Final Report

Evaluation of the efficacy and timing of molluscicide treatments in potato crops 2015 & 2016

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Contents

1. SUMMARY

Issues regarding the loss of effective molluscicides (e.g. methiocarb), and threat of revocation due to metaldehyde contamination of drinking water catchments, suggest that information on the comparative efficacy of other available options such as ferric phosphate, the biopesticide NemaSlug, timing of applications and the persistence of slug pellets are required.

In 2015 and 2016 there were two field trials each year (Lincolnshire and Scotland) with the particularly susceptible potato cultivar Maris Piper to assess the efficacy of several molluscicide treatments and timings at reducing slug damage.

1.1. Methods

2015 Trials

The main aim of these trials was to evaluate the efficacy of programmes using metaldehyde, ferric phosphate and/or *Phasmarhabditis hermaphrodita* (NemaSlug) for the management of slugs with a view to minimising the risk of metaldehyde contamination of water. The three key timings for molluscicide application were:

- just before the crop canopy meets;
- around 4-5 weeks later (if rainfall/irrigation is present);
- at burning down of the crop.

Applications of the biopesticide NemaSlug were timed to coincide with rainfall at early crop emergence, at tuber initiation (providing rainfall/irrigation is present at that time), and at burning down. The treatments were:

1. Untreated – no molluscicide applications

2. Metaldehyde (TDS Major – 7 kg/ha [full recommended rate]) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (timing based on rainfall) followed by metaldehyde (TDS Major – 7 kg/ha) at burn down

3. Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (timing based on rainfall) followed by ferric phosphate (Sluxx HP – 7 kg/ha) at burn down

4. Metaldehyde (TDS Major – 5 kg/ha [reduced rate]) at just before crop canopy meeting followed by metaldehyde (TDS Major – 5 kg/ha [reduced rate] timing based on rainfall) followed by metaldehyde (TDS Major – 5 kg/ha [reduced rate]) at burn down (overall metaldehyde rate of 600 g a.i./ha kept within Metaldehyde Stewardship Group recommended limit of 700 g a.i./ha)

5. Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (timing based on rainfall) followed by *Phasmarhabditis hermaphrodita* (NemaSlug – 50,000 per m^2) at burn down

6. *Phasmarhabditis hermaphrodita* (NemaSlug – 50,000 per m^2) applied three times during the season: early season (to reduce the overall pest pressure), at tuber initiation and at burn down

7 Metaldehyde (TDS Major – 7 kg/ha) at just before crop canopy meeting followed by metaldehyde (TDS Major – 7 kg/ha rate) (timing based on rainfall) followed by *Phasmarhabditis hermaphrodita* (NemaSlug – 50,000 per m^2) at burn down.

2016 Trials

NemaSlug was considered for inclusion in the 2016 field trials, as part of a programme with metaldehyde/ferric phosphate molluscicides. However, the manufacturers of NemaSlug announced that they would be focusing primarily on the high-value crop and home and garden market, and would not be pursuing a role for NemaSlug in potato crops. Consequently the use of NemaSlug in the 2016 trials was discontinued.

The aim of the 2016 trials was to determine whether there is flexibility in the timing of molluscicide application in response to environmental conditions – primarily rainfall. To this end there were ‘fixed’ molluscicide programmes (see Table below) based on a first treatment just before the crop canopy meets, a second treatment approximately a month later based on local rainfall, and a final treatment at burning down of the crop. The ‘variable’ molluscicide programme involved flexibility in the second and subsequent timing of application, where rainfall after the first application timing was used to trigger the timing of the subsequent applications, with a final fixed treatment at burn down.

1 Untreated – no molluscicide applications

2 Metaldehyde (TDS Major – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (approx. 1 month later, timing based on rainfall) followed by metaldehyde (TDS Major – 7 kg/ha) at burn down

3 Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (approx. 1 month later, timing based on rainfall) followed by ferric phosphate (Sluxx HP – 7 kg/ha) at burn down

4 Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) applications with timings based on conditions for slug activity, with a final application of ferric phosphate (Sluxx HP – 7 kg/ha) at burn down

5 Metaldehyde (TDS Major – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) applications with timings based on conditions for slug activity, with a final application of metaldehyde (TDS Major – 7 kg/ha) at burn down

1.2. Results

2015

There was a difference in the results from the two sites. At both sites, ferric phosphate (three applications) resulted in significantly fewer damaged tubers compared to the untreated control. At the Edinburgh site, four of the other five treatments also resulted in significantly fewer damaged tubers compared to the untreated control:

- Metaldehyde (full rate) - Ferric Phosphate – Metaldehyde (full rate) (P = 0.006);
- Metaldehyde (reduced rate) - Metaldehyde (reduced rate) - Metaldehyde (reduced rate) (P = 0.01);
- Ferric Phosphate - Ferric Phosphate - NemaSlug (P = 0.011);
- Metaldehyde - Metaldehyde - NemaSlug (P = 0.021).

Use of the slug biological control NemaSlug alone did not provide effective reductions in slug damage. However, an application of NemaSlug at burning down as part of a molluscicide programme was effective at reducing slug damage at the Edinburgh site.
The results from the first year of trials demonstrated that it is possible to use ferric phosphate as an alternative to metaldehyde, and that both molluscicides deployed in a 3 treatment programme can provide effective slug management.

2016

The molluscicides ferric phosphate (as Sluxx HP) and metaldehyde (as TDS Major) were effective at reducing slug damage by >50% when used in either a 3x or 4x application programme alone or sequentially. Linking molluscicide application timings to local rainfall events and key crop growth timings (just before crop canopy meets across the rows and burning down) provided effective slug control. The use of the flexible 4x application programme, where an extra molluscicide application was applied in response to a local rainfall event did not decrease slug damage beyond that achieved with a 3x programme. Consequently, a 3x molluscicide treatment programme where an application just before the crop canopy meets across the rows, and at burning down as key timings, with a further timing in between those growth stages in response to a period of rainfall is recommended as a robust molluscicide programme.

The retention of the structural integrity of the molluscicide pellets after application was dependent on whether there was any rainfall after application. In instances where there was rainfall after a molluscicide application, pellet integrity tended to decline depending on the amount of rainfall. As different metaldehyde and ferric phosphate molluscicide products will have differing formulations, one cannot assume that all metaldehyde products will maintain pellet integrity for longer than all ferric phosphate products. These trials just compared two products – other products regardless of active ingredient may fare better or worse in terms of pellet integrity.

2. INTRODUCTION

Slugs are a perennial problem in crops across the arable and horticultural sector. Some crops such as oilseed rape (up to 59% of the UK area) and wheat (up to 22% of the UK area) are significantly affected by slugs; the extent of this depends on the season (Clarke *et al.,* 2009). Estimates by Nicholls (2014) suggest that the withdrawal of molluscicide use could lead to potential annual losses to slugs of £18M in oilseed rape, £25.5M in wheat, and £53M in potatoes.

With the loss of methiocarb as a molluscicide treatment in potatoes (and other crops), an independent assessment of alternative molluscicide treatments was necessary, particularly in relation to the risk of drinking water contamination by metaldehyde, which for many is the main alternative to methiocarb..

The high slug pressure on crops in 2012 due to the wet mild summer followed by a wet autumn led to significant concentrations of metaldehyde in rivers and reservoirs during autumn 2012. Some water companies were able to control concentrations by limiting the amount of water abstracted from rivers into storage reservoirs. For others, this was considered as an option, but found not to be feasible or sustainable, particularly where a number of affected drinking water sources are directly abstracted into the water treatment works. Consequently, there have been occasions when trace concentrations of metaldehyde have been detected in treated drinking water. These concentrations are extremely low – the highest being around 1ug/l (micrograms per litre) and mostly much lower. However, the concentrations are above the European and UK standards for pesticides in drinking water set at 0.1ug/l. If the voluntary approach on metaldehyde usage promoted by the Metaldehyde Stewardship Group (MSG) does not generate sustainable reductions in concentrations of metaldehyde in drinking water sources then it may be necessary for the introduction of tighter environmental restrictions, such as the enforcement of Water Protection Zones, which would provide the Environment Agency with additional powers to protect water at a local level – including the prohibition of harmful activities (Marshall, 2013). Consequently, evaluation of the alternatives to metaldehyde, and use of metaldehyde in programmes with these alternatives will provide confidence in the use of programmes of mixed products/actives for the potato grower, and subsequently reducing the risk of metaldehyde contamination of water.

The aims of this project were:

- To evaluate the efficacy of programmes using metaldehyde, ferric phosphate and/or *P. hermaphrodita* (NemaSlug) for the management of slugs, with a view to minimising the risk of metaldehyde contamination of water by staying within the guidelines issued by the MSG.

- To evaluate the efficacy of programmes using fixed and variable timing of applications based on local rainfall events with metaldehyde and ferric phosphate for the management of slugs, with a view to minimising the risk of metaldehyde contamination of water by staying within the guidelines issued by the MSG.

Timing of molluscicide applications are crucial for maximising their efficacy, and the key molluscicide pellet application timing from previous trials has been just prior to the crop canopy meeting. Trials by SRUC and others have found that missing this timing provides inadequate control of slug damage to tubers, despite further applications after this growth stage. Subsequent timing(s) of application should relate to assessment of slug risk based on weather (rainfall), and a final application after burn down of the crop is also recommended to avoid damage at this time.

3. Materials and methods 2015

3.1. Field trial sites 2015

Field trial sites were chosen based on local knowledge, past history of crop damage from slugs, and results from slug traps placed at promising sites prior to potato planting. Two trial sites were finalised: one near Edinburgh, Scotland, and another near Carrington in Lincolnshire, England. Local weather data, particularly rainfall, was collected at each site and used to determine the dates of certain molluscicide treatments.

3.2. Treatments

The molluscicide treatments chosen are listed below with a general guide to their timings. Detailed timings are provided in the trial diaries below, and were chosen based on rainfall data and growth stage of the crop.

The treatments in 2015 were:

1. Untreated – no molluscicide applications

2. Metaldehyde (TDS Major – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (timing based on rainfall) followed by metaldehyde (TDS Major – 7 kg/ha – full recommended rate) at burn down

3. Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (timing based on rainfall) followed by ferric phosphate (Sluxx HP – 7 kg/ha) at burn down

4. Metaldehyde (TDS Major – 5 kg/ha - reduced rate) at just before crop canopy meeting followed by metaldehyde (TDS Major – 5 kg/ha - reduced rate) (timing based on rainfall) followed by metaldehyde (TDS Major – 5 kg/ha - reduced rate) at burn down (overall metaldehyde rate of 600 g a.i./ha kept within Metaldehyde Stewardship Group recommended limit of 700 g a.i./ha)

5. Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (timing based on rainfall) followed by *Phasmarhabditis hermaphrodita* (NemaSlug – 50,000 per m^2) at burn down

6. *Phasmarhabditis hermaphrodita* (NemaSlug – 50,000 per m^2) applied three times during the season: early season (to reduce the overall pest pressure), at tuber initiation and at burn down

7. Metaldehyde (TDS Major – 7 kg/ha) at just before crop canopy meeting followed by metaldehyde (TDS Major – 7 kg/ha rate) (timing based on rainfall) followed by *Phasmarhabditis hermaphrodita* (NemaSlug – 50,000 per m^2) at burn down

3.3. Trial site design

Each trial plot was 12 rows wide and 10m long, with 4 replicates for each treatment. The potato cultivar in both trials was Maris Piper, and received standard fertiliser, herbicide and fungicide programmes.

	5	3	1	7	4	2	6	
	2	3	6	7	5	1	4	
	4	6	7	3	5	1	2	
	1	2	3	4	5	6	7	

Fig. 1 Trial layout for Carrington, Lincolnshire. Plot numbers refer to the Treatments listed in Table 1.

	1	2	3	4	5	6	7	
	4	6	7	1	2	3	5	
	3	7	5	6	4	1	2	
	6	4	3	2	5	7	1	

Fig. 2. Trial layout for Edinburgh, Scotland. Plot numbers refer to the Treatments listed in Table 1.

Trial plots were assessed for slug tuber damage using the centre rows from each plot, and damage was assessed at 4 sample points per plot, with nine plants dug at each sample point (a minimum of 36 plants per plot). All tubers in the 9 plants per sampling plot were washed and assessed for slug damage.

Treatments were scored as percentage of tubers exhibiting slug damage at each sampling point. The distribution of percentages is binomial and arcsine transformation of data allows for an analysis of variance to be carried out on the transformed data to test for any significant differences between the treatments.

3.4. Timing of treatments 2015

The timing of application of the *P. hermaphrodita*, ferric phosphate and metaldehyde treatments were based on the growth stage of the crop and/or rainfall data. Rainfall data in July dictated the timings of the second treatments which were applied based on recent rainfall events.

For the Carrington site, the second molluscicide treatments were applied on 10th July after there had been several days of rainfall (Fig. 3).

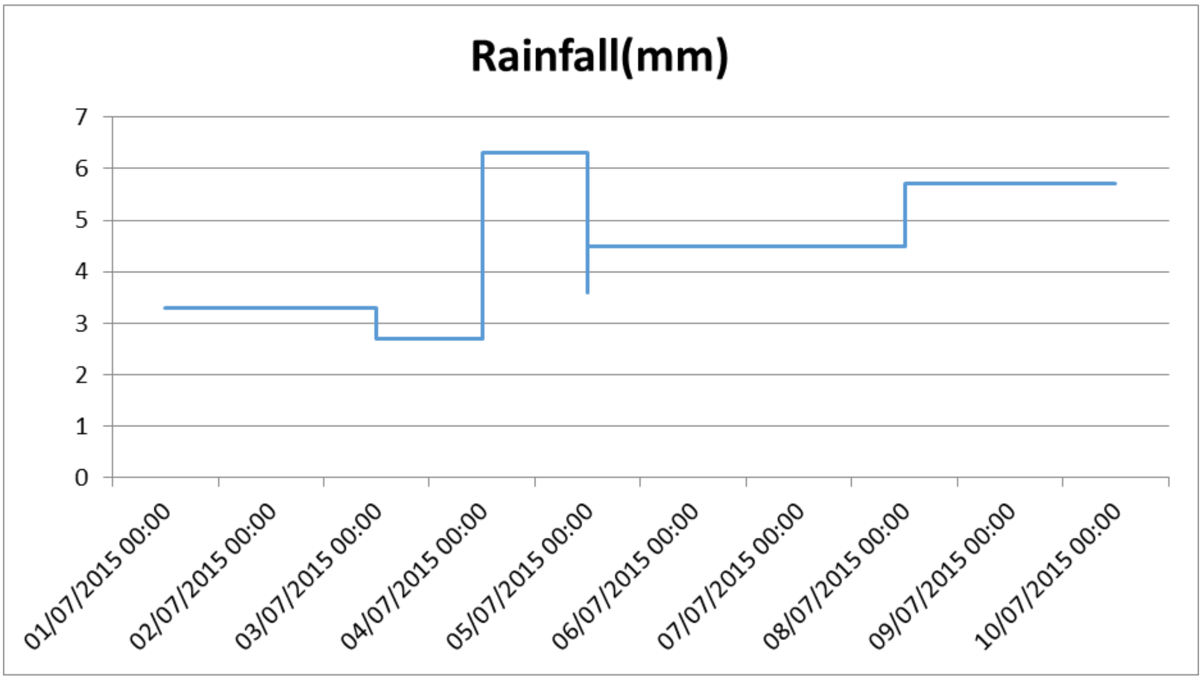


Fig. 3. Rainfall data for the Carrington field trial July 2015.

DIARY **Carrington**	
Crop Planted	24th April
Nemaslug applied (when rainfall was ongoing)	29th May
Sluxx HP and TDS Major applied (just before crop canopy meeting across the rows)	11th June
Nemaslug applied	6th July
Sluxx HP and TDS Major applied	10th July
All applications (before burn down)	14th August

For the Edinburgh site, the second molluscicide treatments were applied on 17th July after there had been a significant rainfall event the day previously (Fig. 4), and rain was forecast for the next few days.

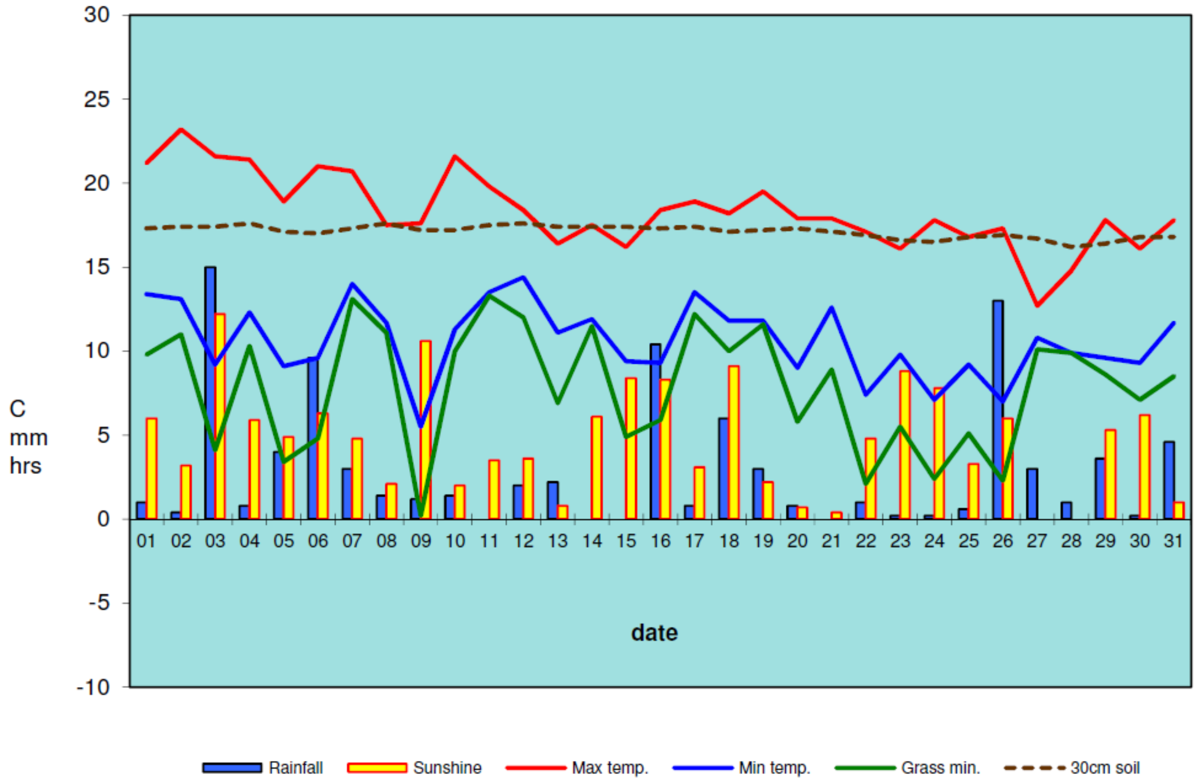


Fig. 4 Meteorological data for the Edinburgh field trial July 2015.

DIARY **Edinburgh**	
Planted	10th May
Nemaslug applied (when rainfall was ongoing)	31st May
Sluxx HP and TDS Major applied (just before crop canopy meeting across the rows)	11th June
Nemaslug applied	26th June
Sluxx HP and TDS Major applied	17th July
All applications (before burn down)	13th August

4. Results 2015

4.1. Carrington slug trial

There was a large amount of variability between plots of the same treatment in respect to percentage of slug damage (Fig. 5).

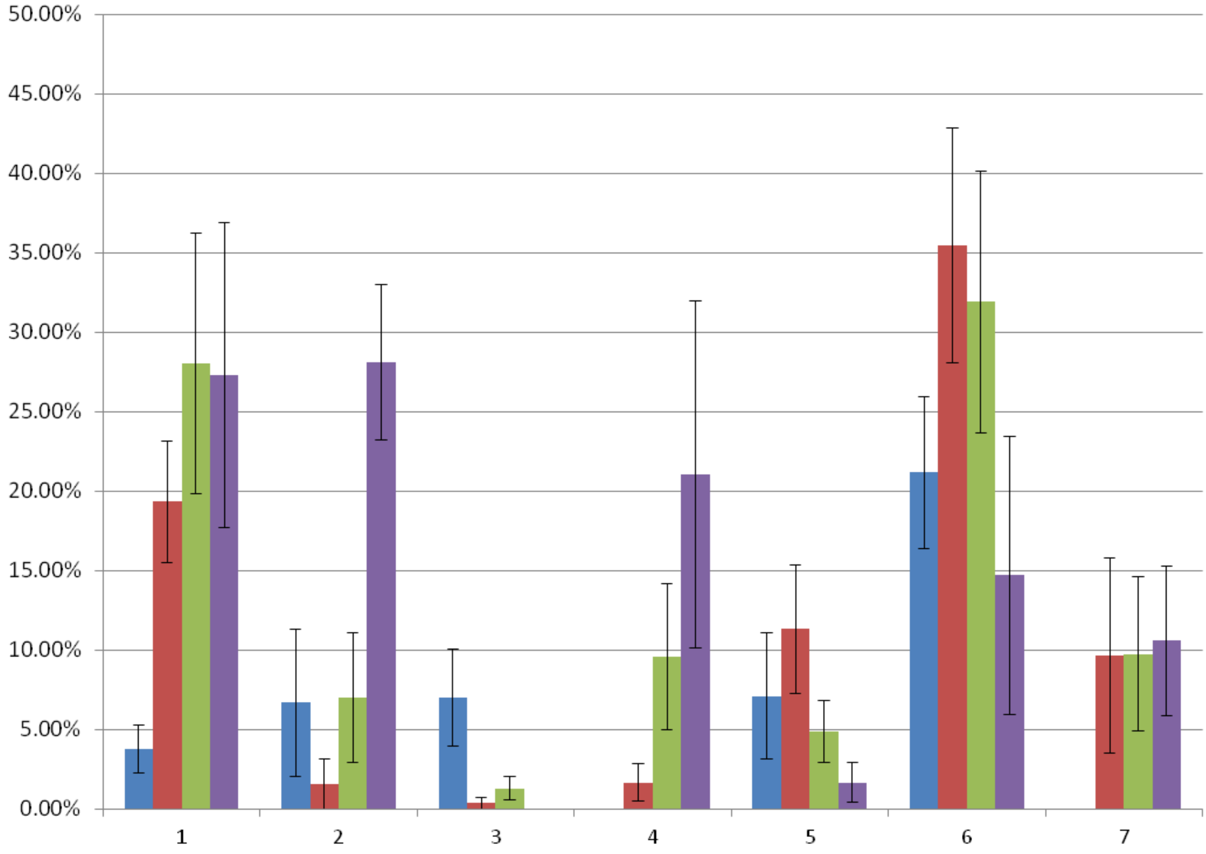


Fig. 5. Carrington mean percentage slug damage (± standard error) per plot for each treatment. Key to treatments:

1 Untreated

2 Metaldehyde (7 kg/ha) at just before crop canopy meeting (11th June) followed by ferric phosphate (7 kg/ha) (10th July) followed by metaldehyde (7 kg/ha) at burn down (14th August).

3 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (11th June) followed by ferric phosphate (7 kg/ha) (10th July) followed by ferric phosphate (7 kg/ha) at burn down (14th August)

4 Metaldehyde (5 kg/ha) at just before crop canopy meeting (11th June) followed by metaldehyde (5 kg/ha) (10th July) followed by metaldehyde (5 kg/ha) at burn down (14th August).

5 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (11th June) followed by ferric phosphate (7 kg/ha) (10th July) followed by *Phasmarhabditis hermaphrodita* (50,000 per m^2) at burn down (14th August).

6 *Phasmarhabditis hermaphrodita* (50,000 per m^2) applied three times during the season: 29th May, 6th July and 14th August.

7 Metaldehyde (7 kg/ha) at just before crop canopy meeting (11th June), followed by metaldehyde (7 kg/ha rate) (10th July) followed by *Phasmarhabditis hermaphrodita* (50,000 per m^2) at burn down (14th August)

Slug damage in the four replicated plots for each treatment in the Carrington trial was particularly variable (Fig. 5), with mean percentage tubers damaged in the Untreated plots ranging from 4% to 28%. Variability was also present in other treated plots where mean percentage slug damage ranged from 0% to 21% in the Metaldehyde - Metaldehyde - Metaldehyde treatments (Treatment 4) for example (Fig. 5).

This variability in slug damage between replicates of the same treatment meant that an analysis of variance of the mean percentage slug damage from the 4 individual replicates for each treatment (Fig. 6), only gave one treatment (Treatment 3 - Ferric

Phosphate - Ferric Phosphate - Ferric Phosphate) having a significantly lower percentage of slug damage than the Untreated (P = 0.025).

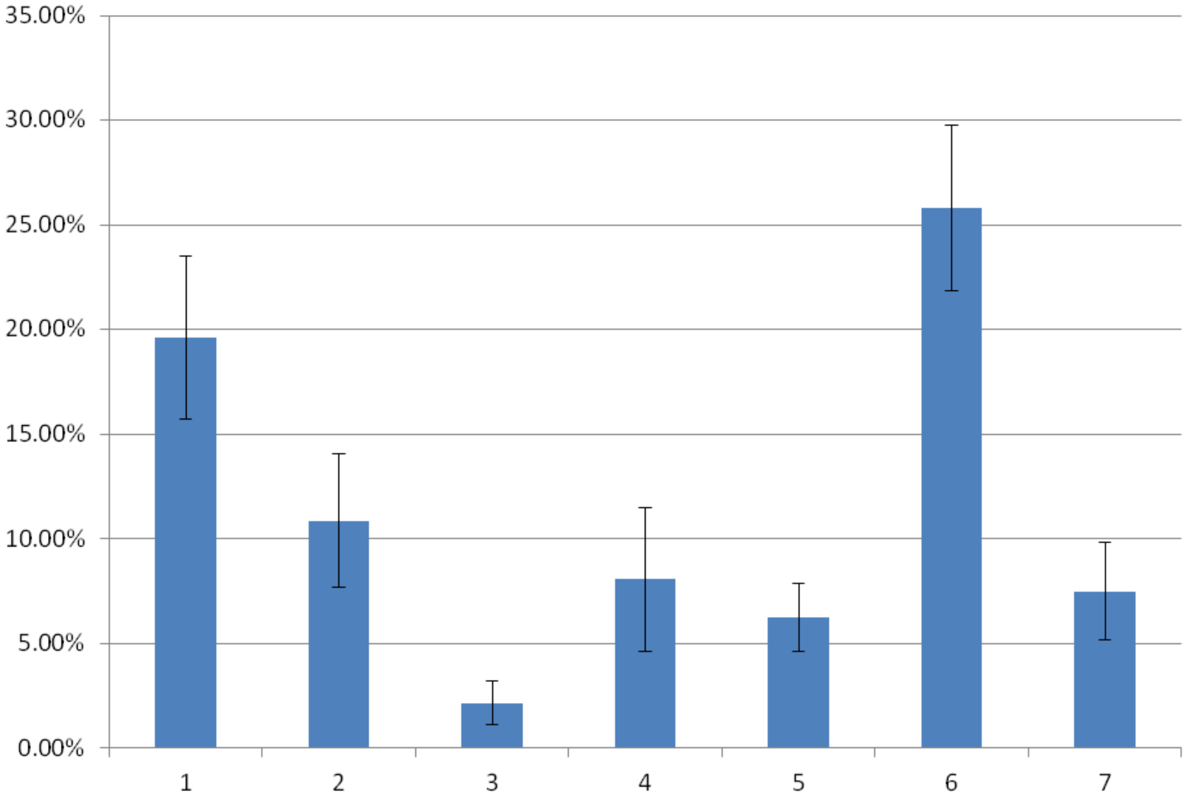


Fig. 6. Mean percentage of tubers with slug damage for each treatment (± standard error of the mean) at the Carrington, Lincolnshire trial.

4.2. Edinburgh slug trial

There was a less variability between plots of the same treatment in respect to percentage of slug damage at the Edinburgh trial (Fig. 7) compared to the Carrington trial (Fig. 5).

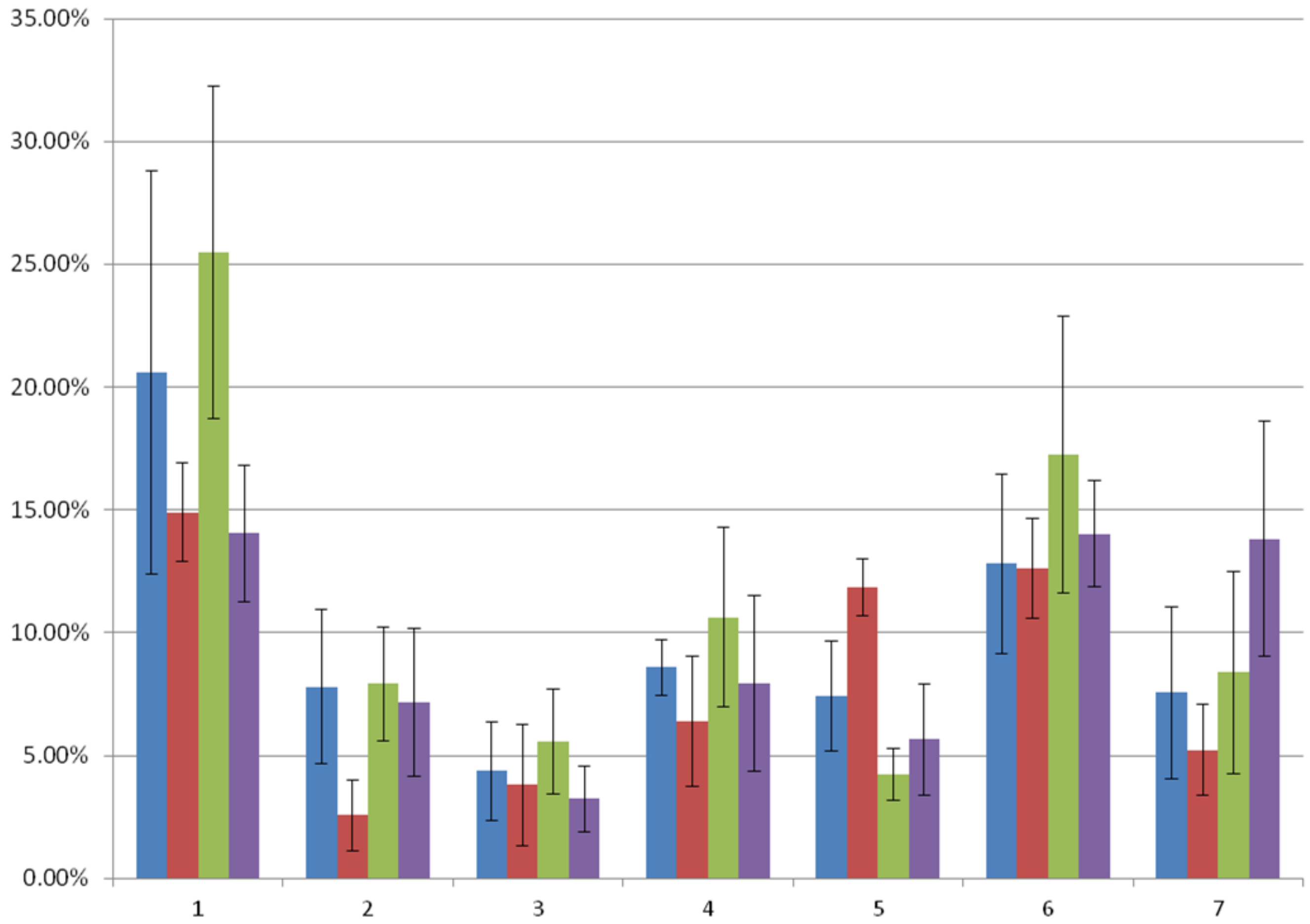


Fig. 7. Edinburgh mean percentage slug damage (± standard error) per plot for each treatment.

1 Untreated – no molluscicide applications

2 Metaldehyde (7 kg/ha) at just before crop canopy meeting (11th June) followed by ferric phosphate (7 kg/ha) (17th July) followed by metaldehyde (7 kg/ha) at burn down (13th August)

3 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (11th June) followed by ferric phosphate (7 kg/ha) (17th July) followed by ferric phosphate (7 kg/ha) at burn down (13th August)

4 Metaldehyde (5 kg/ha) at just before crop canopy meeting (11th June) followed by metaldehyde (5 kg/ha) (17th July) followed by metaldehyde (5 kg/ha) at burn down (13th August)

5 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (11th June) followed by ferric phosphate (7 kg/ha) (17th July) followed by *Phasmarhabditis hermaphrodita* (50,000 per m^2) at burn down (13th August)

6 *Phasmarhabditis hermaphrodita* (50,000 per m^2) applied three times during the season: 31st May, 26th June and 13th August

7 Metaldehyde (7 kg/ha) at just before crop canopy meeting (11th June), followed by metaldehyde (7 kg/ha rate) (17th July) followed by *Phasmarhabditis hermaphrodita* (50,000 per m^2) at burn down (13th August)

In the Edinburgh trial, the mean percentage tubers damaged in the Untreated plots ranged from 14% to 26% (Fig. 7). Analysis of variance of the mean percentage slug damage from the 4 individual replicates for each treatment (Fig. 8), found that the following treatments had a significantly lower percentage of slug damage than the Untreated:

- Treatment 2 - Metaldehyde - Ferric Phosphate - Metaldehyde (P = 0.006);

- Treatment 3 - Ferric Phosphate - Ferric Phosphate - Ferric Phosphate ($P = 0.002$);
- Treatment 4 - Metaldehyde - Metaldehyde - Metaldehyde ($P = 0.01$);
- Treatment 5 - Ferric Phosphate - Ferric Phosphate - NemaSlug ($P = 0.011$);
- Treatment 7 - Metaldehyde - Metaldehyde - NemaSlug ($P = 0.021$).

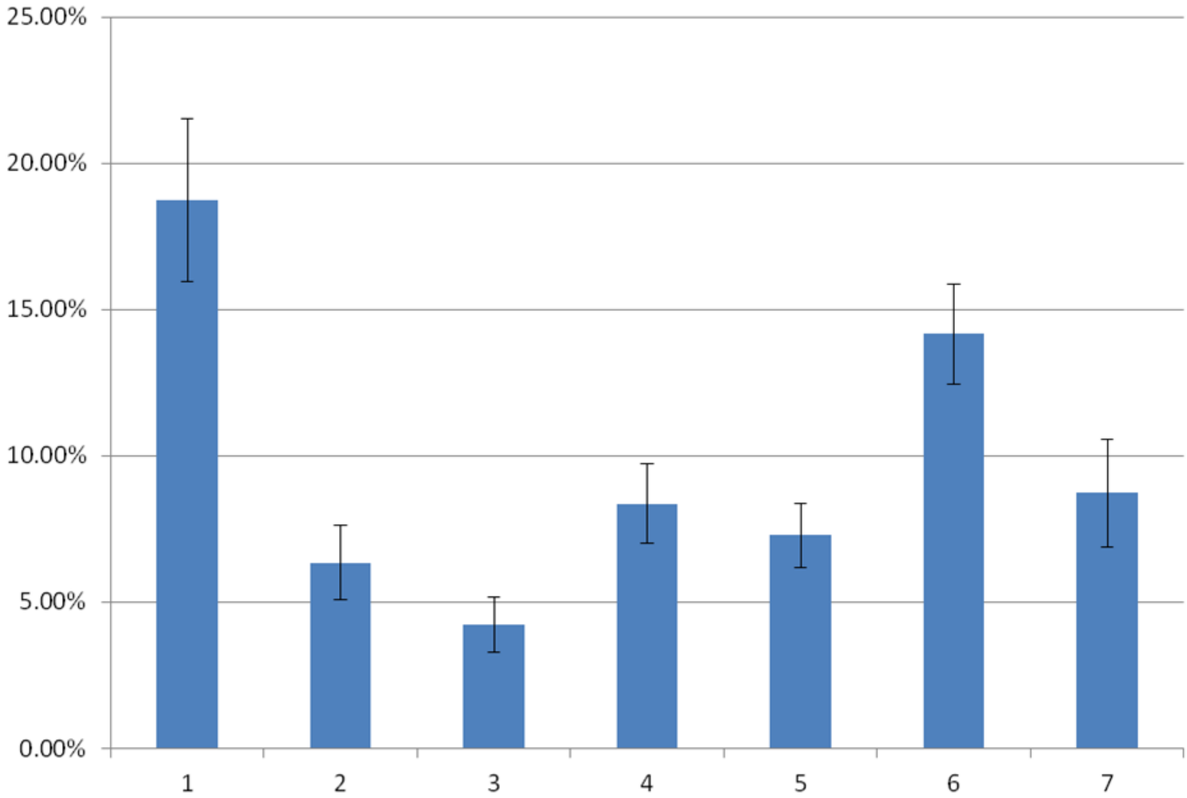


Fig. 8. Mean percentage of tubers with slug damage for each treatment (± standard error of the mean) at the Edinburgh, Scotland trial.

There were some significant differences between molluscicide treatments when an analysis of variance of the mean percentage slug damage from the 4 individual replicates for each treatment were carried out. These were:

- Treatment 2 - Metaldehyde - Ferric Phosphate - Metaldehyde having a significantly lower percentage of slug damage than Treatment 6 - NemaSlug - NemaSlug - Nemaslug ($P = 0.003$);
- Treatment 3 - Ferric Phosphate - Ferric Phosphate - Ferric Phosphate having a significantly lower percentage of slug damage than Treatment 4 - Metaldehyde - Metaldehyde - Metaldehyde ($P = 0.006$);
- Treatment 3 - Ferric Phosphate - Ferric Phosphate - Ferric Phosphate having a significantly lower percentage of slug damage than Treatment 6 - NemaSlug - NemaSlug - Nemaslug ($P = 0.001$);
- Treatment 4 - Metaldehyde - Metaldehyde - Metaldehyde having a significantly lower percentage of slug damage than Treatment 6 - NemaSlug - NemaSlug - Nemaslug ($P = 0.006$);
- Treatment 5 - Ferric Phosphate - Ferric Phosphate - NemaSlug having a significantly lower percentage of slug damage than Treatment 6 - NemaSlug - NemaSlug - Nemaslug ($P = 0.013$);

- Treatment 7 - Metaldehyde - Metaldehyde - Nemaslug having a significantly lower percentage of slug damage than Treatment 6 -NemaSlug - NemaSlug - Nemaslug (P = 0.042).

5. MATERIALS AND METHODS 2016

5.1. Field trial sites 2016

Field trial sites were chosen based on local knowledge, past history of crop damage from slugs, and results from slug traps placed at promising sites prior to potato planting. Two trial sites were finalised: one near Edinburgh, Scotland, and another at Holbeach Marsh, in Lincolnshire, England. Local weather data, particularly rainfall, was collected at each site and used to determine the dates of certain molluscicide treatments.

5.2. Treatments

The molluscicide treatments chosen are listed below with a general guide to their timings. Detailed timings are provided in the trial diaries below, and the Figure legends, and chosen based on rainfall data and growth stage of the crop.

The treatments were:.

1. Untreated – no molluscicide applications
2. Metaldehyde (TDS Major – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (approx. 1 month later, timing based on rainfall) followed by metaldehyde (TDS Major – 7 kg/ha) at burn down
3. Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) (approx. 1 month later, timing based on rainfall) followed by ferric phosphate (Sluxx HP – 7 kg/ha) at burn down
4. Ferric phosphate (Sluxx HP – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) applications with timings based on conditions for slug activity, with a final application of ferric phosphate (Sluxx HP – 7 kg/ha) at burn down
5. Metaldehyde (TDS Major – 7 kg/ha) at just before crop canopy meeting followed by ferric phosphate (Sluxx HP – 7 kg/ha) applications with timings based on conditions for slug activity, with a final application of metaldehyde (TDS Major – 7 kg/ha) at burn down

5.3. Trial design

Each trial plot was 12 rows wide and 10m long, with 4 replicates for each treatment. The potato cultivar in both trials was Maris Piper, and received standard fertiliser, herbicide and fungicide programmes.

Trial plots were assessed for slug tuber damage using the centre rows from each plot, and damage was assessed at 4 sample points per plot, with nine plants dug at each sample point (a minimum of 36 plants per plot). All tubers in the 9 plants per sampling plot were washed and assessed for slug damage.

Treatments were scored as percentage of tubers exhibiting slug damage at each sampling point. The distribution of percentages is binomial and arcsine transformation of data allows for an analysis of variance to be carried out on the transformed data to test for any significant differences between the treatments.

A measurement of molluscicide pellet integrity based on a visual score of 0-5, where 0 = completely disintegrated and 5 = perfect bait was undertaken every 2 days for 10 days post-treatment after each molluscicide application.

5.4. Timing of treatments

The timing of application of the first ferric phosphate (Sluxx HP) and metaldehyde (TDS Major) treatments were based on the growth stage of the crop (just before crop canopy meets across the rows) and with rainfall.

For the second timing, in treatments 2 and 3, the timing was approximately 1 month after the first treatment and also based on there being a rainfall event (see below in trial diaries and Figure legends for detailed dates of timings).

For treatments 4 and 5, the timings for second and third applications (ferric phosphate only) were based on rainfall events as an indicator of slug activity on the soil surface rather than a month after the first application (see below for detailed dates of timings).

For the Holbeach Marsh trial, the first molluscicide treatments were applied on 1st July to all treated plots just before the crop canopy was meeting across the rows, and there had been some rainfall (see Fig. 9).

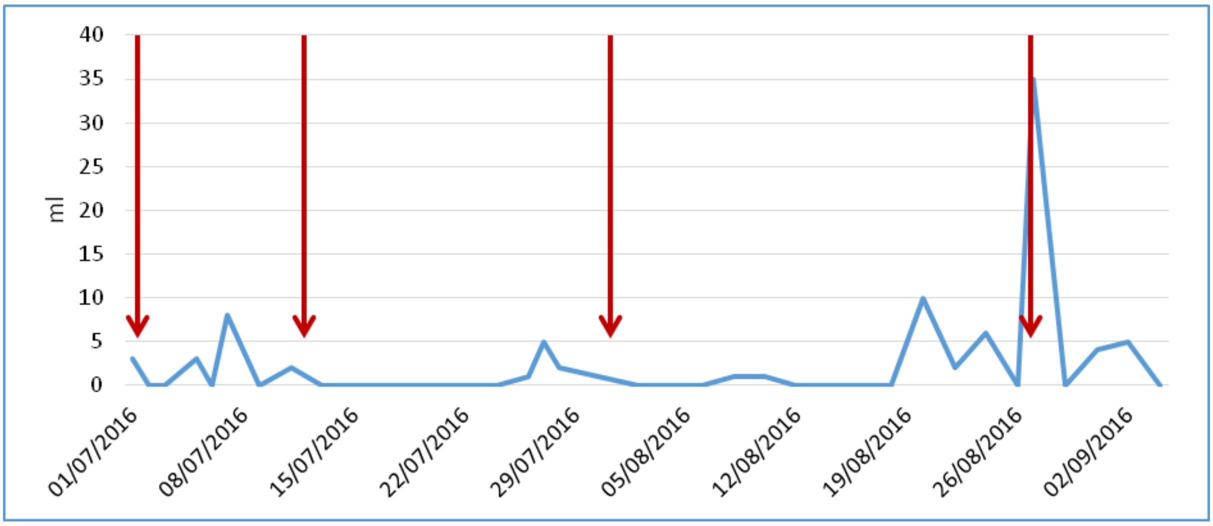


Fig. 9. Rainfall data for the Holbeach Marsh field trial 2016. The red arrows indicate the timing of molluscicide application based on rainfall. The second arrow from the left (14th July) is the timed extra Sluxx treatment in Treatments 4 and 5.

Diary for Holbeach Marsh trial		
1st application	Just before canopy crop meets across rows – Sluxx HP and TDS Major	1st July 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (3rd July – 11th July 2016)		
2nd application	Sluxx HP on treatments 4 and 5	14th July 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (16th July – 24th July 2016)		
3rd application	Sluxx HP applied to all treatments	2nd August 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (4th August – 12th Aug 2016)		
4th application	Final application of Sluxx HP and TDS Major on all treatments applied at burn down	27th August 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (29th Aug – 6th Sept)		
Harvest		8th Sept 2016

There was a Sluxx HP treatment applied on 14th July in treatments 4 and 5 in response to a period of rainfall in the days previously (Fig. 9).

Sluxx HP treatments were applied to all treatments (2, 3 ,4 and 5) on again on 2nd August approximately a month after the first molluscicide treatments after some rainfall (Fig. 9).

The final molluscicide treatments were applied on 27th August at burning down when there was rainfall (Fig. 9).

For the Edinburgh trial, the first molluscicide treatments were applied on 8th July to all treated plots just before the crop canopy was meeting across the rows, and there had been some rainfall (see Fig. 10).

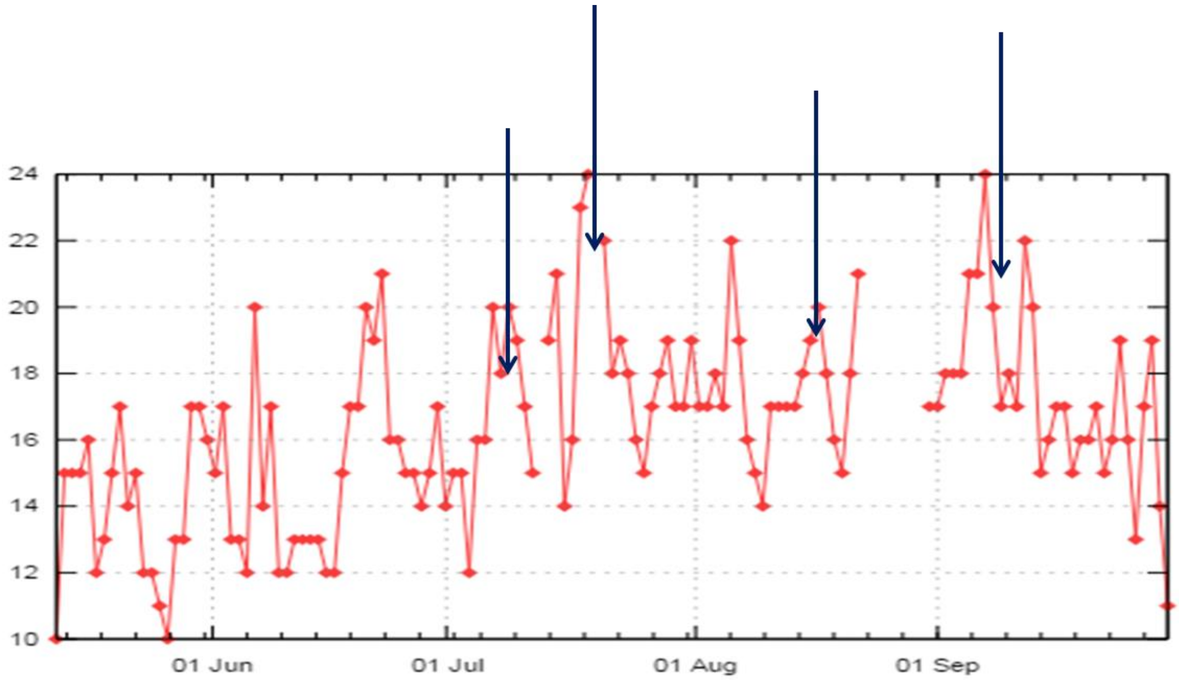


Fig. 10. Rainfall data (ml) for the Edinburgh field trial 2016. The dark arrows indicate the timing of molluscicide application based on rainfall. The second arrow from the left (20th July) is the timed extra Sluxx treatment in Treatments 4 and 5.

Diary for Edinburgh trial		
1st application	Just before canopy crop meets across rows	8th July 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (10th July – 18th July 2016)		
2nd application	Sluxx HP on treatments 4 and 5	20th July 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (22nd July – 30th July 2016)		
3rd application	Sluxx HP applied to all treatments	12th August 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (14th August – 22nd Aug 2016)		
4th application	Final application on all treatments applied at burn down	9th September 2016
Monitor slug pellet degradation for 10 days (48hr intervals) (11th Sept – 19th Sept)		
Harvest		26th Sept 2016

There was a Sluxx HP treatment applied on 20th July in treatments 4 and 5 in response to a period of rainfall in the days previously (Fig. 10). Sluxx HP treatments were applied to all treatments (2, 3, 4 and 5) on 12th August approximately a month after the first molluscicide treatments after some rainfall (Fig. 10). The final molluscicide treatments were applied on 9th September at burning down when there was rainfall (Fig. 10).

6. Results 2016

6.1. Holbeach Marsh Slug Trial

All molluscicide programmes had significantly less slug damage to potato tubers than the Untreated (Fig. 11) except for Treatment 4 (the 4 x Ferric phosphate application; P = 0.074) where there is a large standard error around the mean % of tubers with slug damage (Fig. 11) due to a large variation in % of tubers with slug damage (0% to 19.2%). There are no differences between the standard molluscicide programme (3 x molluscicide treatments – Treatments 2 and 3) and the timed molluscicide treatments (4 x molluscicide treatments – Treatments 4 and 5). Choice of molluscicides (ferric phosphate or metaldehyde) has no difference in the overall level of slug damage.

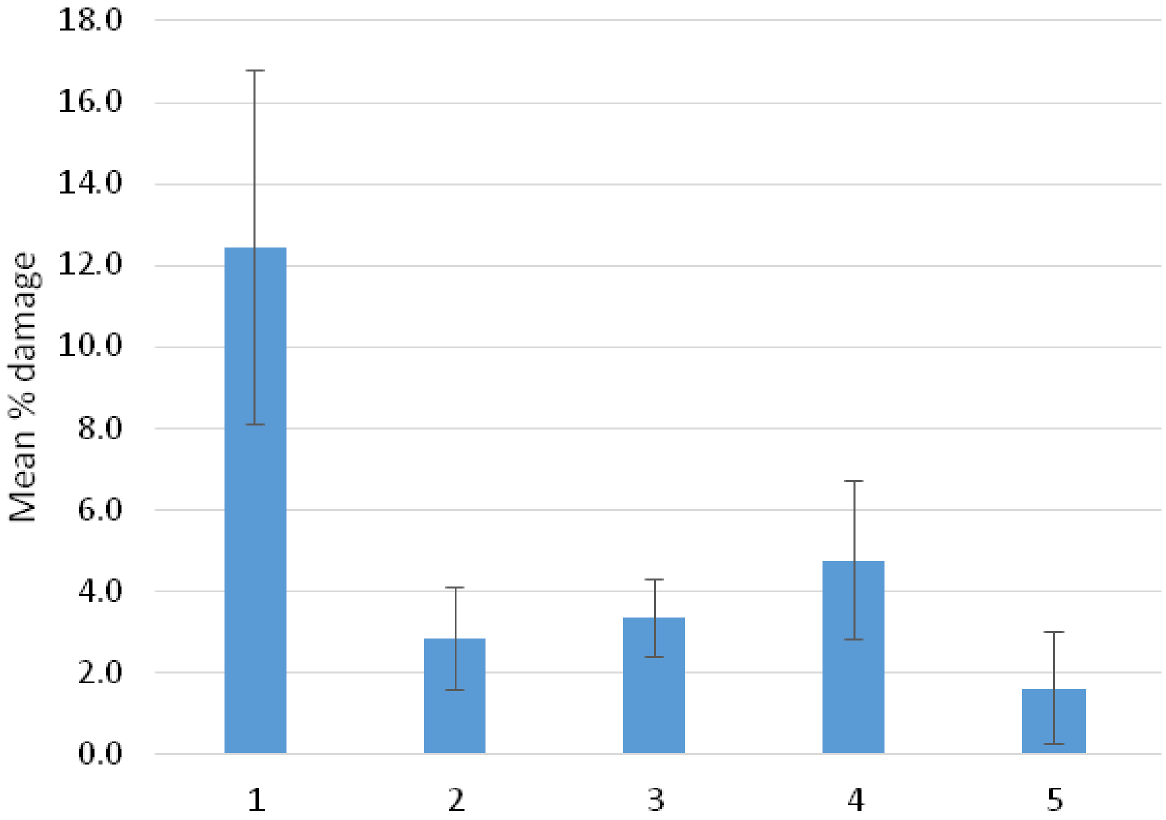


Fig. 11. Mean percentage of tubers with slug damage for each treatment (± standard error of the mean) at the Holbeach Marsh, Lincolnshire trial.

1 Untreated – no molluscicide applications

2 Metaldehyde (7 kg/ha) at just before crop canopy meeting (1st July) followed by ferric phosphate (7 kg/ha) (2nd August) followed by metaldehyde (7 kg/ha) at burn down (27th August)

3 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (1st July) followed by ferric phosphate (7 kg/ha) (2nd August) followed by ferric phosphate (7 kg/ha) at burn down (27th August)

4 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (1st July) followed by ferric phosphate (7 kg/ha) (14th July and 2nd August), with a final application of ferric phosphate (7 kg/ha) at burn down (27th August)

5 Metaldehyde (7 kg/ha) at just before crop canopy meeting (1st July) followed by ferric phosphate (7 kg/ha) (14th July and 2nd August), with a final application of metaldehyde (7 kg/ha) at burn down (27th August)

Pellet degradation monitoring

There is an indication from the molluscicide pellet degradation results at Holbeach Marsh that, particularly after there has been some rainfall (Fig. 12 and Fig. 15), the TDS Major (metaldehyde) pellets retain their structural integrity more consistently than the Sluxx HP (ferric phosphate) pellets. Neither pellet type degraded in dry weather over the 10 days post application (Fig. 13 and Fig. 14).

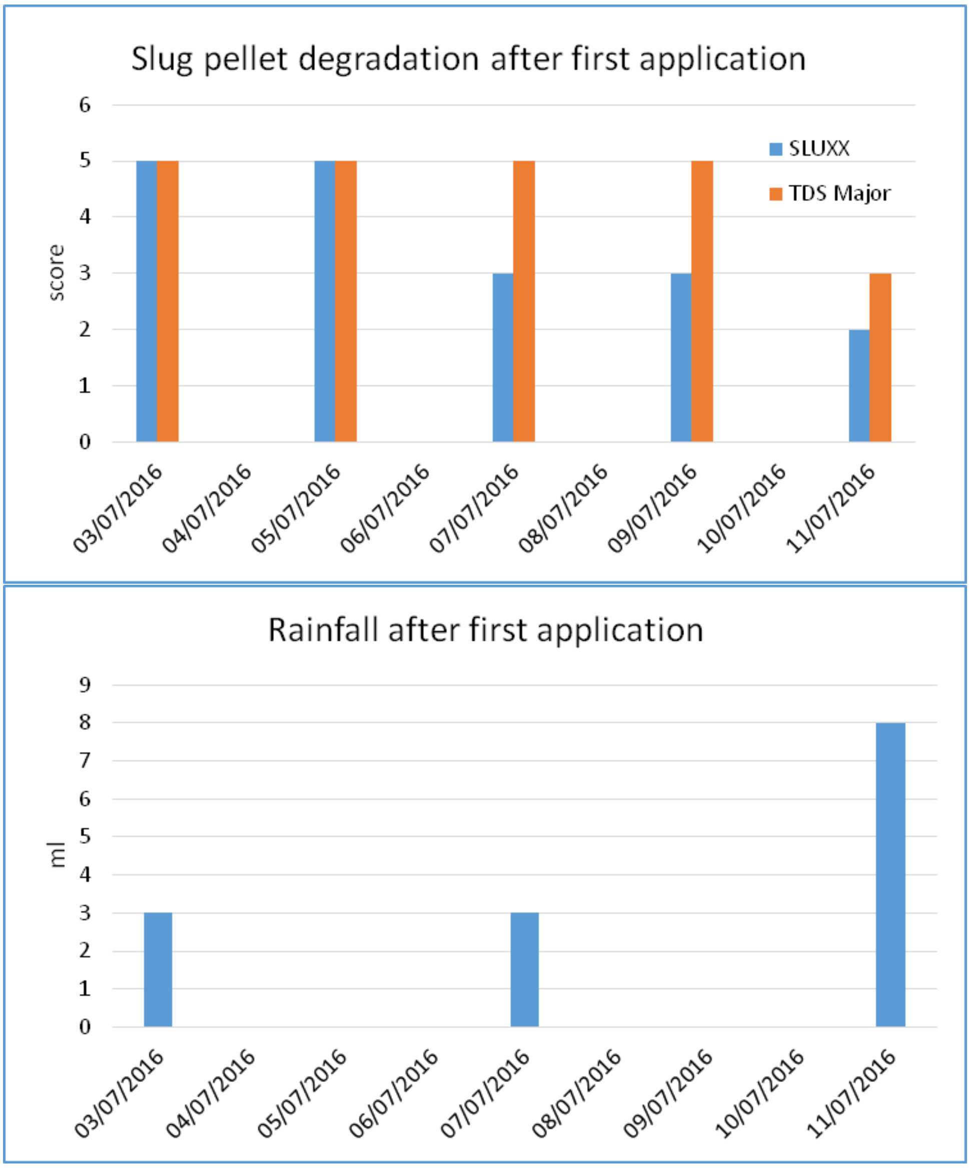


Fig. 12. Molluscicide pellet degradation score (top) and rainfall (bottom) after the first molluscicide pellet application at the Holbeach Marsh, Lincolnshire trial.

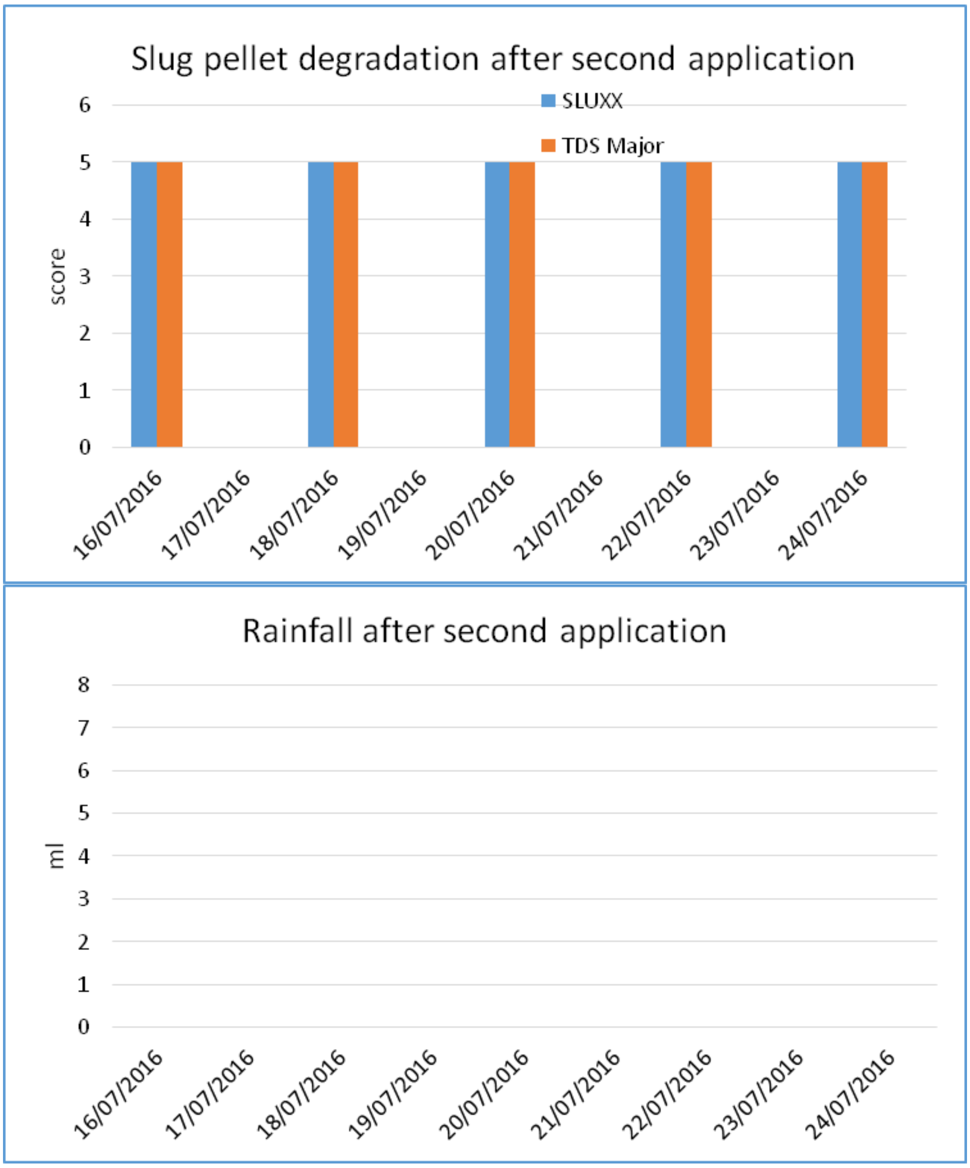


Fig. 13. Molluscicide pellet degradation score (top) and rainfall (bottom) after the second molluscicide pellet application at the Holbeach Marsh, Lincolnshire trial.

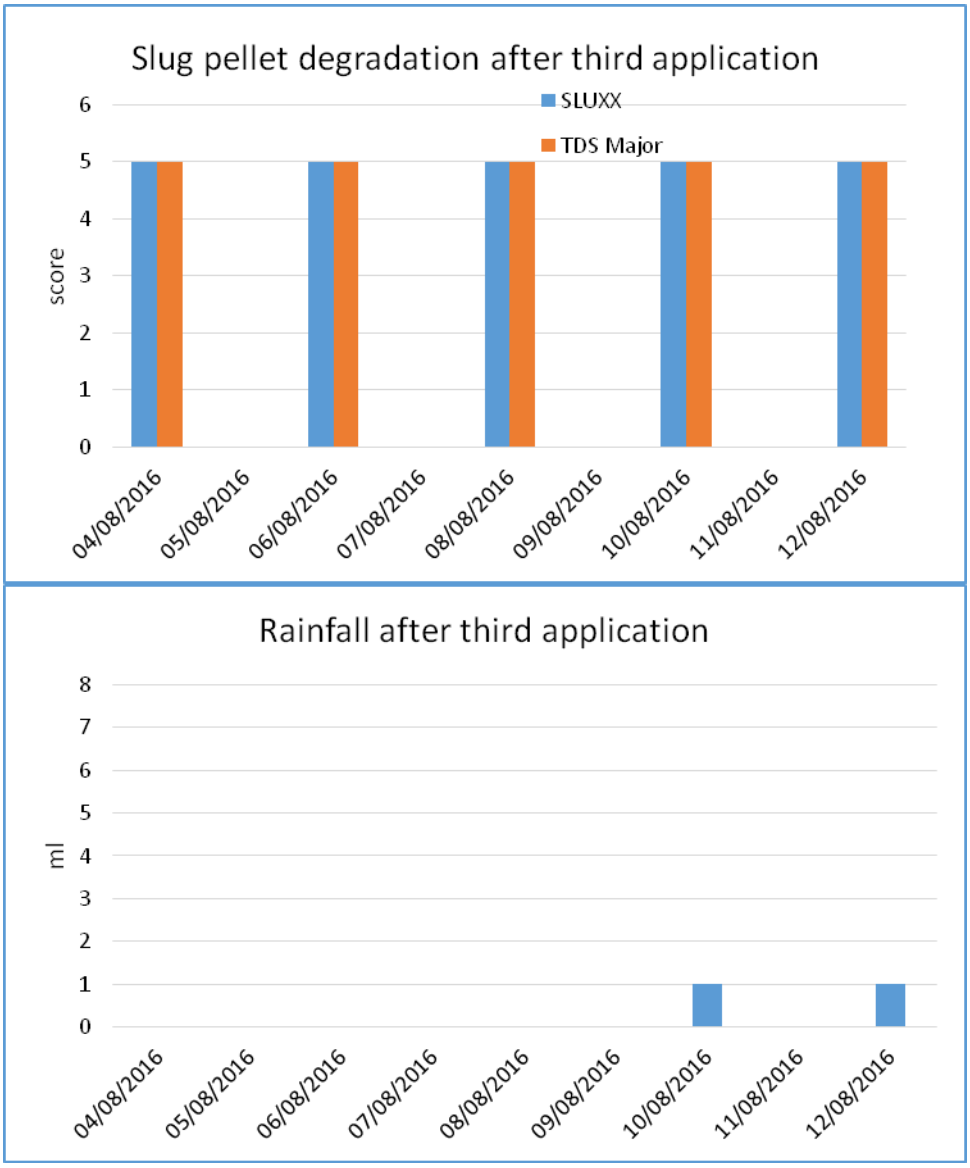


Fig. 14. Molluscicide pellet degradation score (top) and rainfall (bottom) after the third molluscicide pellet application at the Holbeach Marsh, Lincolnshire trial.

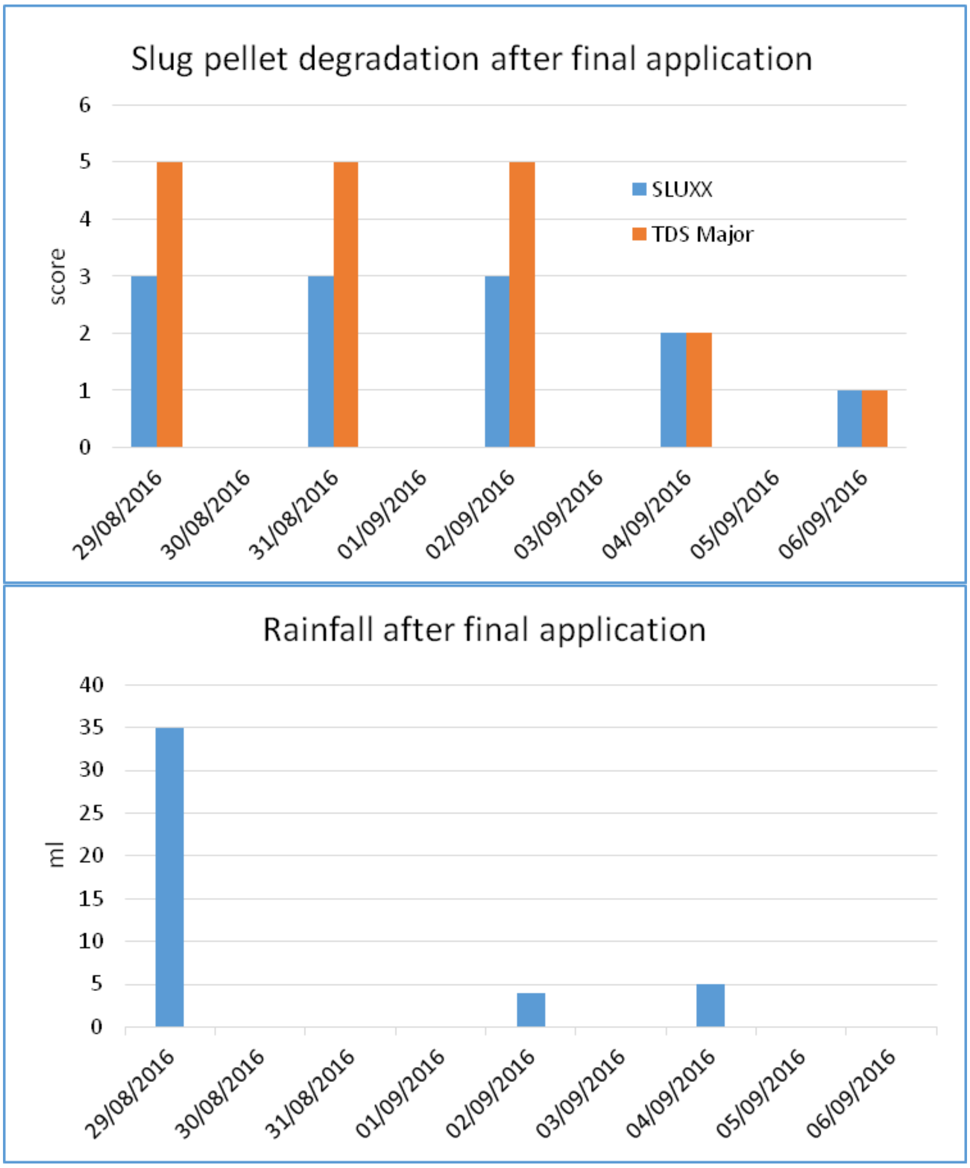


Fig. 15. Molluscicide pellet degradation score (top) and rainfall (bottom) after the final molluscicide pellet application at the Holbeach Marsh, Lincolnshire trial.

Visual examples of molluscicide pellet degradation can be seen below (Fig. 16, Fig. 17, Fig. 18 and Fig. 19). Figure 19 in particular demonstrates that if there has not been much rainfall as at the Holbeach Marsh site, pellets can remain virtually intact and maintain their integrity for at least 20 days.

Fig. 16. Newly applied Sluxx HP pellets (a score of 5).

Fig. 17. Degraded Sluxx HP pellets after rainfall (a score of 1).

Fig. 18. Degraded Sluxx HP pellets (a score of 3).

Fig. 19. Sluxx HP pellets after 20 days of no significant rainfall.

6.2. Edinburgh Slug Trial

All molluscicide programmes had significantly less slug damage to potato tubers than the Untreated (Fig. 20). There are no significant differences between the standard molluscicide programme (3 x molluscicide treatments – Treatments 2 and 3) and the timed molluscicide treatments (4 x molluscicide treatments –Treatments 4 and 5). There was a significantly lower percentage of tubers with slug damage in Treatment 2 (metaldehyde – ferric phosphate – metaldehyde) compared to Treatment 4 (metaldehyde – ferric phosphate – ferric phosphate – metaldehyde) (P = 0.002). Choice of molluscicides (ferric phosphate or metaldehyde) has no real difference in the overall level of slug damage.

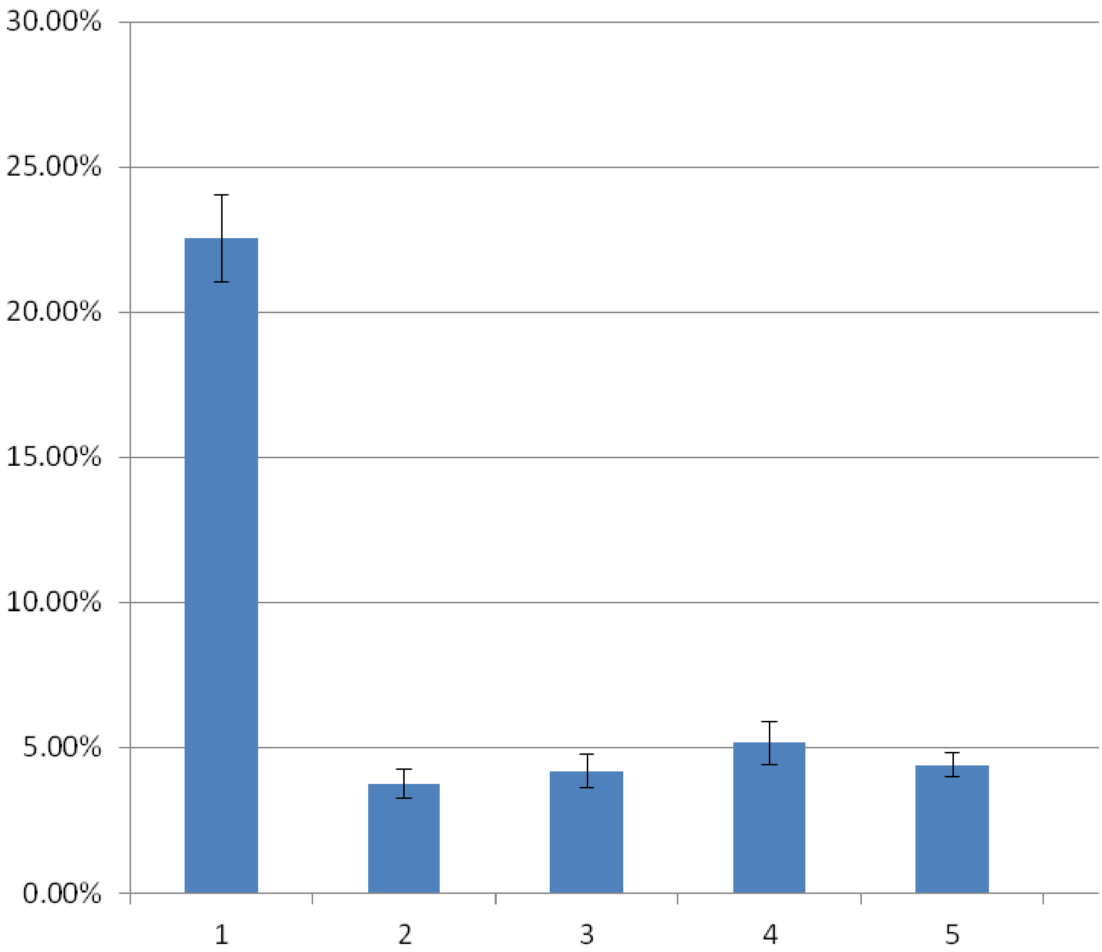


Fig. 20. Mean percentage of tubers with slug damage for each treatment (± standard error of the mean) at the Edinburgh, Scotland trial.

1 Untreated – no molluscicide applications

2 Metaldehyde (7 kg/ha) at just before crop canopy meeting (8th July) followed by ferric phosphate (7 kg/ha) (12th August) followed by metaldehyde (7 kg/ha) at burn down (9th September)

3 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (8th July) followed by ferric phosphate (7 kg/ha) (12th August) followed by ferric phosphate (7 kg/ha) at burn down (9th September)

4 Ferric phosphate (7 kg/ha) at just before crop canopy meeting (8th July) followed by ferric phosphate (7 kg/ha) (20th July and 12th August), with a final application of ferric phosphate (7 kg/ha) at burn down (9th September)

5 Metaldehyde (7 kg/ha) at just before crop canopy meeting (8th July) followed by ferric phosphate (7 kg/ha) (20th July and 12th August), with a final application of metaldehyde (7 kg/ha) at burn down (9th September)

Pellet degradation monitoring

From the molluscicide pellet degradation results at Edinburgh, after there has been some rainfall (Fig. 21, Fig. 22 and Fig. 23), the TDS Major (metaldehyde) pellets retain their structure more consistently than the Sluxx HP (ferric phosphate) pellets.

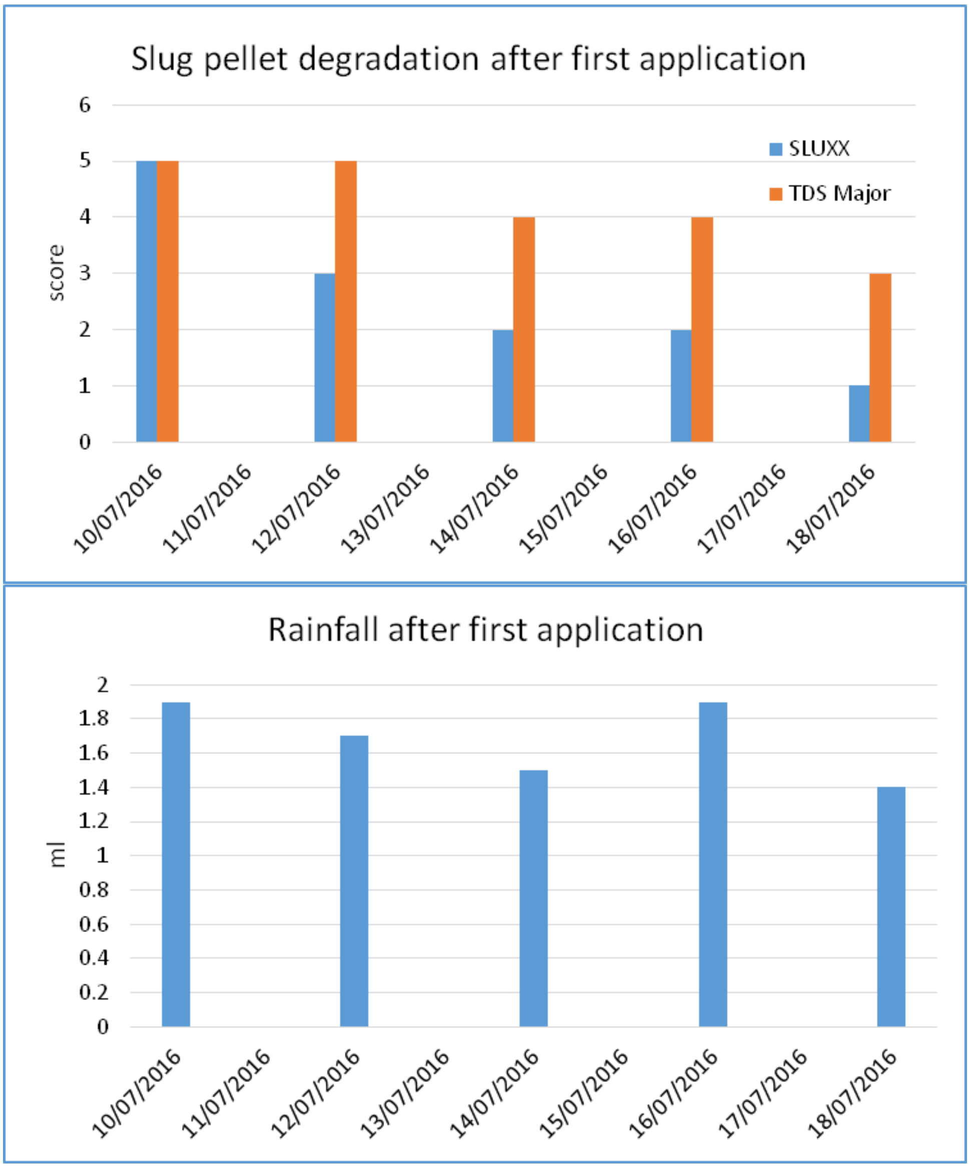
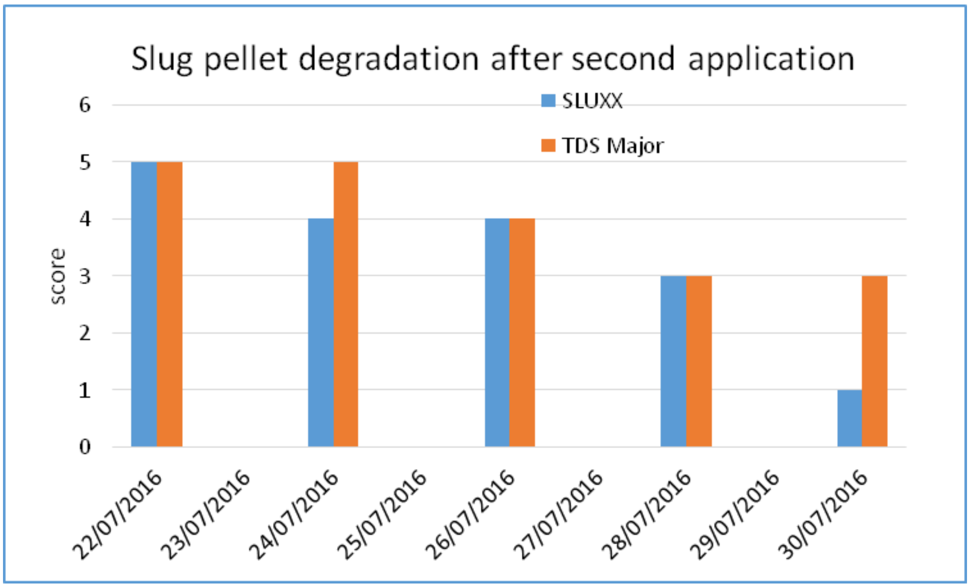


Fig. 21. Molluscicide pellet degradation score (top) and rainfall (bottom) after the first molluscicide pellet application at the Edinburgh trial.



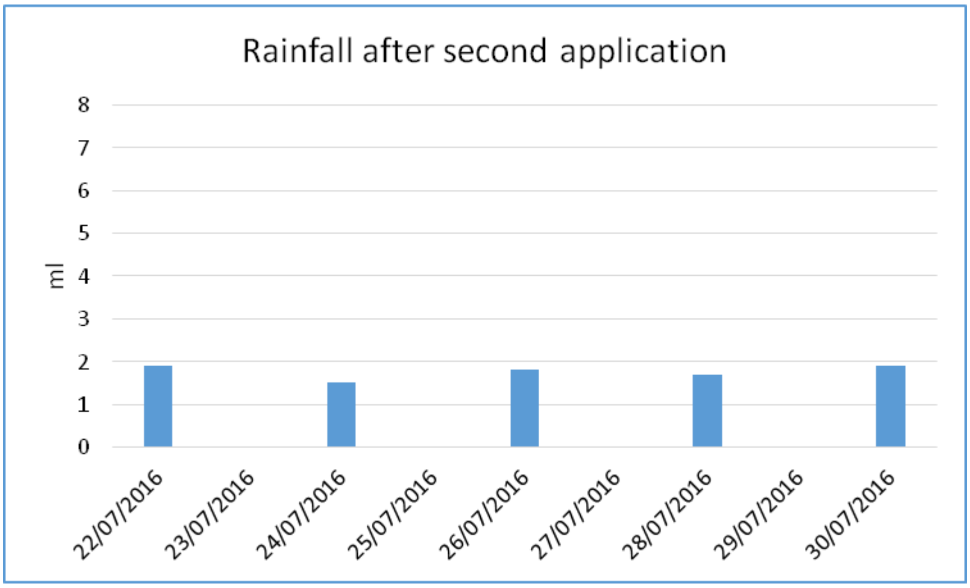


Fig. 22. Molluscicide pellet degradation score (top) and rainfall (bottom) after the second molluscicide pellet application at the Edinburgh trial.

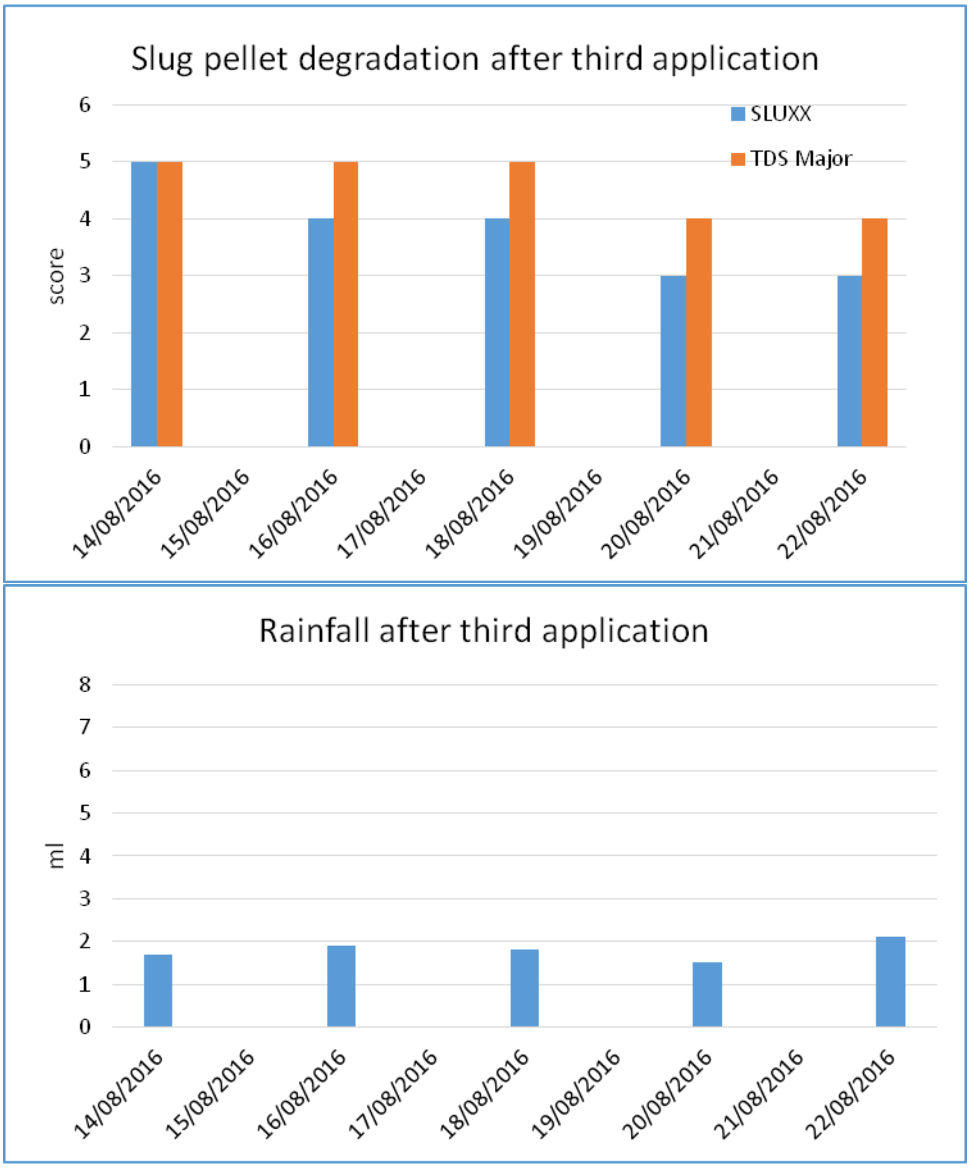


Fig. 23. Molluscicide pellet degradation score (top) and rainfall (bottom) after the third molluscicide pellet application at the Edinburgh trial.

Visual examples of molluscicide pellet degradation can be seen below (Fig. 24 and Fig. 25).

Fig. 24. Newly applied TDS Major pellets (a score of 5).

Fig. 25. Degraded TDS Major pellets (a score of 3).

7. DISCUSSION

The results from the 2015 slug trials demonstrate that the molluscicides ferric phosphate (as Sluxx HP) and metaldehyde (as TDS Major) are effective at reducing slug damage by >50% when used in a 3 application programme alone and sequentially. This confirms the claims by manufacturers of these products that they are effective against slugs, and has provided an independent evaluation of the efficacy of different slug control options. In both trials the timing of molluscicide treatments were based on key stages of the potato crop and/or environmental conditions (rainfall either happening or forecast).

With the loss of methiocarb as a molluscicide in 2015, an alternative in addition to metaldehyde was essential to avoid its overuse and potential risk of water contamination. The results from these trials have demonstrated that it is possible to use ferric phosphate as an alternative to metaldehyde, and that both molluscicides deployed in a 3 treatment programme can provide effective slug management. In addition, the use of metaldehyde at 2 recommended (full) rates and a reduced rate for the final application kept the total applied dose within that recommended by the Metaldehyde Stewardship Group of 700 a.i./ha per calendar year, and provided effective slug control in the 2015 trials.

The slug biological control agent *Phasmarhabditis hermaphrodita*, has been shown to be effective against slugs in certain environmental conditions (Rae *et al*., 2007), but its commercial use has been hampered by a relatively high cost of application. In the two trials (2015) reported here, the application rates of NemaSlug used were equivalent to 50,000 per m^2 (500,000,000 per ha), applied three times in a programme, or at burning down of the crop after two previous molluscicide applications. In both trials, NemaSlug used alone did not give effective control of slugs; in the Carrington trial slug damage was higher than in the Untreated plots, and in the Edinburgh trial slug damage was only reduced by ~25%. However, when NemaSlug was included in a programme with ferric phosphate or metaldehyde as the final treatment at burn down of the crop, slug damage was significantly reduced, indicating that NemaSlug can have a role to play in a slug management programme in conjunction with chemical molluscicides.

Previous studies by SRUC and others have demonstrated that molluscicide efficacy is enhanced when a treatment is applied just before the crop canopies meet across the rows. This places slug pellets at the base of plants, and when the crop canopies meet, the increase in humidity under the crop canopy encourages slugs up onto the soil surface where they are more likely to encounter the molluscicide baits. In these trials this was chosen as the timing for the first application of the molluscicide treatments, with the second timing dictated by rainfall, and the third when the crop was burned down. The first NemaSlug applications were applied when rainfall had occurred and was forecast to continue at early crop emergence (as recommended by the supplier). Subsequent applications were also timed around rainfall events/forecasts. These conditions were specified by the supplier to maximise the efficacy of the NemaSlug treatments.

The results from the 2016 slug trials demonstrate that the molluscicides ferric phosphate (as Sluxx HP) and metaldehyde (as TDS Major) are effective at reducing slug damage by >50% when used in either a 3x or 4x application programme alone or sequentially. Linking molluscicide application timings to local rainfall events and key crop growth timings (just before crop canopy meets across the rows and burning down) provided effective slug control. The use of the flexible 4x application programme, where an extra molluscicide application was applied in response to a local rainfall event did not decrease slug damage beyond that achieved with a 3x programme. Consequently, a 3x molluscicide treatment programme where an application just before the crop canopy meets across the rows, and at burning down as key timings, with a further timing in between those growth stages in response to a period of rainfall is recommended as a robust molluscicide programme.

The retention of the structural integrity of the molluscicide pellets after application is very much dependent on whether there is any rainfall after application. At the Holbeach Marsh trial there was a prolonged period of no rain after an application of molluscicide pellets, and pellet integrity was maintained for 20 days. In instances where there was rainfall after a molluscicide application, pellet integrity tended to decline depending on the amount of rainfall, with the TDS Major pellets maintaining integrity more consistently than the Sluxx HP pellets. As different metaldehyde and ferric phosphate molluscicide products will have differing formulations, one cannot assume that all metaldehyde products will maintain pellet integrity for longer than all ferric phosphate products. These trials just compared two products – other products regardless of active ingredient may fare better or worse in terms of pellet integrity. The key point is that even with a period of quite high rainfall (35ml in one day at Holbeach Marsh on 29th August 2016), pellets maintained integrity and efficacy for several days at a time when slugs would have been active on the soil surface due to the wet conditions, and this was reflected in the significant reductions in slug damage.

With the recent changes in the guidelines issued by the Metaldehyde Stewardship Group where it is recommended that no metaldehyde pellets should be allowed to fall within a minimum of 10 metres of any field boundary or watercourse, the demonstration of ferric phosphate as a viable alternative to metaldehyde, either as a direct replacement or use on the edges of potato crops (with metaldehyde or ferric phosphate applied to the rest of the crop) will provide an option for growers and reduce the risk of metaldehyde contamination of watercourses.

The results from these trials demonstrate that use of crop growth stage (just before crop canopies meet across the rows and burning down) to determine timing of applications of molluscicides coupled with environmental conditions (rainfall and possibly irrigation in the absence of rainfall) can lead to significant reductions in slug damage to potatoes. The molluscicides ferric phosphate and metaldehyde are both effective alone and in sequences, and there is a potential role for the biological control NemaSlug as a treatment within a molluscicide programme at the burning down timing.

8. Conclusions

- Ferric phosphate is an effective alternative to metaldehyde for the reduction of slug damage to potatoes.
- Ferric phosphate and metaldehyde can be used sequentially in programmes with no loss in efficacy.
- The key timings for molluscicide application are; just before the crop canopy meets, and at burning down of the crop.
- The timing of a recommended application of a molluscicide between crop canopy meets and burning down should be dictated by a period of rainfall/irrigation.
- Use of the slug biological control NemaSlug alone is insufficient for effective slug damage management, however, an application of NemaSlug at burning down as part of a molluscicide programme was effective at reducing slug damage at one of the two sites.
- Molluscicide pellets can maintain their integrity for up to 20 days in dry weather, and for at least a week after rainfall

9. References

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10. Acknowledgements

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