliage blight and lower AUDPC values than the standard (Table 3), with the programme including mandipropamid tank-mixed with fluazinam having the least infection. In 2007, although relatively little tuber blight developed, the programme including mandipropamid alone had significantly more blighted tubers than the standard or the programme containing mandipropamid tank-mixed with fluazinam.

In 2008, much more tuber rotting developed, but there were no significant differences between treatments in terms of tuber blight; assessments were complicated by the presence of many rots caused by pathogens other than *P. infestans*, particularly pink rot caused by *P. erythroseptica*, which developed after plots were waterlogged by very high rainfall during August. In neither 2007 nor 2008, were there significant differences between treatments in terms of yield, although in both years plots receiving the programme including mandipropamid tank-mixed with fluazinam had the greatest marketable yield.

2009 TRIAL

In 2009, the increasing incidence of phenylamide-resistant A2 strains of *P. infestans* prompted evaluation of options in which the two applications of metalaxyl-M + mancozeb at the start of the standard programme were replaced by two applications of either mandipropamid alone, mandipropamid tank-mixed with fluazinam or fluopicolide + propamocarb HCl. In each programme, these were followed by an application of fluazinam and then two more applications of the same products as were used at the start of the programme; all programmes were completed with five applications of fluazinam. Fluopicolide + propamocarb HCl was included at these positions in the spray programme at Syngenta's request to give a direct comparison with mandipropamid, although this is not when its use would normally be recommended. At the final assessments, the two programmes including mandipropamid had significantly less foliage blight than the standard or the programme containing fluopicolide + propamocarb HCl. The fluopicolide + propamocarb HCl programme had the largest AUDPC, which was significantly greater than those of the other three programmes. There were no significant effects of treatment on tuber blight or yield.

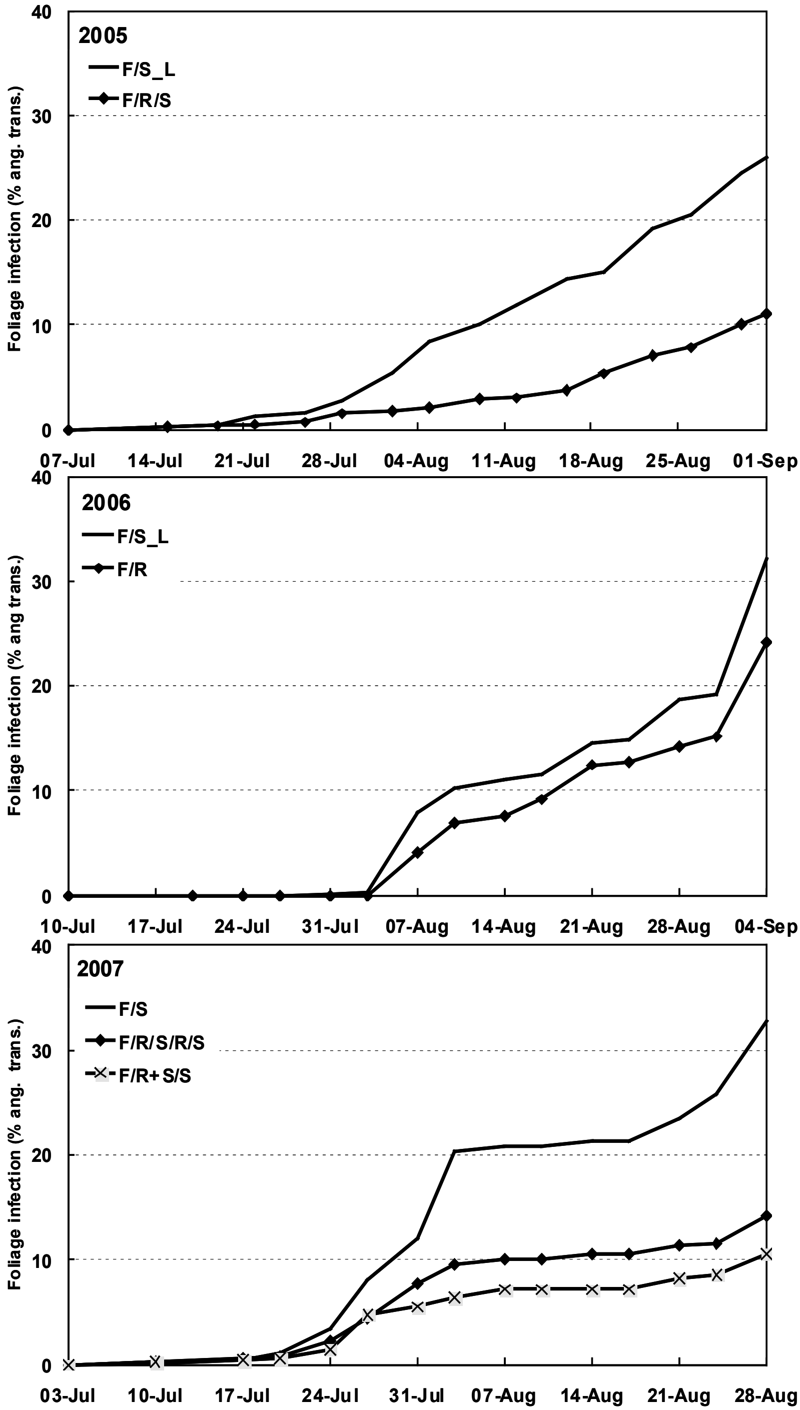

Figure 1. *Foliage blight development in field trials for the control of potato blight, 2005-2007 from the inoculation date until haulm destruction (for abbreviations, see Table 1)*

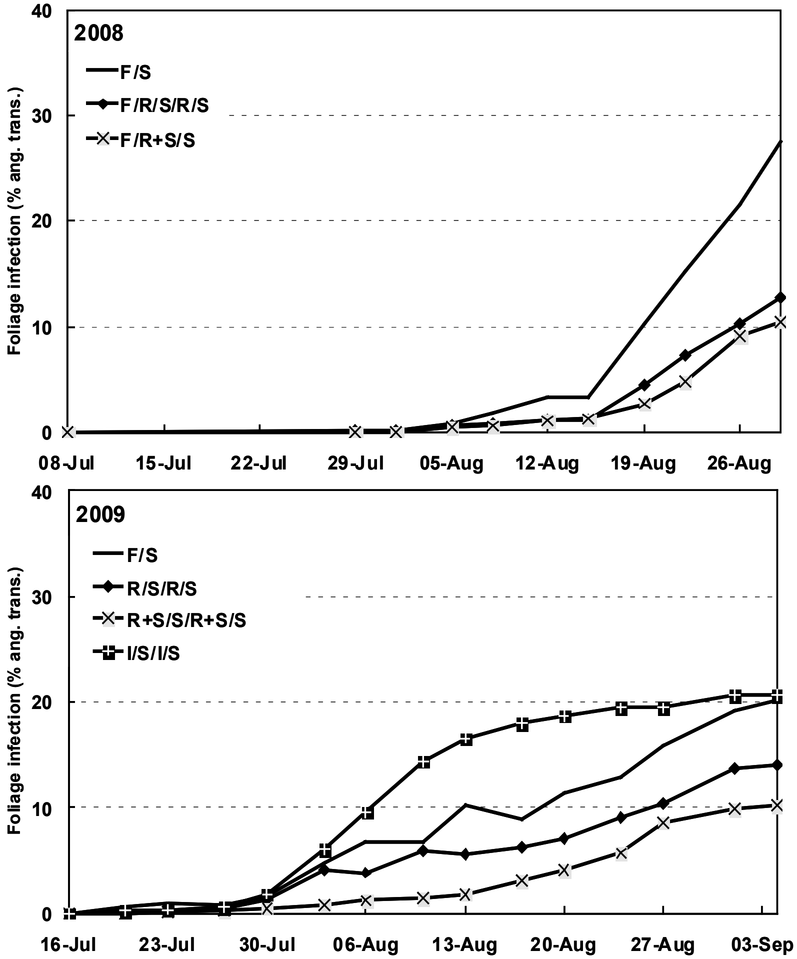

Figure 2. *Foliage blight development in field trials for the control of potato blight, 2008-2009 from the inoculation date until haulm destruction (for abbreviations, see Table 1)*

DISCUSSION

The difficulty of controlling potato late blight in Northern Ireland has been increased since 2005 by the arrival of fit A2 genotypes of *P. infestans* which are also phenylamide-resistant. Mandipropamid provides an alternative to metalaxyl-M, since, although not as systemic, it moves into plant tissue and helps to protect new foliage. In the trials reported here, mandipropamid gave excellent control of foliage blight and consistently out-performed the standard programme even in the trials from 2007 onwards in which fluazinam was applied at the 200 g a.i./ha rate. However, programmes including mandipropamid alone tended to be associated with more tuber blight than the standard programme, whereas programmes including mandipropamid tank-mixed with fluazinam were generally associated with less tuber blight. It was concluded that in regions of high rainfall such as Northern Ireland, where tuber blight is often a problem, mandipropamid should be used in a tank-mix with fluazinam to improve tuber protection.

Using the mandipropamid/fluazinam tank-mix at the start of the spray programme proved to be an effective alternative to metalaxyl-M + mancozeb. Fluopicolide + propamocarb HCl did not perform well when used at this position in the spray programme: previous trials have shown that this product is most effective when used mid-late season when its activity against tuber blight is particularly beneficial (Cooke & Little, 2007).

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