Final Report

Evaluating the effectiveness of aphid management programmes in minimising the spread of non-persistent viruses in potato seed crops in GB

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1. SUMMARY.

1.1. Aim

The project aims to understand newer approaches for management of aphids in potato crops, and how these contribute to minimising the spread of potyviruses in seed tubers. Potyviruses, principally strains of PVY, have become increasingly prevalent in ware crops, leading to concerns over the health status of seed tuber supply chains. Methods for reducing spread in seed crops are limited, due to loss of insecticides, resistance to currently available products, and the difficulty of controlling non-persistent virus transmission with insecticides. Generally milder winters are also increasing vector pressure early in the season. Mineral oils are known to be effective in reducing virus incidence, but effects have been inconsistent. Recently, work in Europe and Canada showed that frequency and timing of sprays is critical, and that combination with some cultural techniques (straw mulches and intercropping) can provide additional benefits.

1.2. Methodology

Two trials have been conducted. In 2020 a trial was located at Cambridge (Cambridgeshire, England), with an expected high vector pressure, and in 2021 the same trial was repeated near Oldmeldrum(Aberdeenshire, Scotland), with an expected lower vector pressure. Both trials were planted to the same overall plan and used the same virus infector pressure. Eight control programmes repeated in 5 replicate blocks were used at both sites. Plots were planted with a virus free stock of Maris Piper (PreBasic) and infector plants planted in the trial area to give an incidence of 14% $PVY^{O/C}$ and 2% PVY^{N}. Vector pressure was assessed by yellow water traps. Treatments were applied from 30% emergence at weekly intervals and consisted of combinations of untreated; full insecticide programme; mineral oil Olie-H, an adjuvant spray oil (Newman Cropspray 11-E) ; CCL742 mineral oil (DeSangosse Ltd, France),straw mulch and a vetch inter-row crop applied as 8 different programmed treatments. Plots were harvested and graded, and tubers taken from each plant for virus testing by ELISA.

1.3. Key findings

Insecticide treatments alone were ineffective in reducing the spread of PVY infection in these two trials. Restrictions on insecticide applications, which have further tightened since this trials programme was designed and executed demonstrate that insecticides cannot be relied upon as an effective means of control for PVY. Potato leaf roll virus (PLRV) was not present in this trial and control with insecticides remains the presumed most effective means of control (Syller 1996).

Some mineral oils were effective in reducing the spread of PVY strains at the Cambridge site. At this site an early, presumed insecticide resistant, aphid vector influx was observed. The early application of mineral oils was effective in reducing the spread of PVY. Under these same conditions, wheat straw mulch in combination with mineral oil was also effective in reducing the spread of PVY. The use of mulches and their practical constraints warrants further investigation.

Mineral oils can affect potato plants with appreciable damage being observed at the Oldmeldrum site in this study. Our understanding of the conditions which cause mineral oils phytotoxicity to the potato foliage is limited. Additional work at the same site (Burgess and Jessiman pers comm.) and previous study (Dawson et al, 2014), demonstrated significant differences between varieties and application timings in respect of the amount of damage caused by mineral oil application. Despite these concerns, mineral oils are used in many other regions (Mainland Europe, North America) where they have become an essential part of the IPM programme.

These observed phytotoxic effects can translate into effects on the yield and tuber number of crops. There is thus a physiological impact from application of oils to crops under some circumstances.

Forecasting of aphid flights before the season and in crop aphid monitoring are essential tools in the development of an integrated approach to control of PVY spread in seed potatoes. Preseason forecasts can be used to determine the requirement for tools such as mulches which are likely to be most effective against early season virus spread. Crop monitoring should be used to determine the requirements for mineral oil or other applications. Prophylactic applications are likely to lead to further resistance development (in the case of insecticides) or phytotoxicity and potentially yield penalties (in the case of mineral oil applications).

1.4. Practical recommendations

Insecticide treatments were ineffective in reducing the spread of PVY infection in these two trials and programmes reliant on insecticides alone should not be applied for control of PVY. Potato leaf roll virus (PLRV) was not present in this trial and control with insecticides remains the presumed most effective means of control (Syller, 1996).

Mineral oils CCL742 and Olie-H can be used to reduce the spread of PVY strains ($PVY^{O/C}$ and PVY^{N} serotypes in this study) and in these trials in which oil programmes were applied from soon after emergence, application of these treatments was shown to be effective.

Wheat mulches show some promise as a means of improving control of PVY spread into seed crops. They can be expected to be most effective when early flights of aphids occur.

Phytotoxicity from mineral oil applications is an important consideration. Repeated applications through the whole growing season are not recommended. Applications should be made in accordance with IPM principles, and environmental conditions. Previous work (Dawson et al 2014) has stated that certification authorities should be notified of mineral oil applications with a view to ensuring the best timing for visual crop inspection.

2. INTRODUCTION

Potyviruses such as Potato virus Y (PVY), in particular of the PVY^N serotype, have increased in prevalence in ware crops, leading to concerns over its impact on virus health in seed crops. Aphid pressure is generally increasing in milder winters and warmer summers, and the difficulty of controlling non-persistent viruses with insecticides are well known. Few potato varieties show any resistance to $PVY^{O/C}$ or PVY^N, and thus high health standards in seed tubers remains a major challenge. Previous work in AHDB project R449 (Dawson *et al*., 2014) demonstrated that the use of mineral oil sprays could reduce the incidence of potyvirus in potato seed crops, but the effects were variable, and, in some situations, there was no benefit. Since then, further evidence has emerged from investigations in continental Europe (Dupuis *et al*., 2017a,b) and Canada (McKenzie *et al*., 2016) that the timing and frequency of sprays were critical in determining outcomes. Moreover, there was evidence that the use of certain cultural control strategies gave further reduction in potyvirus incidence in harvested seed tubers (Dupuis *et al*., 2017a,b). The aim of this project is to define optimum timings and frequencies for mineral oil application to reduce transmission and spread of potyviruses in UK conditions, and to investigate whether physical additives to the growing environment can augment the activity of mineral oils. The mineral oil CCL742, formerly known as Reaper (DeSangosse Ltd, France), was included in the trials. Two contrasting trial sites were proposed: 1) a site with "high vector pressure" and 2) a site with "lower vector pressure", each trial using the same virus inoculum pressure.

In 2020 a trial was conducted at Cambridge, and this represented the high vector pressure site. The same trial was repeated near Oldmeldrum, Aberdeenshire in 2021 and this represented the low vector pressure site.

3. MATERIALS AND METHODS

In both 2020 and 2021 seasons, a virus free pre-basic stock of Maris Piper was obtained via SASA. Infector plants of the variety Marfona were also obtained from SASA. The infector plants contained both $PVY^{O/C}$(100% of tubers) and PVY^{N} (14 % of tubers) serotypes, confirmed by testing leaves from the field by ELISA. Test (bait) plots of Maris Piper were 4 rows wide and 4.5 m long, with a plant spacing of 25 cm. Infectors were planted in rows either side of each plot, giving an overall incidence in the whole planted trial area of 14 % $PVY^{O/C}$ and 2 % PVY^{N} serotypes. The trial consisted of 8 treatments randomised in 5 replicates. A schematic of the layout is shown in Figure 1.

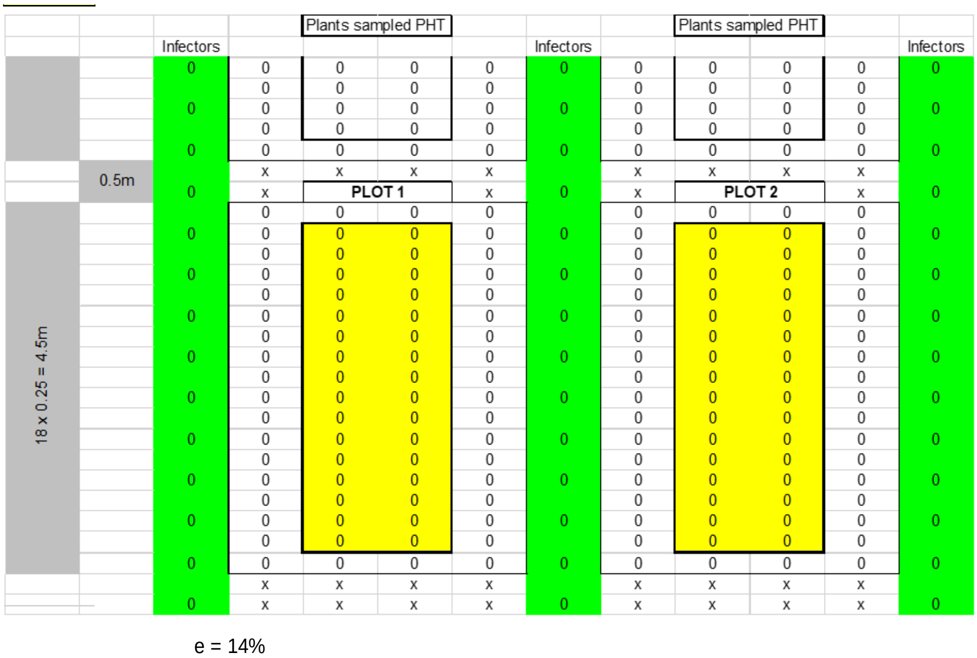

Figure 1 Schematic representation of plot layout. Yellow shaded plants are sampled for virus and then taken for yield. Green shaded plants are infector rows

Cambridge trial 2020:

Test plots and infectors were all planted on14/04/20.Four yellow water traps were placed at each corner of the trial just inside each corner plot on 15/05/20 and emptied weekly. Contents were sent to FERA for examination under the AHDB Aphid Monitoring Scheme.

All products were applied in 200 l/ha with an EP-001 sprayer at a walking speed of 1m/s, at 2.1 bar, with Flat Fan 015 nozzles spraying along the rows. A standard late blight programme for the site was applied by a tractor mounted sprayer separately from the insecticide and oil programmes. Herbicide (Stomp Aqua) was applied on 29/04/20 at 2.9 l/ha., also by tractor mounted sprayer. 200 kg/ha of nitrogen was applied post-planting on 24/04/20.

Oldmeldrum, Aberdeenshire, trial 2021

Test plots and infectors were all planted on 2/6/21. Four yellow water traps were placed in at each corner of the trial just inside each corner plot on 15th June 2021 and checked for the presence of aphids and if necessary emptied weekly and sent to FERA for examination under the AHDB Aphid Monitoring Scheme.

All products were applied in 167 l/ha with an AZO sprayer at a walking speed of 5km/hr, at 2.9 bar, with Yellow nozzles spraying along the rows. A standard late blight programme for the site was applied by a tractor mounted sprayer separately from the insecticide and oil programmes. Herbicide was applied on 13/06/21, also by tractor mounted sprayer. During herbicide application, vetch plots were covered with plastic (applied 11/6/21). This was removed the day after spraying (14/6/21).

Table 1: Treatments, products, rates and timings.

No.	**Programme**	**Description**[1]
1	Untreated	No treatments applied
2	Insecticide	Kingpin(esfenvalerate) at 0.2 l/ha every 2 weeks to maximum number permitted, then Hallmark Zeon® (lambda cyhalothrin) at 0.075 l/ha every two weeks to maximum number permitted. Optional sprays depending on trap catches: Teppeki® (flonicamid) at 0.16 kg/ha and InSyst® (acetamiprid) at 0.25 kg/ha added in alternation until maximum number permitted, then Movento® (spirotetramat) at 0.48 l/ha, after flowering, to maximum 4 applications, or when burn down complete.
3	Olie H plus insecticide	Olie H at 3.1% weekly inspray volume, plus the insecticide programme (no. 2).
4	Newman CropSpray 11-E™ then insecticide	Newman Cropspray 11-E at 2.5% in spray volume until tuber initiation, then switch to insecticide programme (No 2)
5	CCL742 plus insecticide	CCL742 at 10 l/ha weekly until emergence complete, then 15 l/ha weekly until burn down complete. Insecticide programme added in (No 2)
6	CCL742	CCL742 at 10l/ha weekly until emergence complete, then 15 l/ha weekly
7	CCL742+ straw	CCL742 at 10l/ha weekly until emergence complete, then 15 l/ha weekly
8	CCL742+ Intercrop (vetch)	CCL742 at 10l/ha weekly until emergence complete, then 15 l/ha weekly

[1] The full programmes applied to each treatment are given in Appendix 8.2

For treatment 7, chopped wheat straw (approximately 15 cm lengths) was placed between the plot rows on05/05/20(Cambridge) and 21/6/21 (Oldmeldrum) and between the outer infector and outer plot row at a rate of 5 t/ha, measuring the area as that between mid-point to mid-point of the ridge. For treatment 8, a stock of certified hairy vetch seed (*Vicia villosa* cv. Villana) was obtained from Cotswold Seeds (UK) and planted between the rows at a rate of 50kg/ha on 24/04/20 (Cambridge) and 9/6/21 (Oldmeldrum). Seed was distributed by hand in an approximate 2-3cm wide band in the bottom of the furrow, covered by approximately 1cm of soil, and lightly trodden down.

Height of the crop was assessed on one occasion at the Cambridge site by measuring from the stem base at soil level to top of the leaf canopy at three points within each plot. A visual estimate of the incidence of flowering spikes in each plot was also made at the same site, on one occasion. Plots were inspected visually for signs of phytotoxicity after each spray timing up to burn down.

The number of plants emerged was assessed on the 21/06/21and 30/06/21 at the Oldmeldrum site.

At Cambridge, burn down was achieved by firstly flailing plots on 19/08/20 to leave a stem height of 8-10 cm and then spraying immediately afterwards with Spotlight at 1/ha followed by a further Spotlight spray on 27/08/20 at 0.6l/ha. Canopy debris was moved to the furrow to ensure good exposure of cut stems. At the Oldmeldrum site0.6 l/ha Spotlight was applied on 10/9/21 and plots flailed on 10/9/21.

Tuber samples for virus testing were harvested on 04/09/20 (Cambridge site) and on the 20/10/2021 and 22/10/2021 (Oldmeldrum site) by hand digging each plant, with the exception of the end plants, within the central two rows of each plot. Two tubers of approximately 45-50 mm were harevsted from each plant at the Cambridge site. At both sites, the remaining tubers were then harvested (4/9/20 at Cambridge and 27/10/21 at Oldmeldrum) by an elevator digger so that all tubers were brought to the surface. They were then collected by hand and bagged per plot for weighing and grading.

In 2020, ELISA tests were carried-out for $PVY^{O/C}$, PVY^{N} and PVA at NIAB using reagents supplied by SASA (Lacomme *et al*, 2015). Eye plugs were grown in an insect-free glasshouse and each “two tubers” sample was extracted as a bulk after 6 weeks growth. Two technical replicates were then assayed from each extract. In 2021, ELISA tests were performed for $PVY^{O/C}$ and PVY^{N} at SASA as described in Lacomme *et al* (2015). Three tubers were collected from each of 32 non-plot-edge plants in the middle two rows of each plot at Oldmeldrum site. All 96 sampled tubers from each plot were grown in an insect-free glasshouse. Leaves from up to five grown-on tubers were bulked together and tested for $PVY^{O/C}$ and PVY^{N}. For any bulk tested positive, each individual plantlet was tested separately to identify the number of positive tubers in that bulk.

Crop measurements, graded yields and tuber numbers were transformed prior to statistical analysis where appropriate and are presented in the text. For non-virus crop data programmes were compared by Anova for a randomized block design. Virus data were analysed using logistic regression models allowing for over-dispersion and fitting both field replicate and programme effects. P values for programme comparisons of *a priori* interest have been made using linear contrasts including to test for main effects and an insecticide x CCL742 oil interaction on the response variables. Due to the exploratory nature of the trial no adjustment has been made to *p*-values in multiple comparisons and hence they should be treated as indicative. The two trials have been analysed separately.

4. RESULTS

(a) CAMBRIDGE 2020

Just under 30% emergence (between 27-29%) was reached on 19/05/20 and 100% on 28/05/20. The first treatment applications were made on 20/05/20. All application dates for the treatment programme are summarised in Appendix 8.2 Dates are also given in Appendix 8.2 , together with fungicide, herbicide and fertiliser applications, and full programme details in Appendix 8.3. Most sprays were applied at the intended 7-day interval, where weather conditions did not permit spraying the treatment was applied within 24 hours of the planned application timing. Chopped straw remained in the furrows and was not replaced, and the amount used covered the soil surface between the ridges (Figure 2). Vetch emerged well, but early growth was relatively slow, with plants below the canopy until late July/early August (Figure 3).

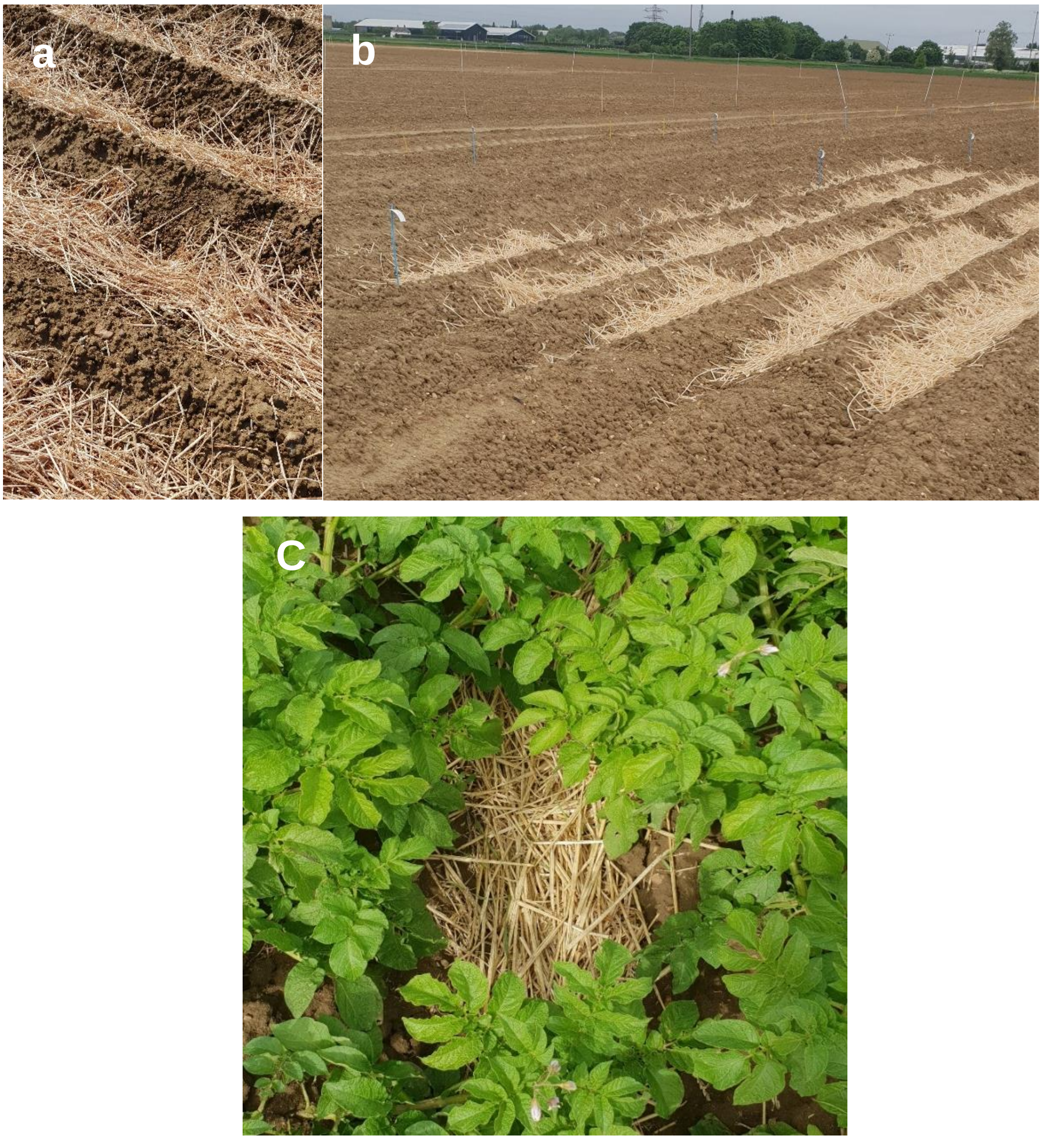

Figure 2: Chopped straw appearance a) before emergence b) plot view and c) after canopy closure on 30/06/20.

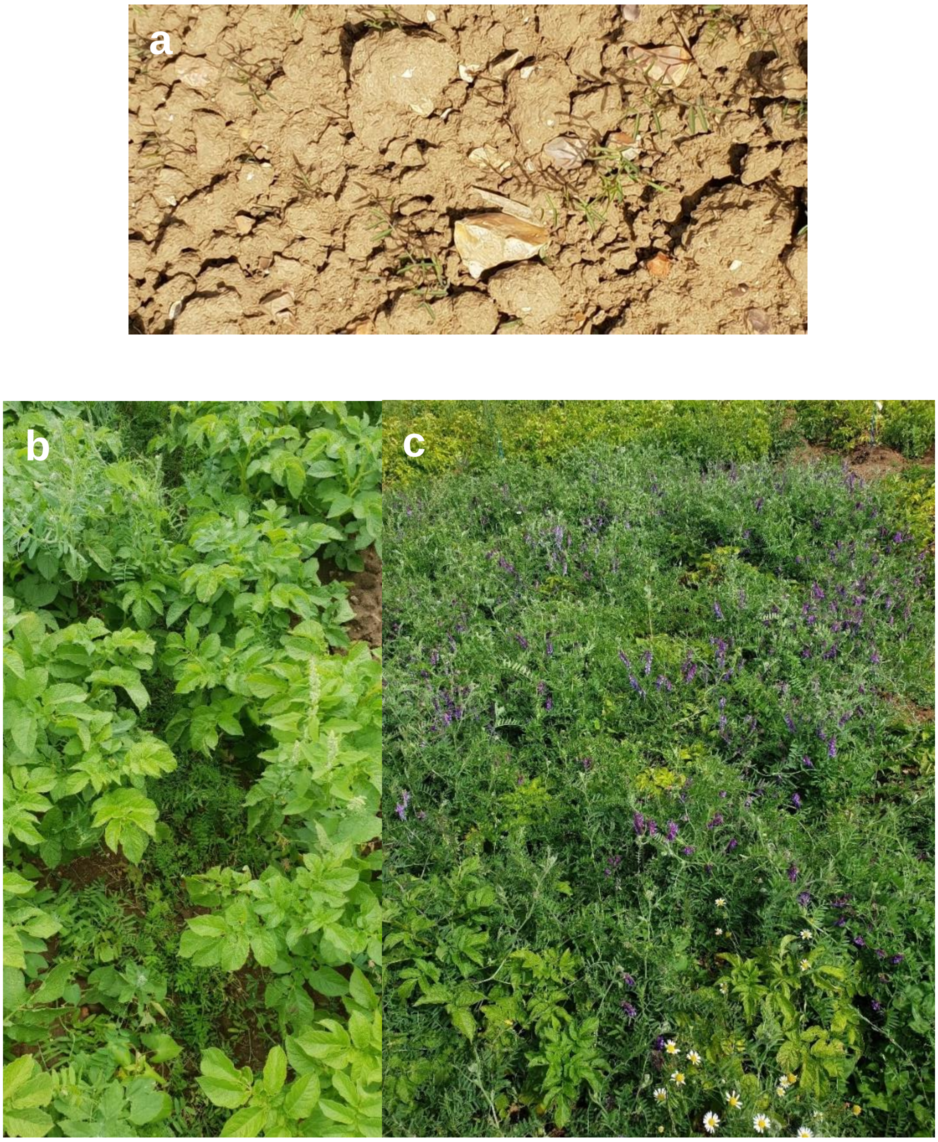

Figure 3: Inter-row vetch a) emergence on 12/05/20, b) growth beneath canopy on 30/06/20 and c) growth above canopy on 05/08/20.

Aphid pressure was very high towards the end of May (Figure 4) and though it declined, any spray that was optional depending on aphid pressure was still applied. This was due to intermittent difficulties with maintaining the integrity of the yellow water traps due to bird or animal damage, and some under-estimation of aphid numbers may have occurred.

The predominant aphid species was *Myzus persicae* at the initial stages (Table 2). *Brevicoryne brassicae* reached very high numbers in mid-June but has a comparatively low PVY index. Only small numbers of *Cavariella aegopodii* were recorded in the first half of June.

Crop heights and incidence of flowering spikes per plot were assessed on 22/06/20. There were no statistically significant effects of programmes on plant height, but flowering incidence was significantly reduced in the CCL742 oil plus vetch programme compared to CCL742 oil alone (Table 3).

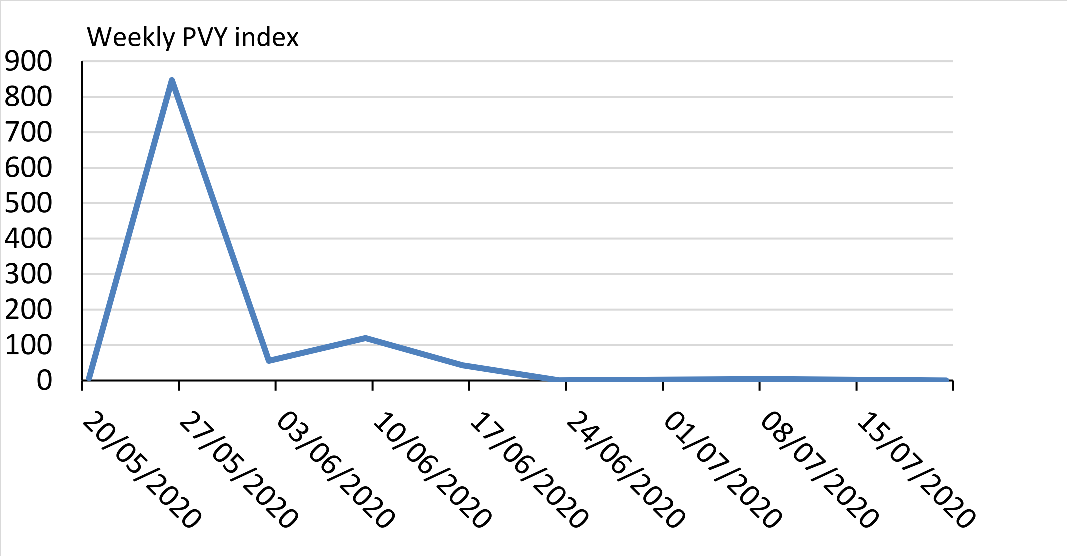

Figure 4: Weekly PVY indices from yellow water trap catches (trap 1 only shown).

Table 2: Aphid species counts in yellow water trap catches*, Cambridge 2020.

Aphid species	**20/05**	**27/05**	**03/06**	**10/06**	**17/06**	**24/06**	**01/07**	**08/07**	**15/07**	**22/07**	**PVY index**
Myzus persicae	7	847	54	117	31		2	2	1		1061
Sitobion avenae				1							0.6
Cavariella aegopodii			1	2	1						2
Brachycaudes helichrysae			3	4					1		1.7
Aulacorthum solani			1								0.2
Macrosiphum euphorbiae			1	2							0.6
Hyperomyzus lactucae			1	1	5						1.1
Aphis fabae		1	6	1	5		1	20	5	1	4
Brevicoryne brassicae		3	6	13	1000	27	9	4			10.6
Total	7	851	73	141	1042	27	12	26	7	1	108

*Counts for trap I (highest *M. persicae* counts) only are shown

Table 3: Canopy height and flowering incidence on 22/06/20.

	Treatment	**Canopy Height (cm)**	**Flowering %**
1	1 Untreated	43.5	41.0
2	2 Insecticide	41.9	56.0
3	3 Olie H + insecticide	39.5	60.0
4	4 Cropspray 11-E + insecticide	40.1	58.0
5	5 CCL742 + insecticide	41.3	60.0
6	6 CCL742	41.0	58.0
7	7 CCL742 + straw	42.4	37.0
8	8 CCL742 + vetch	40.0	32.0
	L.S.D. (5%)	3.30	21.84
	Overall P value	0.238	0.050
	CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.180	0.175
	Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.544	0.269
	CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.404	0.396
	Olie-H when on top of insecticide (2 vs 3)	0.159	0.710
	Early oil when on top of insecticide (2 vs 4)	0.274	0.853
	CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.291	1.000
	Mulch on oil (6 vs 7)	0.393	0.059
	Vetch on oil (6 vs 8)	0.540	0.021

No visual phytotoxicity damage was observed at levels which could be accurately recorded. Occasional brown markings were seen in the CCL742 oil treatment with extremely low leaf area cover(Figure 5).

There was some statistical evidence (P=0.033) of an interaction between CCL742 mineral oil and insecticide in the total number of graded tubers (Table 4). Application of CCL742 oil increased observed tuber numbers by 19% in the presence of insecticide but decreased it by 6% in its absence. There also were some statistically significant effects on total graded yield (Table 4) and on the tuber size grade distribution (Tables 5 and 7 for number and yield in different grades respectively). Total graded yield of the CCL742 plus vetch programme was lower (P<0.001) than that of untreated plots, and that of the CCL742 programme alone (P=0.001). There were more smaller tubers in the CCL742 plus vetch programme than for the untreated programme, and fewer larger ones than in either the untreated or CCL742 only programmes. Addition of CCL742 oil reduced total graded weight of tubers by 11% compared to untreated and insecticide only programmes. The effect appeared to be due to a greater number of smaller tubers. The combined CCL742 plus insecticide increased total yield of graded tubers compared to CCL742 alone (P<0.05).

Figure 5: Single leaf showing brown necrotic markings (arrowed) in CCL742 oil treated plot (02/07/2020).

Table 4: Mean total graded tuber number, and total graded weights, per hectare, values for weights are back-transformed figures.

	Treatment	Number of tubers	Ln (weight)	Back-transformed weight (t/ha)
1	1 Untreated	347,667	3.385	29.52
2	2 Insecticide	306,333	3.364	28.92
3	3 Olie H + insecticide	322,667	3.305	27.26
4	4 Cropspray 11-E + insecticide	328,000	3.324	27.77
5	5 CCL742 + insecticide	364,667	3.344	28.32
6	6 CCL742	327,000	3.162	23.61
7	7 CCL742 + straw	310,333	3.227	25.21
8	8 CCL742 + vetch	311,333	2.870	17.64
	S.E.D. (28 d.f.)	24,949	0.0814	
	L.S.D. (5%)	51,105	0.1668	
	Overall P value	0.290	P<0.001	
	CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.295	0.043	
	Insecticide; Yes/No (1 and 6 vs. 2 and 5)	0.918	0.172	
	CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.033	0.090	
	Olie-H when on top of insecticide (2 vs 3)	0.518	0.473	
	Early oil when on top of insecticide (2 vs 4)	0.393	0.624	
	CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.103	0.641	
	Mulch on oil (6 vs 7)	0.510	0.428	
	Vetch on oil (6 vs 8)	0.535	0.001	

Table 5: Mean total tuber numbers (square root transformation) per hectare in seed grade size categories (mm ranges). Back transformed values presented in Table 6.

	Programme	**10-25**	**25-30**	**30-35**	**35-40**	**40-45**	**45-50**	**50-55**	**55-60**	**>60**
1	Untreated	96	119	159	193	294	301	217	172	60
2	Insecticide	64	103	140	167	243	273	236	200	47
3	Olie H + insecticide	100	124	171	194	256	267	209	186	77
4	Cropspray 11-E + insecticide	82	131	134	197	266	296	224	155	72
5	CCL742 + insecticide	103	132	186	223	297	298	207	144	74
6	CCL742	84	124	175	235	273	293	190	123	0
7	CCL742 + straw	86	118	157	204	253	287	209	144	57
8	CCL742 + vetch	89	155	186	247	333	229	95	35	0
	S.E.D. (28 d.f.)	18.4	20.7	12.6	16.0	21.0	21.5	20.6	19.7	22.7
	L.S.D. (5%)	37.7	42.3	25.9	32.8	43.0	44.0	42.2	40.3	46.4
	Overall P value	0.526	0.431	0.001	<0.001	0.004	0.037	<0.001	<0.001	0.005
	CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.300	0.245	0.002	<0.001	0.267	0.575	0.067	<0.001	0.315
	Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.627	0.815	0.668	0.099	0.363	0.460	0.215	0.086	0.068
	CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.062	0.434	0.104	0.533	0.017	0.282	0.935	0.829	0.011
	Olie-H when on top of insecticide (2 vs 3)	0.061	0.318	0.020	0.109	0.530	0.802	0.193	0.483	0.197
	Early oil when on top of insecticide (2 vs 4)	0.324	0.189	0.631	0.073	0.273	0.279	0.560	0.031	0.277
	CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.866	0.703	0.257	0.079	0.061	0.164	0.944	0.042	0.914
	Mulch on oil (6 vs 7)	0.920	0.776	0.160	0.068	0.342	0.788	0.363	0.279	0.018
	Vetch on oil (6 vs 8)	0.779	0.147	0.397	0.440	0.008	0.006	<0.001	<0.001	1.000

Table 6: Back-transformed mean tuber numbers per hectare by size grading.

	Programme	10-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	>60
1	Untreated	9,139	14,044	25,286	37,423	86,441	90,459	46,962	29,741	3,633
2	Insecticide	4,086	10,702	19,630	27,893	58,899	74,403	55,890	40,096	2,190
3	Olie H + insecticide	9,964	15,493	29,384	37,456	65,560	71,468	43,645	34,691	5,889
4	Cropspray 11-E + insecticide	6,788	17,227	17,946	38,741	70,832	87,891	50,290	24,160	5,177
5	CCL742 + insecticide	10,598	17,537	34,615	49,600	88,253	88,811	43,035	20,837	5,515
6	CCL742	7,061	15,442	30,590	55,165	74,645	85,698	36,161	15,039	0
7	CCL742 + straw	7,379	13,999	24,539	41,808	63,978	82,320	43,767	20,837	3,237
8	CCL742 + vetch	7,962	24,045	34,511	61,216	111,185	52,228	8,966	1,196	0

Table 7: Mean yields (t/ha) in seed grade sizes (mm ranges).

Programme	10-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	>60
1 Untreated	0.06	0.23	0.71	1.59	5.53	8.80	6.23	5.31	1.13
2 Insecticide	0.04	0.19	0.56	1.20	3.96	7.39	7.28	7.14	1.59
3 Olie H + insecticide	0.07	0.27	0.83	1.60	4.24	6.87	5.93	6.11	1.81
4 Cropspray 11-E + insecticide	0.06	0.31	0.51	1.88	4.40	8.57	6.33	4.28	1.67
5 CCL742 + insecticide	0.08	0.32	0.97	2.16	5.81	8.31	5.76	3.80	1.47
6 CCL742	0.06	0.29	0.85	2.37	4.99	8.12	4.86	2.63	0.00
7 CCL742 + straw	0.05	0.26	0.69	1.78	4.05	8.13	5.90	3.77	1.10
8 CCL742 + vetch	0.06	0.45	0.98	2.53	6.69	5.10	1.51	0.47	0.00
S.E.D. (28 d.f.)	0.018	0.098	0.138	0.294	0.730	1.095	0.911	1.086	0.822
L.S.D. (5%)	0.037	0.200	0.282	0.603	1.496	2.243	1.866	2.224	1.685
Overall P value	0.336	0.324	0.012	0.002	0.007	0.044	<0.001	<0.001	0.197
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.087	0.190	0.009	<0.001	0.214	0.877	0.033	<0.001	0.291
Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.845	0.933	0.852	0.167	0.472	0.436	0.140	0.061	0.110
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.067	0.624	0.182	0.652	0.029	0.312	0.909	0.672	0.390
Olie-H when on top of insecticide (2 vs 3)	0.061	0.419	0.057	0.190	0.701	0.642	0.150	0.353	0.783
Early oil when on top of insecticide (2 vs 4)	0.149	0.248	0.720	0.028	0.553	0.288	0.305	0.014	0.923
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.521	0.636	0.336	0.064	0.041	0.201	0.850	0.042	0.677
Mulch on oil (6 vs 7)	0.713	0.735	0.241	0.058	0.208	0.996	0.263	0.303	0.191
Vetch on oil (6 vs 8)	0.783	0.116	0.360	0.580	0.028	0.010	0.001	0.057	1.000

There was statistical evidence of programme effects on virus incidence in harvested tubers (Tables 8 and 9). The incidence of $PVY^{O/C}$ was 100% in untreated plots. All of the programmes except the insecticide only and insecticide plus Newman Cropspray 11-E programme gave statistically significant reductions ($P<0.05$) in virus incidence, though the level of reduction was extremely low. However, the CCL742 oil with straw mulch programme gave the largest reduction.

The incidence of PVY^{N} was very high in the untreated plots (85.4%), but there was statistical evidence that all programmes reduced virus incidence compared to the untreated plots, with the exception of the insecticide only programme. There was strong statistical evidence (P=0.001) that applying CCL742 oil throughout the growing period reduced the proportion of PVY^{N} infected plants compared to not applying it. Similarly, the addition of OlieH to the insecticide programme further reduced virus incidence (P=0.002) compared to insecticide treatment alone. The addition of straw mulch to the full CCL742 programme gave the lowest incidence of virus, and there was weak statistical evidence (P=0.081) of the additional benefit of straw mulch. As expected, no PVA was detected in any harvested tubers of Maris Piper, which is known to be resistant to this potyvirus. Percentage control values are shown in Figure 6 for each virus.

Table 8: Incidence of PVY^{N}.

Treatment	**Logit (proportion infected)**	**Back-transformed % infected**
1 Untreated	1.765	85.4%
2 Insecticide	1.608	83.3%
3 Olie H + insecticide	0.160	54.0%
4 Cropspray 11-E + insecticide	0.759	68.1%
5 CCL742 + insecticide	0.750	67.9%
6 CCL742	0.235	55.9%
7 CCL742 + straw	-0.494	37.9%
8 CCL742 + vetch	0.607	64.7%
S.E.D. (28 d.f.) range	0.397 - 0.538	
L.S.D. (5%) range	0.814 – 1.103	
Overall P value	0.001	
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.001	
Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.411	
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.247	
Olie-H when on top of insecticide (2 vs 3)	0.002	
Early oil when on top of insecticide (2 vs 4)	0.078	
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.154	
Mulch on oil (6 vs 7)	0.081	
Vetch on oil (6 vs 8)	0.382	

Table 9: Incidence of $PVY^{O/C}$.

Treatment	**Logit (proportion infected)**	**Back-transformed % infected**
1 Untreated	-	100.00%
2 Insecticide	4.51	98.5%
3 Olie H + insecticide	3.52	96.3%
4 Cropspray 11-E + insecticide	4.55	98.6%
5 CCL742 + insecticide	3.81	97.1%
6 CCL742	3.17	94.8%
7 CCL742 + straw	2.17	87.4%
8 CCL742 + vetch	3.39	95.7%
S.E.D. (24 d.f.) range [excluding Untreated]	0.500 – 1.058	
Overall P value	<0.001	
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	-	
Insecticide; Yes/No (1 and 6 vs. 2 and 5)	-	
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	-	
Olie-H when on top of insecticide (2 vs 3)	0.263	
Early oil when on top of insecticide (2 vs 4)	0.972	
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.699	
Mulch on oil (6 vs 7)	0.046	
Vetch on oil (6 vs 8)	0.736	

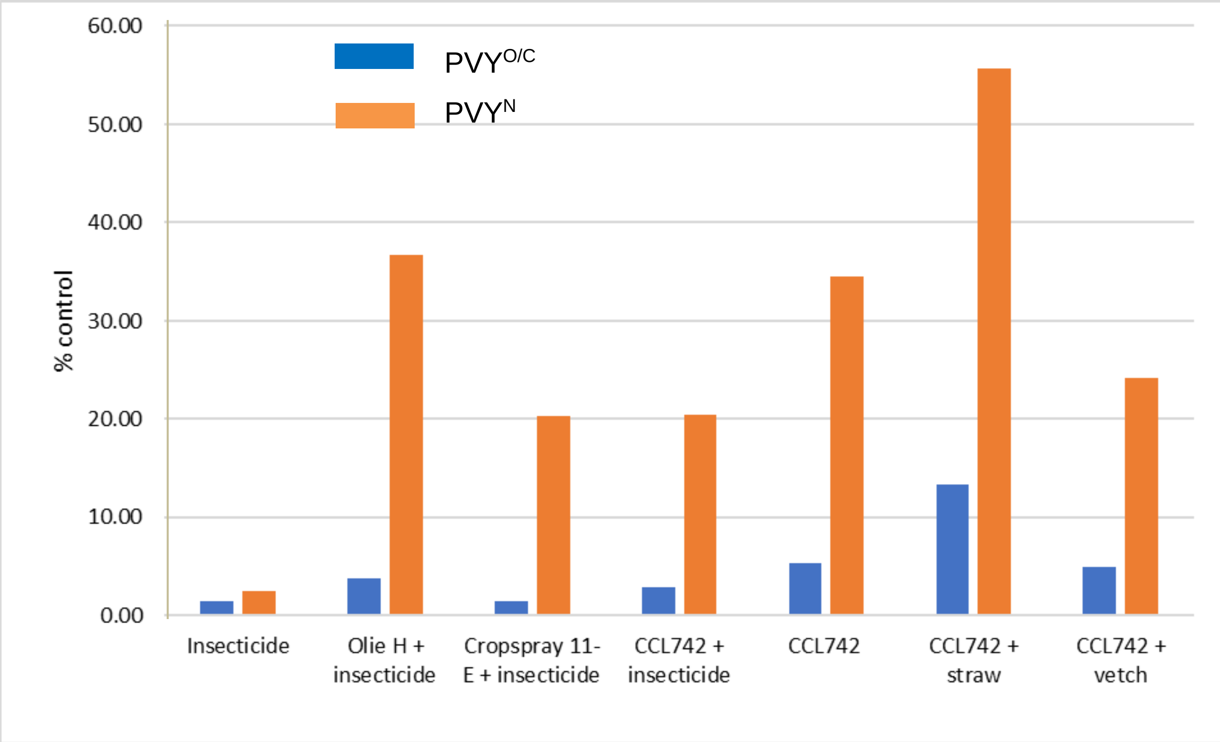

Figure 6: Mean PVY$^{O/C}$ and PVY^{N}incidence reduction expressed as a percentage compared to Untreated control for all listed programmes.

(b) OLDMELDRUM 2021

On 21/06/21, the average emergence across all plots was 59% with no significant differences recorded between different treatments (Table 10). The first application was made the following day (22/6/21), with subsequent applications being made at 7 days intervals. On 28/06/21 emergence was almost complete and there remained no significant differences recorded between the treatments. All application dates for the treatment programme are summarised in Appendix 8.2.

Similar to the Cambridge site the previous season, the straw remained in the position throughout the season and was present at harvest time. Some slight difficulties were experienced with harvest due to the presence of straw. Vetch grew well initially but was soon smothered by the potato crop which grew rapidly after the later planting and warm conditions experienced.

Aphid pressure was very low during early crop growth with the first aphids being caught on 6/07/21 coinciding with the 3rd treatment application (Figure 7; Table 11). However, the number of aphids trapped at this time was still very low (a total only 5 aphids across all 4 traps) and the vector pressure generally continued to be low in stark contrast to the Cambridge site in 2020. Very few colonising aphids were detected at the site, the first Potato aphid was recorded on 20th July and the first Peach Potato aphid on 27th July. The weekly PVY index reached a maximum of 7 on 10th August. This catch comprised a large number of ‘other’ aphid species. The main contributor to the high PVY index being the rose grain aphid.

Table10: Treatment means for percentage emergence at two assessment dates.

Treatment	21st June Emergence %	30th June Emergence %
1 Untreated	53.9	98.8
2 Insecticide	72.2	98.8
3 Olie H + insecticide	48.9	97.2
4 Cropspray 11-E + insecticide	68.9	99.4
5 CCL742 + insecticide	50.6	97.0
6 CCL742	62.8	97.6
7 CCL742 + straw	56.7	99.4
8 CCL742 + vetch	59.4	98.2
S.E.D. (28 d.f.)	10.48	1.40
L.S.D. (5%)	21.47	2.87
p value	0.296	0.507
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)		0.142
Insecticide; Yes/No (1 and 6 vs.2 and 5)		0.764
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))		0.764
Olie-H when on top of insecticide (2 vs 3)		0.264
Early oil when on top of insecticide (2 vs 4)		0.672
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)		0.888
Mulch on oil (6 vs 7)		0.210
Vetch on oil (6 vs 8)		0.672

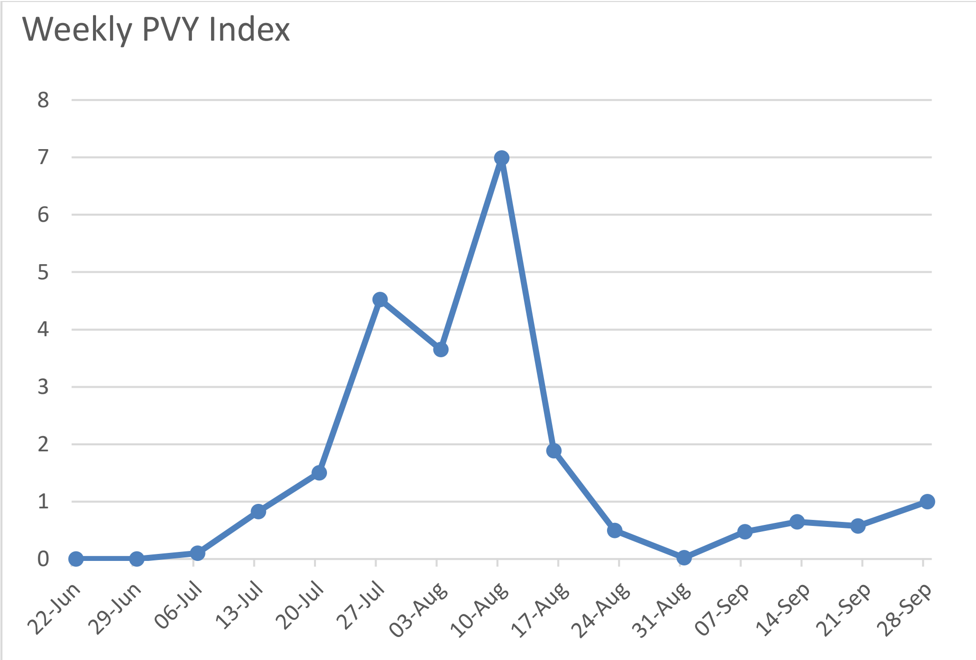

Figure 7: Weekly PVY indices from yellow water trap catches (total all 4 traps).

Table 11: Aphid species in yellow water traps (Total all 4 traps).

Most common aphids	**22-Jun**	**29-Jun**	**06-Jul**	**13-Jul**	**20-Jul**	**27-Jul**	**03-Aug**	**10-Aug**	**16-Aug**	**23-Aug**	**31-Aug**	**07-Sep**	**13-Sep**	**20-Sep**	**28-Sep**	**Total index**
Others (unidentified)	0	0	2	55	48	67	54	115	12	8	3	1	2	5	2	
Rose grain aphid (0.3)	0	0	0	5	9	27	25	42	17	0	0	0	0	0	0	37.5
Black Bean Aphid (0.1)	0	0	2	1	5	55	9	9	7	1	2	0	2	1	0	9.4
Bird cherry oat aphid (0.4)	0	0	0	0	1	0	5	9	12	3	0	3	6	5	10	21.6
Potato aphid (0.2)	0	0	0	0	7	0	8	5	2	1	0	0	0	0	0	4.6
Grain aphid (0.6)	0	0	0	0	0	0	1	8	8	2	1	0	0	0	0	12
Leaf curling plum aphid (0.21)	0	0	1	0	0	0	8	1	2	0	0	0	0	1	0	2.7
Willow Carrot aphid (0.5)	0	0	0	2	2	0	3	2	0	0	0	1	0	0	0	5.0
Currant sowthistle aphid (0.16)	0	0	0	0	0	0	0	1	5	1	3	0	0	0	0	1.6
Peach Potato aphid (1.0)	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	6.0
Pea Aphid (0.7)	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	2.1
Shallot aphid (0.2)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0.2
Totals	0	0	5	66	72	152	113	192	68	16	9	6	10	12	12	103

Prior to 13th July 2021, no damage was recorded to potato plants in the plots. However, after this date damage was noted. This ranged from small necrotic lesions (1-3 mm across, often on the lower leaves) to necrotic marking of the leaves' veinal structures. As the observed damage became more severe, it was more apparent in the upper leaves of plants. In some of the worst affected plants, areas of leaves became bleached. Figure 8.

Figure 8: Severe leaf damage observed in plots treated with CCL747 mineral oil.

The damage was assessed using a subjective scale which used the percentage of the green foliage affected as the measurement criteria. These assessments (Table 12) indicate damage was observed to the foliage of potatoes plants on 13th July and 20th July. Symptoms continued to be apparent, but no further assessment was made.

No symptoms were seen on untreated, or insecticide only treated plots. The amount of phototoxic damage to foliage was limited on treatments where either Olie-H or early applications of Newman CropSpray 11E were made. All plots treated with CCL742 were more severely affected and with visually similar symptoms.

There was strong statistical evidence ($p<0.001$) of mean differences in total graded yield between treatments (See Table 13). There was strong statistical evidence ($p<0.001$) that application of CCL742 oil reduced the total yield of tubers (18%). Similarly, in the presence of insecticide the addition of Olie-H reduced ($p=0.003$) the total yield of tubers (16%). None of the other *a priori* contrasts for total yield were statistically significant at the 5% level. These significant differences in yield did not translate into a significant difference to the total tuber numbers recorded.

However, there was statistical evidence ($p<0.05$) of differences in mean numbers of tubers between the treatments for the two largest size grade (55-65mm and >65mm) categories (Table 14). The corresponding back-transformed means are presented in Table 15. There was some evidence of fewer tubers in the larger grading categories (55-65mm and >65mm) when CCL742 mineral oil ($p<0.05$) was used or Olie-H was added to the insecticide programme ($p=0.012$, >65mm only). These reductions in tuber numbers in these size bands was reflected in the results for yield in these categories (Tables 15 and 16).

In the presence of CCL742 mineral oil, the addition of vetch led to an increase in the numbers of tubers under 35mm (p=0.011). The only significant effect of the use of a straw mulch seen in tuber numbers or yield was for weight of tubers graded >65mm (p=0.044). However, this was impacted by one exceptionally low yielding plot.

Table 12: Phytotoxicity damage recorded using a subjective scale and presented as percentage leaf area affected (no statistical analysis).

Treatment	**30 June**	**13 July**	**20 July**
1 Untreated	0	0	0
2 Insecticide	0	0	0
3 Olie H + insecticide	0	0.02	0.02
4 Cropspray 11-E + insecticide	0	0.02	0
5 CCL742 + insecticide	0	0.1	0.72
6 CCL742	0	0.1	0.72
7 CCL742 + straw	0	0.14	0.3
8 CCL742 + vetch	0	0.1	0.2

Table 13: Treatment mean total graded yields(t/ha) and total graded tuber number (no/ha).

Treatment	**Number of tubers / ha**	**Ln (weight)**	**Back-transformed weight (t/ha)**
1 Untreated	407,772	3.588	36.17
2 Insecticide	421,615	3.547	34.72
3 Olie H + insecticide	399,514	3.378	29.32
4 Cropspray 11-E + insecticide	408,015	3.502	33.19
5 CCL742 + insecticide	413,600	3.360	28.80
6 CCL742	385,671	3.379	29.35
7 CCL742 + straw	399,271	3.321	27.68
8 CCL742 + vetch	410,200	3.394	29.78
S.E.D. (28 d.f.)	21,582	0.0517	
L.S.D. (5%)	44,210	0.1058	
Overall p value	0.821	p<0.001	
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.332	p<0.001	
Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.182	0.419	
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.648	0.769	
Olie-H when on top of insecticide (2 vs 3)	0.315	0.003	
Early oil when on top of insecticide (2 vs 4)	0.534	0.391	
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.519	0.730	
Mulch on oil (6 vs 7)	0.534	0.266	
Vetch on oil (6 vs 8)	0.265	0.782	

Table 14: Tuber numbers (square root transformation) by size grading (mm).

Treatment	**<35**	**35-45**	**45-55**	**55-65**	**>65**
1 Untreated	205	352	375	250	189
2 Insecticide	219	348	396	251	171
3 Olie H + insecticide	210	365	392	227	124
4 Cropspray 11-E + insecticide	218	359	375	249	157
5 CCL742 + insecticide	239	366	394	221	117
6 CCL742	213	354	375	234	132
7 CCL742 + straw	235	368	386	217	101
8 CCL742 + vetch	260	356	390	219	115
S.E.D. (28 d.f.)	17.2	20.3	15.8	13.4	17.8
L.S.D. (5%)	35.3	41.6	32.3	27.4	36.4
Overall p value	0.055	0.964	0.683	0.045	<0.001
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.241	0.488	0.952	0.020	<0.001
Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.107	0.794	0.079	0.543	0.213
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.637	0.571	0.920	0.466	0.917
Olie-H when on top of insecticide (2 vs 3)	0.615	0.410	0.795	0.081	0.012
Early oil when on top of insecticide (2 vs 4)	0.957	0.587	0.185	0.868	0.429
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.101	0.948	0.884	0.652	0.702
Mulch on oil (6 vs 7)	0.213	0.483	0.516	0.218	0.099
Vetch on oil (6 vs 8)	0.011	0.922	0.349	0.277	0.357

Table 15: Back-transformed mean tuber numbers per hectare by size grading (mm).

Treatment	<35	35-45	45-55	55-65	>65
1 Untreated	41.871	123,985	140,483	62,483	35,602
2 Insecticide	47,990	120,869	157,019	63,073	29,365
3 Olie H + insecticide	44,231	132,969	153,765	51,492	15,330
4 Cropspray 11-E + insecticide	47,575	128,745	140,513	61,954	24,685
5 CCL742 + insecticide	57.354	133,946	155,588	48,766	13,674
6 CCL742	45,543	125,288	140,821	54,590	17,320
7 CCL742 + straw	55,390	135,729	148,706	46,991	10,251
8 CCL742 + vetch	67,601	126,714	152,316	47,874	13,219

Table 16: Mean natural log transformed yields (t/ha) by treatment and tuber size grades (mm).

Treatment	<35	35-45	45-55	55-65	>65
1 Untreated	-0.04	1.72	2.46	2.20	2.10
2 Insecticide	0.12	1.66	2.51	2.20	1.90
3 Olie H + insecticide	-0.02	1.75	2.50	1.93	1.20
4 Cropspray 11-E + insecticide	0.04	1.73	2.48	2.16	1.67
5 CCL742 + insecticide	0.27	1.70	2.47	1.89	1.07
6 CCL742	0.00	1.64	2.44	2.03	1.35
7 CCL742 + straw	0.21	1.78	2.46	1.83	0.73
8 CCL742 + vetch	0.42	1.73	2.55	1.88	1.04
S.E.D. (28 d.f.)	0.163	0.131	0.065	0.120	0.294
L.S.D. (5%)	0.333	0.268	0.133	0.246	0.602
Overall p value	0.087	0.966	0.773	0.011	P<0.001
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.405	0.849	0.590	0.008	P<0.001
Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.071	1.000	0.362	0.407	0.258
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.656	0.536	0.886	0.417	0.864
Olie-H when on top of insecticide (2 vs 3)	0.395	0.506	0.880	0.031	0.026
Early oil when on top of insecticide (2 vs 4)	0.634	0.588	0.671	0.698	0.451
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.086	0.716	0.739	0.756	0.658
Mulch on oil (6 vs 7)	0.205	0.283	0.773	0.103	0.044
Vetch on oil (6 vs 8)	0.016	0.486	0.101	0.219	0.308

Table 17: Back-transformed mean yields (t/ha) by treatment and tuber size grades (mm).

Treatment	**<35**	**35-45**	**45-55**	**55-65**	**>65**
1 Untreated	0.96	5.56	11.67	9.06	8.18
2 Insecticide	1.13	5.24	12.26	9.04	6.67
3 Olie H + insecticide	0.98	5.73	12.14	6.88	3.34
4 Cropspray 11-E + insecticide	1.04	5.63	11.92	8.63	5.33
5 CCL742 + insecticide	1.31	5.46	11.87	6.63	2.93
6 CCL742	1.00	5.15	11.46	7.63	3.86
7 CCL742 + straw	1.24	5.95	11.68	6.24	2.07
8 CCL742 + vetch	1.53	5.65	12.79	6.57	2.84

Mean virus $PVY^{O/C}$ levels were very low across all eight treatments (see Table 18). It is, therefore, perhaps not surprising that the overall test of mean differences between treatments was not statistically significant (p=0.319). The *a priori* contrast testing the effect of adding CCL742 oil bordered on statistical significance at the 5% level and would have been helped by being a contrast of the average of two treatments with that of another two treatments and hence have a reduced LSD. There was, therefore, weak statistical evidence that CCL742 oil reduced the mean percentage of tubers infected with virus $PVY^{O/C}$. In light of the non-significant overall test of treatment differences, no pairwise comparisons should be made beyond the specified *a priori* contrasts.

Table 18: Mean proportions of tubers infected* with $PVY^{O/C}$.

Treatment	**Logit (proportion infected)**	**Back-transformed % infected**
1 Untreated	-3.80	2.29%
2 Insecticide	-3.08	4.59%
3 Olie H + insecticide	-3.88	2.13%
4 Cropspray 11-E + insecticide	-3.35	3.57%
5 CCL742 + insecticide	-5.40	0.47%
6 CCL742	-4.40	1.28%
7 CCL742 + straw	-4.71	0.94%
8 CCL742 + vetch	-4.26	1.47%
S.E.D. (27 d.f.) range	0.694 – 1.397	
Overall p value	0.319	
CCL742 oil; Yes/No (treatment 1 and 2 vs 5 and 6)	0.050	
Insecticide; Yes/No (1 and 6 vs.2 and 5)	0.560	
CCL742 oil X insecticide ((1 – 2) vs. (6 – 5))	0.229	
Olie-H when on top of insecticide (2 vs 3)	0.314	
Early oil when on top of insecticide (2 vs 4)	0.702	
CCL 742 vs. Olie-H when on top of insecticide (3 vs 5)	0.318	
Mulch on oil (6 vs 7)	0.781	
Vetch on oil (6 vs 8)	0.891	

*PVY^N was only detected in two tested tubers in the entire study – one from an untreated plot and the other from a plot treated with insecticide only.

5. Discussion

The results obtained during both years of the project demonstrate some evidence for the positive effects of mineral oil programmes in reducing the incidence of PVY species in seed potato tubers. They confirm some of the previous data in AHDB project R449 (Dawson *et al*., 2014) from trials at the NIAB site (2011-2013), and data from Canada (McKenzie *et al*., 2016) and Europe (Dupuis *et al*., 2017a,b).

In 2020, the application of CCL742 mineral oil resulted in a significant ($P<0.001$) reduction in PVY^{N} incidence (from 83-85% to 56-68%). PVY^{O} incidence was close to 100% for all programmes with the exception of the CCL742 + straw programme. The high level of virus transmission can be attributed to a large peak of aphid (primarily *Myzus persicae,* peach-potato aphid) during the early part of the trial. It can be assumed that a large amount of virus spread occurred during the weeks soon after emergence.

In 2021, the aphid vector pressure was generally low throughout GB. The site at Oldmeldrum in Aberdeenshire, in an area with historically lower aphid virus vectors recorded very low vector pressure during the 2021 season. Subsequently the amount of $PVY^{O/C}$ detected in progeny tubers was low (2.3% in the untreated and 4.6% in the insecticide only). With very low virus levels the statistical power to detect mean differences between programmes would have been low. Thus, it is important to recognize that non-significance simply means that there was no statistical evidence of an effect. It does not mean there was evidence of no effect. However, the use of CCL742 mineral oil did result in a significant reduction in the proportion of tubers infected (0.5% and 1.3% respectively), further confirming the efficacy of the CCL742 mineral oil-based treatment.

The insecticide programme alone based on the use of both pyrethroids and translaminar products did not reduce virus transmission in either of the trials. In Cambridge (2020) applications of insecticide were made every 14 days and included both a pyrethroid (the maximum of 8 applications were made during the season) and translaminar products. The main aphid species present was *Myzus persicae* and resistance of this species to pyrethroids is widespread and thus the ineffectiveness of the programme is not unexpected. However, this does also provide additional evidence of the ineffectiveness of translaminar products in preventing the transmission of potyvirus.

At the Aberdeen site (2021) there was also no evidence of efficacy from a similar insecticide only based programme. However, although this is probably due to the low incidence of virus in progeny tubers and the variability inherent in the data, it is notable that an increase in virus incidence was recorded following an insecticide only programme (4.6% compared to 2.3% in the untreated). At this site, the aphid species present (Table 11) are not generally reported as being resistant to pyrethroids and some evidence of effectiveness might have been expected. The use of pyrethroids at 14-day intervals during the whole season may have provided opportunity for aphids to transmit virus between applications. It is important to note that the maximum number of applications currently permitted of pyrethroid sprays is 8 and that 7 of these were applied spread over the period of this trial.

In 2020, the addition of straw mulch to the CCL742 mineral oil programme gave the lowest virus incidence observed, and confirms results obtained by Dupuis *et al*. (2017a). Straw mulch is thought to operate by reducing the visual contrast between soil and plant to incoming aphids, making it less likely that they locate plant surfaces and is more effective in reducing aphid borne virus transmission when flights occur early in the growing season and the mulch can be ‘seen’ by aphids on the ground before full canopy coverage (closure) between drills. At Cambridge in 2020 this treatment, with CCL742 mineral oil applications, resulted in the lowest recorded incidence of $PVY^{/CN}$ (38%) although not significantly lower than the CCL742 oil treatment used without wheat mulch. The apparent effectiveness of this treatment at this site supports the view that the mulch disrupts the activity of aphids early in the season. At Oldmeldrum in 2021, there was no significant effect of wheat mulch on the incidence of virus. In 2021 at the Oldmeldrum site the aphid flights were intermittent and generally after canopy closure and the wheat mulch would not have been expected to be effective. Although there were fewer infected progeny tubers following the use of a mulch, this result was not significant.

Wheat straw mulch was applied successfully at both sites and remained in place though the growing season. During harvest, it remained present but presented minimal difficulty for the small plot machines used in these trials.

The use of vetch as a between row inter-crop is potentially thought to provide a “stylet cleansing” surface, and/or a physical barrier between crop leaves. In this project, the vetch had no effect on virus incidence, and it is possible that in 2020, insufficient plant material had grown between the rows by the time of the early influx of aphids experienced in 2020. In 2021, the treatment might have been expected to be more effective as growth of vetch was greater at the time of aphid flights. However, there was no evidence of its effectiveness in this trial.

The project used the Olie H mineral oil to provide linkage to previous work in R449, and it was clear, in 2020, that the OlieH application reduced virus incidence in combination with an insecticide programme. Since the latter offered little reduction in infection, it is probable that the oil alone is likely to be the main contributor. In addition, CCL742 mineral oil, at present available only in continental Europe for commercial use, also proved effective, both with and without insecticide. In 2021, the results provided no further evidence on the merits of different oils.

Newman Cropspray 11E is currently the only approved spray oil product in the UK, and is approved for application up to tuber initiation, but only when applied as an adjuvant (i.e. to improve the efficacy of an approved crop protection product). There was some weak ($P<0.1$) statistical evidence, in 2020, that this oil with insecticide reduced the incidence of virus compared to insecticide alone. However, it was applied as a separate treatment in this trial series and not as an adjuvant. It is presumed that the effects of this oil treatment as an adjuvant would result in similar effects on aphid borne virus transmission. when applied within the constraints outlined above. This is consistent with the observed early aphid migrations which occurred essentially during the period when this application was being made. The amount of oil used was less for Newman Cropspray 11E than either CCL742 or Olie H.

At the Cambridge site, there was no visually recordable phytotoxicity with any of the programmes, in contrast to the localised necrosis seen in previous work with mineral oil treatments in some conditions (Dawson *et al*., 2014). However, in 2021, at Oldmeldrum there was recordable levels of phytotoxicity identified. This was particularly related to the application of CCL742 mineral oil. Symptoms were such that inspection of the crop for the presence of virus symptoms could have been compromised. Mineral oils are used in many other regions globally to reduce virus spread. The presence of visible crop damage at a site in the north of the UK where conditions are generally cooler is a concern which might impact upon the uptake of mineral oil applications by seed potato growers in Scotland. . In previous work (Dawson et al, 2014) phytotoxic damage occurred where application of mineral oil treatments coincided with periods of strong sunlight.

At the Cambridge site in 2020, there were significant recorded effects on the tuber’s numbers and yield. Oil treatments resulted in a reduction in tuber size (fewer tubers in some of the larger size fractions). Similar, related, effects on the yield of different size fractions were also recorded. In 2021, a similar picture emerged of lower yields and smaller tubers following application of oil-based treatments with an 18% reduction in total graded yield following CCL742 application (compared to untreated) , and 16% for Olie-H (compared to insecticide application alone).

Intercropping with Vetch also had an effect on yield with significant reductions in the yield (and number) of tubers in the larger size fractions at the Cambridge site. This was probably due to the to competition between the potato and vetch plants. However, at the

Aberdeenshire site there were no such effects recorded on yield. It is notable that at this site the Vetch was less vigorous. Wheat straw mulch had no significant effect on the yield or tuber number in either trial.

6. CONCLUSIONS

Insecticide treatments were ineffective in reducing the spread of PVY infection in these two trials. Restrictions on insecticide applications, which have further tightened since this trial programme was designed and executed demonstrate that insecticides cannot be relied upon as an effective means of control for PVY. Potato leaf roll virus (PLRV) was not present in these trials and control with insecticides remains the presumed most effective means of control.

The Cambridge trial (2020) demonstrated that CC742 is an effective mineral oil-based treatment for the control of PVY strains. At this site an early, presumed insecticide resistant, aphid vector influx was observed, and the early application of mineral oils was effective in reducing the spread of PVY. Under these same conditions wheat straw mulch, in combination with mineral oil, was also effective in reducing the spread of PVY. The use of mulches and their practical constraints warrants further investigation.

Mineral oils can cause damage to potato plants with significant phytotoxicity being observed at the Oldmeldrum site in this study. Our understanding of the conditions which cause mineral oils to damage potato foliage is limited. Additional work at the same site (Burgess and Jessiman, Pers comm.) demonstrated statistically significant differences between varieties and application timings in respect of the amount of damage caused by mineral oil application. Variety effects were also reported in a preceding AHDB funded project (Dawson et al, 2014). However, mineral oils are used, successfully, in many other seed potatoes producing regions, such as Northern and Eastern mainland Europe and North America to reduce the spread of non-persistent viruses. (for a review see Dupuis *et al*, 2017b)

These observed phytotoxic effects can impact on the yield and tuber number of crops. There is thus a physiological impact from application of oils to crops under some circumstances. It has been recommended (Dawson et al., 2014) that inspection authorities are informed of application such that the most appropriate time for an effective crop inspection can be chosen.

Forecasting of aphid flights before the season and in crop aphid monitoring are essential tools in the development of an integrated approach to control of PVY spread in seed potatoes. Pre-season forecasts can be used to determine the requirement for tools such as mulches which are likely to be most effective against early season virus spread. Crop monitoring (e.g. Yellow water traps) should be used to determine the requirements for mineral oil or other applications. Prophylactic applications are likely to lead to further resistance development (in the case of insecticides) or phytotoxicity and potentially yield penalties (in the case of mineral oil applications).

7. References

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8. APPENDICES

8.1 Products, rates and application dates for agrochemicals and fertilisers

Cambridge 2020

Application date	Product	Type	Rate	Unit (ltr/kg) ha	growth stage	Comments
23/03/2020	TSP	fertiliser	220	kg	pre-drill	P
24/03/2020	MOP	fertiliser	170	kg	pre-drill	K
14/04/2020	**Trial Planted**					
29/04/2020	Stomp Aqua	Herbicide	2.9	lt	Pre-em	
20/05/2020	Curzate M	fungicide	2	Kg		blight 1
20/05/2020	1st Treatments application					30% Emergence
27/05/2020	2nd Treatments application					
30/05/2020	Invader	fungicide	2.4	kg		blight 2
03/06/2020	3rd Treatments application					
07/06/2020	ZorvecEndavia	fungicide	0.4	lt		blight 3
07/06/2020	Video	fungicide	2	kg		blight 3
07/06/2020	Falcon	herbicide	1	lt		blight 3
09/06/2020	4th Treatments application					
17/06/2020	5th Treatments application					
17/06/2020	ZorvecEndavia	fungicide	0.4	lt		blight 4
24/06/2020	6th Treatments application					
24/06/2020	Invader	fungicide	2.4	kg		blight 5
24/06/2020	Option	fungicide	0.15	kg		blight 5
24/06/2020	Falcon	herbicide	1	lt		blight 5
01/07/2020	7th Treatments application					
01/07/2020	Revus	fungicide	0.6	lt		blight 6
06/07/2020	Derrex	molluscicide	7	kg		slugs
09/07/2020	8th Treatments application					
12/07/2020	Infinito	fungicide	1.6	lt		blight 7
14/07/2020	Derrex	molluscicide	7	kg		slugs
15/07/2020	9th Treatments application					
18/07/2020	Zampro	fungicide	0.8	lt		blight 8
18/07/2020	Tizca	fungicide	0.4	lt		blight 8
22/07/2020	Revus	fungicide	0.6	lt		blight 9
22/07/2020	10th Treatments application					
29/07/2020	Infinito	fungicide	1.6	lt		Blight 10
29/07/2020	11th Treatments application					
06/08/2020	12th Treatments application					

06/08/2020	Infinito	fungicide	1.6	lt		blight 11
12/08/2020	Zampro	fungicide	0.8	lt		blight 12
12/08/2020	13th Treatments application					
19/08/2020	Infinito	fungicide	1.6	lt		blight 13
19/08/2020	Flailed	physical	N/A	N/A		Desiccation
19/08/2020	Spotlight	herbicide	1	lt		Desiccation
20/08/2020	14th Treatments application					
27/08/2020	Infinito	fungicide	1.6	lt		blight 14
27/08/2020	Spotlight	herbicide	0.6	lt		Desiccation
27/08/2020	15th Treatments application					
04/09/2020	**Trial Harvested**					

Aberdeen 2021

BACK OF FINGASK SRUC PLOTS **Potatoes** **0.80 ha** **Harvest Date: 31/08/2021** **EHD: No Restriction**

Activity Date / Timing	Operation	Advisor	Product	HI	Rate	Reason	Water	Area	Wind Spd / Dir Temp / Hum	Operator	Machine
13/06/2021 (plan date) -1:Pre Emergence	Spray Plan #78	Charlie Catto (20039270)	Backrow (ADJ0850) Paraffinic Petroleum Oil (60 % w/w)		0.300 lts/ha	Soil binding adjuvant	300.00 lts/ha	0.80 ha	_ / _ _ / _	Sandy Mitchell	RB 35
			Clayton Mizuna (19659) Metribuzin (70 % w/w)		0.750 kgs/ha	Weed Control					
			Praxim (16871) Metobromuron (500 g/l)		2.200 lts/ha	Weed control					
01/07/2021 (plan date) 65:10% ground cover	Spray Plan #84	Charlie Catto (20039270)	Select MAP (MBS984) Phosphorus (61 %); nitrogen (12 %)		5.000 kgs/ha	Growth Stimulation - Tuber Numbers	200.00 lts/ha	0.80 ha	_ / _ _ / _	Sandy Mitchell	RB 35
			Nautile DG (16653) Mancozeb (68 % w/w); Cymoxanil (5 % w/w)		2.000 kgs/ha	Blight control					
			Dimix 500 SC (18459) Dimethomorph (500 g/l)	7 days	0.300 lts/ha	Blight control					
05/07/2021 (plan date) 90:40% ground cover	Spray Plan #88	Charlie Catto (20039270)	Select MAP (MBS984) Phosphorus (61 %); nitrogen (12 %)		5.000 kgs/ha	Growth Stimulation - Tuber Numbers	200.00 lts/ha	0.80 ha	_ / _ _ / _	Sandy Mitchell	RB 35
			Nutri-Phite PGA (MBS264)		0.500 lts/ha	Phosphite Root enhancment					
			Leimay (19280) Amisulbrom (200 g/l)	7 days	0.500 lts/ha	Blight control					
			Sipcam C50 WG (16743) Cymoxanil (50 % w/w)	7 days	0.240 kgs/ha	Blight control - Kick Back					
13/07/2021 (plan date) 100:60% ground cover	Spray Plan #94	Charlie Catto (20039270)	Evagio (18279) Mandipropamid (250 g/l)	3 days	0.600 lts/ha	Blight control	200.00 lts/ha	0.80 ha	_ / _ _ / _	Sandy Mitchell	RB 35
			Option (16959) Cymoxanil (60 % w/w)	1 days	0.150 kgs/ha	Blight control					
15/07/2021 (plan date) 110:80% ground cover	Spray Plan #96	Charlie Catto (20039270)	Versilus (18618) Benthiavalicarb (15 % w/w)	3 days	0.400 kgs/ha	Blight control	200.00 lts/ha	0.80 ha	_ / _ _ / _	Sandy Mitchell	RB 35
			Nautile DG (16653) Mancozeb (68 % w/w); Cymoxanil (5 % w/w)		1.500 kgs/ha	Blight control					

23/07/2021 (plan date) 125:Early Flowering	Spray Plan #102	Charlie Catto (20039270)	Infinito (16335) Propamocarb hydrochloride (625 g/l); Fluopicolide (62.5 g/l)	7 days	1.600 lts/ha	Blight control	200.00 lts/ha	0.80 ha	_/_ _/_	Sandy Mitchell	RB 35
28/07/2021 (plan date) 125:Early Flowering	Spray Plan #106	Charlie Catto (20039270)	Evagio (18279) Mandipropamid (250 g/l)	3 days	0.600 lts/ha	Blight control	200.00 lts/ha	0.80 ha	_/_ _/_	Sandy Mitchell	RB 35
			Nautile DG (16653) Mancozeb (68 % w/w); Cymoxanil (5 % w/w)		2.000 kgs/ha	Blight control					
11/08/2021 (plan date) 135:Late Flowering	Spray Plan #110	Charlie Catto (20039270)	Leimay (19280) Amisulbrom (200 g/l)	7 days	0.500 lts/ha	Blight control	200.00 lts/ha	0.80 ha	_/_ _/_	Sandy Mitchell	RB 35
			Nautile DG (16653) Mancozeb (68 % w/w); Cymoxanil (5 % w/w)		1.875 kgs/ha	Blight control					
17/08/2021 (plan date) 135:Late Flowering	Spray Plan #112	Charlie Catto (20039270)	Versilus (18618) Benthiavalicarb (15 % w/w)	3 days	0.350 kgs/ha	Blight control	200.00 lts/ha	0.80 ha	_/_ _/_	Sandy Mitchell	RB 35
			Nautile DG (16653) Mancozeb (68 % w/w); Cymoxanil (5 % w/w)		2.000 kgs/ha	Blight control					
23/08/2021 (plan date) 135:Late Flowering	Spray Plan #116	Charlie Catto (20039270)	Crusade (MBS726)		0.350 lts/ha	Blight Spray Adjuvant & Drift Reduction	200.00 lts/ha	0.80 ha	_/_ _/_	Sandy Mitchell	RB 35
			Evagio (18279) Mandipropamid (250 g/l)	3 days	0.600 lts/ha	Blight control					
			Dimix 500 SC (18459) Dimethomorph (500 g/l)	7 days	0.300 lts/ha	Blight control					
31/08/2021 (plan date) 155:75% senescence	Spray Plan #120	Charlie Catto (20039270)	Tizca (18813) Fluazinam (500 g/l)		0.400 lts/ha	Blight Control	200.00 lts/ha	0.80 ha	_/_ _/_	Sandy Mitchell	RB 35
			Nautile DG (16653) Mancozeb (68 % w/w); Cymoxanil (5 % w/w)		2.000 kgs/ha	Blight control					
10/09/2021 (plan date) 150:50% senescence	Spray Plan #124	Charlie Catto (20039270)	Ranman Top (14753) Cyazofamid (160 g/l)	7 days	0.500 lts/ha	Blight control	200.00 lts/ha	0.80 ha	_/_ _/_	Sandy Mitchell	RB 35
			Spotlight Plus (18698) Carfentrazone-ethyl (60 g/l)	7 days	0.600 lts/ha	Haulm dessication					

8.2 Programme details and application dates

Cambridge 2020

Timing		Appplication	T1	T2	T3	T4	T5	T6	T7	T8
E	week 1	20/05/2020	untreated	Kingpin	Olie H + Kingpin	CropSpray 11 E	Reaper+ Kingpin	Reaper	Reaper + straw	Reaper + vetch
E+ 7	week 2	27/05/2020	untreated		Olie H	CropSpray 11 E	Reaper	Reaper	Reaper + straw	Reaper + vetch
E +14	week 3	03/06/2020	untreated	Kingpin + Teppeki	Olie H + Kingpin + Teppeki	CropSpray 11 E	Reaper + Kingpin + Teppeki	Reaper	Reaper + straw	Reaper + vetch
E +21	week 4	09/06/2020	untreated		Olie H	CropSpray 11 E	Reaper	Reaper	Reaper + straw	Reaper + vetch
E +28	week 5	17/06/2020	untreated	Kingpin + Insyst	Olie H+ Kingpin + Insyst	Kingpin + Insyst	Reaper+ Kingpin + Insyst	Reaper	Reaper + straw	Reaper + vetch
E +35	week 6	24/06/2020	untreated		Olie H		Reaper	Reaper	Reaper + straw	Reaper + vetch
E+ 42	week 7	01/07/2020	untreated	Kingpin + Teppeki	Olie H + Kingpin + Teppeki	Kingpin + Teppeki	Reaper + Kingpin + Teppeki	Reaper	Reaper + straw	Reaper + vetch
E + 49	week 8	09/07/2020	untreated		Olie H		Reaper	Reaper	Reaper + straw	Reaper + vetch
E + 56	week 9	15/07/2020	untreated	Hallmark Zeon + Insyst	Olie H + Hallmark Zeon + Insyst	Kingpin + Insyst	Reaper+ Hallmark Zeon + Insyst	Reaper	Reaper + straw	Reaper + vetch
E + 63	week 10	22/07/2020	untreated		Olie H		Reaper	Reaper	Reaper + straw	Reaper + vetch
E+ 70	week 11	29/07/2020	untreated	Hallmark Zeon + Movento	Olie H + Hallmark Zeon + Movento	Kingpin + Teppeki	Reaper+ Hallmark Zeon + Movento	Reaper	Reaper + straw	Reaper + vetch
E+ 77	week 12	06/08/2020	untreated		Olie H		Reaper	Reaper	Reaper + straw	Reaper + vetch
E +84	week 13	12/08/2020	untreated	Hallmark Zeon + Movento	Olie H +Hallmark Zeon + Movento	Hallmark Zeon + Movento	Reaper +Hallmark Zeon + Movento	Reaper	Reaper + straw	Reaper + vetch
E + 91	week 14	20/08/2020	untreated		Olie H		Reaper	Reaper	Reaper + straw	Reaper + vetch
E + 98	week 15	27/08/2020	untreated	Hallmark Zeon + Movento	Olie H + Hallmark Zeon + Movento	Hallmark Zeon + Movento	Reaper + Hallmark Zeon + Movento	Reaper	Reaper + straw	Reaper + vetch

Aberdeen 2021

Growth stage	Week	Date	T1	T2	T3	T4	T5	T6	T7	T8
Planting		02/06								
	1	22/06	Untreated	Kingpin	Olie h + Kingpin	CropSpray 11 E	CCL742+ Kingpin	CCL742	CCL742 + straw	CCL742 + vetch
	2	29/06	Untreated		Olie h	CropSpray 11 E	CCL742	CCL742	CCL742 + straw	CCL742 + vetch
100% emergence	3	06/07	Untreated	Kingpin + Teppeki	Olie h + Kingpin + Teppeki	CropSpray 11 E	CCL742 + Kingpin + Teppeki	CCL742	CCL742 + straw	CCL742 + vetch
	4	13/07	Untreated		Olie h	CropSpray 11 E	CCL742	CCL742	CCL742 + straw	CCL742 + vetch
Tuber initiation	5	20/07	Untreated	Kingpin + Insyst	Olie h + Kingpin + Insyst	Kingpin + Insyst	CCL742+ Kingpin + Insyst	CCL742	CCL742 + straw	CCL742 + vetch
	6	27/07	Untreated		Olie h		CCL742	CCL742	CCL742 + straw	CCL742 + vetch
	7	03/08	Untreated	Kingpin + Teppeki	Olie h + Kingpin + Teppeki	Kingpin + Teppeki	CCL742 + Kingpin + Teppeki	CCL742	CCL742 + straw	CCL742 + vetch
	8	10/08	Untreated		Olie h		CCL742	CCL742	CCL742 + straw	CCL742 + vetch
	9	16/08	Untreated	Hallmark Zeon + Insyst	Olie h + Hallmark Zeon + Insyst	Kingpin + Insyst	CCL742+ Hallmark Zeon + Insyst	CCL742	CCL742 + straw	CCL742 + vetch
	10	23/08	Untreated		Olie h		CCL742	CCL742	CCL742 + straw	CCL742 + vetch
	11	31/08	Untreated	Hallmark Zeon + Movento	Olie h + Hallmark Zeon + Movento	Kingpin + Teppeki	CCL742+ Hallmark Zeon + Movento	CCL742	CCL742 + straw	CCL742 + vetch
	week 12	07/09	Untreated		Olie h		CCL742	CCL742	CCL742 + straw	CCL742 + vetch
	week 13	Flail 10/9	Untreated	Hallmark Zeon + Movento	Olie h +Hallmark Zeon + Movento	Hallmark Zeon + Movento	CCL742 +Hallmark Zeon + Movento	CCL742	CCL742 + straw	CCL742 + vetch

8.3 Products used and rate of application

Product name	**Active ingredient**		**Application rate**
Kingpin	Esfenvalerate (25g/l)	Pyrethroid	200 ml/ha
Teppeki	flonicamid (500g/kg)	Pyridine carboxamide	160 g/ha
Insyst	Acetamiprid (20% w/w)	Neonicotinoid	250 g/ha
Hallmark Zeon	Lambda-cyhalothrin (100 g/l)	Pyrethroid	75 ml/ha
Movento	Spirotetramat (150 g/l)	Tetramic acid	480 ml/ha
CCL742	Mineral oil	Oil	10 l/ha (first three sprays) then 15 l/ha
OlieH	Mineral oil	Oil	3.1% in 200 l/a (Cambridge) or 167 l/ha (Aberdeenshire).
Newman Cropspray 11E	Mineral oil	Oil	2.5% in 200 l/a (Cambridge) or 167 l/ha (Aberdeenshire

9. KNOWLEDGE EXCHANGE ACTIVITIES

KE activities were constrained during 2020 and 2021 by the Covid-19 pandemic. However, the project was described in several virtual meetings during 2020 and 2021

Cambridge University Farm Potato Grower Association events:

1. Video and description of the project at the trial site 16th June 2020 (JET)
2. Update video and description at the trial site 28th July 2020 (JET)
3. CUPGRA virtual conference 16th December 2020– Virus Forum – general discussion on virus management (JET, CL, PB)

AHDB:

1. AHDB Webinar 7th July 2020– project outline and update (JET)
2. AHDB Agronomy Week 3rd December 2020: presentation of available results (JET)

Other activities:

1. Presentations to corporate SACAPP members, February 2021 and 2022 (PB, IJ)
2. Presentations to Association of Independent Potato Consultants, Feb 2021 and 2022 (PB)
3. Presentations to SACAPP agronomy groups (6), various dates during winter 2021 and 2022 (PB, IJ and others)
4. National Virus Form11th February 2021 – overview of results, via AHDB presenter (PB, CL, JET)
5. Discussion during SABVWG meeting, March 2021 and March 2022 (PB, CL)
6. SPot Farm and seed growers' liaison meeting 4th March 2021 (PB, JET, CL)
7. NIAB internal seminar 28th April 2021 (JET)
8. Project mention in Potato Review, July 2020
9. CPM, April 2021, "Integrated approach for PVY"
10. Publication of SABVWG Guidelines for 2021 growing season and updated for 2022 (PB)

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