



Final Report

Strategies for Quantifying and Controlling Free Living Nematode Populations and Consequent Damage by Tobacco Rattle Virus to Improve Potato Yield and Quality

Work package 2 (Field Trials)

Ref: R440

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1. SUMMARY

The aims of this work package were:

- to establish the importance of (*Para*)*Trichodorus* direct feeding damage on yield and processing quality, and the response of potatoes to a nematicide treatment;
- to evaluate potato varietal responses to high pressure nematode and Tobacco Rattle Virus (TRV) situations, by measuring yield and quality responses to nematicide for a range of crisping, french fry and fresh market varieties;
- to evaluate alternative control strategies for managing free-living nematode (FLN) populations in the soil.

1.1. Methods

A total of twelve field trials were carried out. These were at four sites (Yorkshire, West Midlands, Norfolk and Scotland) over three seasons (2011-2013). Each trial used the same 12 potato varieties and received a nematicide treatment (Vydate 10G) as well as no nematicide treatment. All trials were fully replicated (n=6) with assessments of nematode populations pre-planting and post-harvest, crop emergence, vigour, yield, quality and processing characteristics.

To evaluate alternative treatments against FLN, sites were planted with biofumigant mustards or oil radish the season before potatoes over 3 seasons in England and two seasons in Scotland (a total of 5 trials). Other treatments against FLN were applied in the season of potato planting. These included novel crop protection products (derived from mustard and chilli), terpenes, plant defence elicitors (harpin), and a standard nematicide (Vydate 10G). The trials were fully replicated (n=6). All the potato crops were treated with a standard fertiliser, herbicide and fungicide programme.

1.2. Results

The FLN counts reported from individual plots ranged from 1 to 870 trichodorids and 0 to 141 *Pratylenchus* species per 200 g soil. The outcomes of these trials demonstrated that the spatial distribution of FLN can vary significantly across a field, highlighting the importance of ensuring that a representative sample of the entire field is taken when sampling for FLN.

1.2.1. Direct Feeding Damage

The impact of FLN on the potato crop is dependent on soil conditions and the rate at which the crop can get established, and if crops can emerge rapidly, they can 'grow away' from even relatively high FLN populations without any significant reduction in yield and quality.

Pentland Dell responds negatively to the presence of FLN, with significant reductions in yield (total and marketable), tuber number, and average tuber size. Other varieties such as Harmony (tuber number), Lady Rosetta (total and marketable yield), Crisp4All (standardised marketable dry matter 23% yield) and Saxon (standardised dry matter 23% yield) were significantly affected in a negative way by FLN feeding.

Overall, the analyses of the response of varieties to the use of Vydate 10G with differing FLN counts show that there is no clear indication of a FLN threshold population for impact on total yield or marketable yield.

In terms of FLN feeding damage risk, the use of a nematicide may provide a consolidation of yield (i.e. maintain yield stability), particularly where planting in conditions that will prolong crop emergence and establishment.

1.2.2. TRV spraing

In the trials the use of a nematicide (Vydate 10G) significantly reduced TRV spraing symptoms. Varieties varied in the extent to which they showed symptoms. Overall, Shelford, Lady Rosetta and Saxon showed the least spraing in the untreated plots whereas Casablanca and Pentland Dell had the highest level of spraing symptoms. Where the presence of TRV is confirmed either through past history in the field or via a diagnostic test, use of a nematicide and/or the use of a resistant variety is recommended.

1.2.3. Alternative Control Options

Previous experience of growing crops with a biofumigant potential (such as indian mustards and oil radish) suggests that getting the agronomy of the biofumigant crops (weed management, seed rate, fertiliser input, sowing date and incorporation) right is crucial to get the best nematocidal effects from these crops. In the trials carried out as part of this project, issues with finding a 12 week window for optimum biofumigant growth, especially in Scotland, were highlighted. A suitable window is required to allow sufficient biofumigant biomass to be produced. Drilling beyond mid-August is a risk.

Potato crops following incorporation of biofumigant crops did occasionally have an increase in yield but not significantly so compared to untreated crops. Growing oil seed radish (Contra) prior to Pentland Dell led to a significant reduction in TRV spraing symptoms compared to the untreated crop. However, use of a nematicide, whether a biofumigant treatment was used or not, was the most effective approach at reducing TRV spraing symptoms.

Use of novel 'in season' treatments such as harpin, terpene and liquid mustard did not significantly improve yields or reduce TRV spraing symptoms.

2. INTRODUCTION

2.1. Work Package 2: Field Trials

There has been a lack of consensus on the relationship between nematode populations and their impact on potato yield (Olthof & Potter, 1973; Olthof, 1987; Mathias, 1990). Damage thresholds for (*Para*)*Trichodorus* tend to be at the 100 nematodes in 250 g soil level upwards (Mathias, 1990, Dale & Neilson, 2006), whereas *Pratylenchus* damage thresholds in potato have been stated from as low as 25 nematodes/250 g soil (Olthof, 1987) up to 625 nematodes/250 g soil (Dale & Neilson, 2006). *Longidorus* populations of 20-25 nematodes/250 g soil have been reported as damaging to potatoes (Mathias, 1990; Dale & Neilson, 2006). Potato cultivars respond differently to nematode populations, and other factors such as soil temperature and moisture content which are important for nematode activity, damage

and survival have a significant impact on whether yield loss occurs (Verschoor *et al.*, 2001; Dale & Neilson, 2006).

Alternative nematode control methods have been investigated, with the nematode-suppressive effect of incorporating brassica residues into soil being often demonstrated, with subsequent benefits to the following crop in a rotation (Brown & Morra 1997; Matthiessen & Kirkegaard, 2006; Monfort *et al.*, 2007). This “mustard effect” is attributed to glucosinolate compounds contained in brassica residues. Toxicity is attributed to enzymatically induced breakdown products of glucosinolates, a large class of compounds known as isothiocyanates and nitriles that suppress nematodes by interfering with their reproductive cycle. These glucosinolate breakdown products are similar to the chemical fumigant metam-sodium, which degrades in soil to methyl isothiocyanate. Oil radish as a green manure has dramatically reduced stubby root nematode (*Para*)*Trichodorus*) and root lesion nematode (*Pratylenchus*) in Idaho potato fields (Anon, 2001, Smallwood, *pers. comm.*). Rapeseed and sudan grass green manures grown prior to potatoes in Washington, provided between 72 and 86 percent control of the root-knot nematode in that crop (Stark, 1995). Studies in Sweden are also showing promise in the use of mustard, oil radish and arugala (*Eruca sativa*) in reducing free-living nematode populations (Manduric, 2008) and are being evaluated as TRV management in potatoes.

While there are other approaches such as biocontrol agents such as fungi with known nematophagous activity, the data are based on *in vitro* laboratory experiments which are difficult to extrapolate to field scale and practices. Unpublished research at SRUC has looked at a liquid formulation of mustard and chilli (Liquid Caliente), which reduced nematode populations by 40 % when applied as a soil drench to a potato field prior to planting (Evans, unpublished).

Another approach that has been utilised in field trials in potatoes is to stimulate the natural defences of potatoes to reduce nematode feeding and virus infection. Harpin proteins isolated from a plant-pathogenic bacterium elicit hypersensitive responses when applied to plants which turn on stress-defence and growth systems in a range of different plant groups (Wei *et al.*, 1992). In potatoes, harpins can be applied to the tubers before planting, and as a foliar spray during vegetative growth. It has no direct effect upon nematodes or viruses, but treatment will trigger responses within the plants’ tissue that give the plant resistance to nematode feeding activity, reduces nematode populations, and also reduces the ability of viruses to replicate within the plant (Collins *et al.*, 2006).

Use of a harpin product (N-Hibit Gold – Plant Health Care Ltd) on potatoes in trials in the USA and in South Africa have demonstrated yield increases of up to 20 %, reductions in viral load of 76 %, and reductions in nematode infestation in the roots of up to 62 %. Nematode fecundity has also been affected with up to 73 % fewer eggs produced in nematodes feeding on harpin-treated potatoes (Jason Holohan, PHC, *pers.comm.*). Harpin as an elicitor of plant defences in potato has potential to be used to reduce the effects of feeding damage by nematodes and to reduce the infection of nematode-vectored viruses such as TRV (Navarre, 2007). A novel granular nematicide being developed by Eden Research PLC has shown significant reductions in *Trichodorus* and *Pratylenchus* populations (Edmonds, *pers.comm.*). The primary objectives for the field trials to be undertaken in Work Package 2 were:

- To establish the importance of *Pratylenchus*, (*Para*)*Trichodorus* and *Longidorus* direct feeding damage on yield, quality and processing quality, and the response of potatoes to a nematicide treatment.
- To establish potato varietal response to high pressure nematode and TRV situations, by measuring yield and quality responses to nematicide for a range of crisping, french fry and fresh market varieties.
- To establish nematode thresholds for yield loss from feeding damage, external and internal defects and processing quality.
- To evaluate alternative control strategies for controlling nematode populations in the soil.

These objectives were addressed by a series of field trials at sites in Scotland and England. This report summarises the outputs from the variety field trials over 3 seasons (12 trials in total) and the outcomes of several alternative treatments field trials in Shropshire and Scotland.

3. MATERIALS AND METHODS

3.1. Work Package 2: Field Trials

3.1.1. Identification of field trial sites

Fields that were likely to have high FLN populations based on previous knowledge and soil type at 4 geographical areas (Yorkshire, Norfolk, Shropshire, and Perthshire) were identified and sampled in the autumn/winter prior to potato planting potatoes in 2011, 2012 and 2013. Soil sampling was undertaken when soil was moist (but not sodden) to ensure that a true reflection of the FLN population was obtained.

Soil was sampled using a narrow-bladed fern trowel, at least 2.5 cm across and 20-25 cm deep, randomly on a “W” configuration. Approximately 1 kg of soil was taken from each field.

Soil samples for FLN were sent to JHI for extraction and estimation of a population count. In summary, nematodes were extracted from 200 g soil using a modified Baermann funnel for 48 h (Brown & Boag, 1988) and the final volume reduced to 10 ml. Nematodes were identified (to genus level) and enumerated using low-powered light microscopy.

Based on the results from JHI, potential trial sites were identified and soil samples taken to test for the presence of potato cyst nematode (PCN), as fields needed to be clear of PCN for final choice of trial sites. Soil samples were taken with a small 'cheese-corer' probe (Southey, 1974), with each probe taking approximately 10 g of soil. A minimum of 500 g of soil was obtained from each field. The soil samples were processed as follows (Southey, 1986): soil is placed on a clean tray in a soil drying frame. When dry, the soil is rolled, weighed and an appropriate weight (ideally 500 g) is washed through a Fenwick can. The Fenwick cans comprise of a 9 inch funnel and a 850 µm sieve, and the washings from the sieve are passed through a 250 µm sieve. The sieves are washed into funnels with lined filter paper. The filter paper is placed onto a plate and the number of cysts determined. To determine whether cysts were viable, they were broken open and the presence of live juveniles or eggs recorded.

Based on the presence of FLN, specifically (*Para*)*Trichodorus* and *Pratylenchus*, 4 trial sites were confirmed each season for potato variety trials in the 2011, 2012 and

2013 season. These were at Elveden (Norfolk), Harper Adams (Shropshire), Gospel (2011), North Cliffe (2012), Weighton Common (2013) (all Yorkshire) and Meigle (Perthshire).

For the alternative treatment trials, a site was planted with the mustard and oil radish treatments at Harper-Adams in Shropshire in 2011 followed by potatoes (Pentland Dell) in 2012, and again in 2012 followed by potatoes (Pentland Dell and Harmony) in 2013, and again in 2013 followed by potatoes (Pentland Dell and Harmony) in 2014. Identical trials were carried out in Scotland (Meigle): planted with the mustard and oil radish treatments in 2012 followed by potatoes (Harmony) in 2013, and again in 2013 followed by potatoes in 2014 (Pentland Dell and Harmony).

3.1.2. Potato variety trials

The 12 potato varieties used at each of the trial sites over the three seasons are listed in Table 3.1.1 below.

Table 3.1.1. Potato cultivars and supplier used in variety trials

Variety Name	Supplier
Maris Piper	McCain
Pentland Dell	McCain
Shepody	McCain
Markies	McCain
Innovator	McCain
Lady Rosetta	PepsiCo
Shelford	PepsiCo
Crisp4All	PepsiCo
Casablanca	Cygnnet PB
Saxon	Cygnnet PB
Melody	Farmcare
Harmony	Farmcare

Each trial had Untreated and Vydate 10G (oxamyl) treated plots. Vydate 10G was applied as a broadcast treatment equivalent to 55 kg/ha. Each plot was 6.25 m long by 4 rows wide, with a 1.5 m discard between plots along the row.

Assessments carried out at each trial site were as follows:

- Evaluation of FLN nematode numbers pre-planting. Nematodes identified to species level as outlined previously.
- Emergence assessments at 7 day intervals to capture date of 50 % and full emergence.
- Ground cover at weekly intervals after first emergence using grid and Cambridge University Farm (CUF) protocol.
- At harvest 2 x 3 m digs per plot:
 - one 3 m dig for 10 mm size grading and internal defect assessments - TRV and PMTV testing if necessary (50 tubers per plot).
 - one 3 m dig for quality assessments (including dry matter).
 - Yield and number of tubers in each fraction (<45, 45-65, 65-85, >85 mm).

In each site/year the trial design required that all varieties were harvested at the same time. The data from the trials has been analysed individually for each season,

and together across all 3 seasons to determine any relationships between FLN population and variables such as days to 50 percent crop emergence, 100 percent ground cover, yield, marketable yield, tuber number and spraing symptoms

The results of these analyses are summarised in the Results section.

3.1.3. Alternative treatments trials

The trials were designed to evaluate the impact of a range of treatments on the FLN population and subsequent effects on the potato crop. Treatments planted/applied in the season prior to the potato crop at Harper Adams and in Scotland:

- *Brassica juncea* (cv. Caliente 99) – a mustard biofumigant crop.
- *Brassica juncea* (cv. Caliente 99) + *Eruca sativa* (cv. Nemat) – a mustard biofumigant and nematode attractant crop.
- *Raphanus sativus* (cv. Bento) – specifically targeted at reducing TRV transmission capability of nematodes (www.senova.uk.com/#/bento/4583227434)
- *Raphanus sativus* (cv. Contra) – a multi-resistant oil radish to FLN (www.senova.uk.com/#/contra/4583312620).

Treatments applied just prior to planting:

- Liquid mustard/chilli extract.
- Harpin.
- Terpene.

The varieties planted at each site were Harmony and/or Pentland Dell depending on the season/site:

Harper-Adams

- 2011 followed by potatoes (Pentland Dell) in 2012
- 2012 followed by potatoes (Pentland Dell and Harmony) in 2013
- 2013 followed by potatoes (Pentland Dell and Harmony) in 2014.

Scotland (Meikle):

- 2012 followed by potatoes (Harmony) in 2013
- 2013 followed by potatoes (Pentland Dell and Harmony) in 2014.
- A third trial in Scotland (2104) was abandoned due to issues with potato emergence in 2015 (severe stem canker, *Rhizoctonia solani*).

Untreated treatments in the experimental design comprised nitrogen (120 kg/ha) applied in the autumn to allow comparison with the nitrogen inputs from the mustard and radish crops. All plots received a fertiliser treatment equivalent to 100 kg/ha 5 weeks after planting.

Chemical treatment was applied by broadcasting Vydate 10G using a Jones veg tiller. This was done post destoning just prior to planting. Harpin was applied as a seed treatment, and as foliar treatments at 100% crop emergence, and 3 other timings – see Table 3.1.2 below. The terpene and liquid mustard were applied as a broadcast spray and incorporated using the Jones veg tiller.

The potato crop was planted as one block of Pentland Dell and another block of Harmony and managed as a commercial crop with the following inputs (Harper-Adams inputs shown as an example – similar inputs were used in Scotland):

Table 3.1.2. Example of key operations for 2014 alternatives trials at Harper Adams

Date	Operation	Notes
30/07/2013	Drilling	Treatment 1: Caliente Treatment 2: Caliente + Nemat Treatment 3: Contra Radish Treatment 4: Bento Radish
04/10/2013	Incorporation	Treatment 1: Caliente Treatment 2: Caliente + Nemat Treatment 3: Contra Radish Treatment 4: Bento Radish
30/04/2014	Alternative treatments at planting	Liquid Mustard @ 1.2 l/ha Terpene @ 1.8 l/ha
30/04/2014	Planting	Includes Vydate 10G treatments broadcast (equivalent to 55 kg/ha) and in-furrow (equivalent to 210g per 100m of row)
30/04/2014	Harpin	Coat seed at planting
23/05/2014	Herbicide	Diquat @ 2 l/ha Afon @ 1.35 l/ha Defy @ 5 l/ha
28/05/2014	Ground cover assessment	
30/05/2014	Emergence assessment	
02/06/2014	Emergence assessment	
04/06/2014	Emergence assessment	
06/06/2014	Harpin	150g/ha - 100% emergence
06/06/2014	Fungicide	Revus @ 0.6 l/ha
13/06/2014	Ground cover assessment	
13/06/2014	Fungicide	Ranman @ 1 l/ha Curzate @ 2 kg/ha
16/06/2014	Fungicide	Revus @ 0.6 l/ha
19/06/2014	Fungicide	Curzate @ 2 kg/ha
21/06/2014	Harpin	150g/ha
23/06/2014	Ground cover assessment	
24/06/2014	Fungicide + Herbicide	Ranman @ 0.5 l/ha Titus @ 50g/ha

30/06/2014	Harpin	150g/ha
30/06/2014	Ground cover assessment	
30/06/2014	Fungicide	Curzate @ 2kg/ha Nando @ 0.4 l/ha
07/07/2014	Ground cover assessment	
14/07/2014	Ground cover assessment	
15/07/2014	Fungicide	Sipcam @ 240g/ha Nando @ 0.4 l/ha
19/07/2014	Harpin	150g/ha
21/07/2014	Ground cover assessment	
21/07/2014	Fungicide	Sipcam @ 240g/ha Nando @ 0.4 l/ha
28/07/2014	Ground cover assessment	
04/08/2014	Ground cover assessment	
04/08/2014	Fungicide	Ranman @ 0.5 l/ha Nando @ 0.4 l/ha
12/08/2014	Ground cover assessment	
27/08/2014	Fungicide + Dessicant	Reglone @ 4 l/ha Diquat @ 2 l/ha Nando @ 0.4 l/ha
13/09/2014	Dessicant	Diquat @ 4 l/ha
21/11/2014	Harvest	
24/11/2014	Grading	

Emergence and ground cover measurements were taken on a weekly basis. The trials were assessed for crop emergence, ground cover, yield, tuber number and presence of spraing symptoms.

3.1.4. Statistical analyses

Variety trials (across all 3 years and sites)

To determine the effects of *(Para)trichodorus* population on a specific response variable, the null hypothesis is that for both Vydate 10G and Untreated plots in all the trials, the *(Para)trichodorus* counts have the same, potentially non-linear, functional relationship with the response variable (e.g. yield). The alternative hypothesis is that the *(Para)trichodorus* counts have a different, potentially non-linear, functional relationship with the response variable depending on whether or not the Vydate 10G has been used. Consequently, any significant P values ($P < 0.05$) indicate an effect of *(Para)trichodorus* on that variable. The above analysis was done using an additive model, with a term accounting for effects from Site and Year.

To determine the effects of Vydate 10G treatment on a specific response variable, the null hypothesis is that for a particular variety, the Vydate 10G treated and untreated plots display the same level of response variable (e.g. yield) – i.e. no difference, varying only together depending on year, site, and replication. The alternative hypothesis is that the Vydate 10G treated and untreated plots display different levels of response variable, together with a year, site and replication effect. Consequently, any significant P values ($P < 0.05$) indicate an effect of Vydate 10G treatment on that variable.

In order to summarise the response of varieties to *(Para)trichodorus* population and use of Vydate 10G, 'heatmaps' were used to visually indicate the propensity for a particular variety to demonstrate a relationship between use of Vydate 10G and, for example, mean yield response. An explanation of the interpretation of 'heatmaps' is given in the Results section.

Alternative trials (across 3 years and 2 sites)

The total yield (t/ha), marketable yield > 45 mm (t/ha), the number of tubers (000/ha), and for TRV spraing, the proportion of infected tubers from a total of 50 tubers, were recorded from each plot. We treated each year and site individually.

A set of linear mixed effects models were fitted to each data set. Using replications as a random effect, we restricted to different varieties and/or treatments, and compared the different biofumigants to see if there are differences between them. To compare Vydate 10G to non-Vydate 10G, we fitted a similar model, this time either restricting to individual biofumigants, or including the biofumigant as a covariate for an overall assessment of the effect.

4. RESULTS

4.1. Work Package 2: Variety Trials

4.1.1. Impact of *(Para)trichodorus* population

The mean *(Para)trichodorus* populations across the 4 sites and three seasons are provided in the tables below and summarised in the 'heatmap' (Fig. 4.1.1).

Table 4.1.1 The average FLN *(Para)trichodorus* or *Pratylenchus* counts and range of nematode counts (in 200g of soil) from the trial plots sampled prior to planting at each trial site in 2011:

	Norfolk		Harper		Yorkshire		Scotland	
	<i>Trichodorus</i>	<i>Pratylenchus</i>	<i>Trichodorus</i>	<i>Pratylenchus</i>	<i>Trichodorus</i>	<i>Pratylenchus</i>	<i>Trichodorus</i>	<i>Pratylenchus</i>
Mean + SE	36.4 ± 1.9	3.0 ± 0.4	43.8 ± 1.9	7.4 ± 0.6	321 ± 8.7	5.4 ± 0.4	29.6 ± 1.4	9.1 ± 1.1
Range	2 > 163	0 > 36	2 > 129	0 > 57	103 > 870	0 > 38	1 > 94	0 > 99

Table 4.1.2 The average FLN counts (*(Para)trichodorus* – *Trich*; *Pratylenchus* – *Prat*) and range of nematode counts (in 200 g of soil) from the 144 trial plots sampled prior to planting at each trial in 2012

	Norfolk		Harper-Adams		Yorkshire		Scotland	
	<i>Trich</i>	<i>Prat</i>	<i>Trich</i>	<i>Prat</i>	<i>Trich</i>	<i>Prat</i>	<i>Trich</i>	<i>Prat</i>
Mean	12.22 ±	0.42 ±	8.26 ±	34.75 ±	32.89 ±	0.56 ±	39.30 ±	1.04 ±

± SE	0.10	0.15	0.61	2.27	2.71	0.13	2.52	0.30
Range	1 - 62	0 - 12	0 - 37	2 - 141	1 - 185	0 - 8	2 - 141	0 - 36

Table 4.1.3 The average FLN counts (*(Para)trichodorus* – *Trich*; *Pratylenchus* – *Prat*) and range of nematode counts (in 200 g of soil) from the 144 trial plots sampled prior to planting at each trial in 2013

	Norfolk		Harper Adams		Yorkshire		Scotland	
	<i>Trich</i>	<i>Prat</i>	<i>Trich</i>	<i>Prat</i>	<i>Trich</i>	<i>Prat</i>	<i>Trich</i>	<i>Prat</i>
Mean	44.8 ±	1.1 ±	19.6 ±	40.2 ±	87.9 ±	10.9 ±	266.9 ±	0.3 ±
± SE	3.6	0.3	1.6	2.9	6.2	1.2	12.1	0.1
Range	1 - 297	0 - 26	0 - 84	2 - 141	0 - 446	0 - 65	38 - 926	0 - 13

The 'heatmap' (Fig. 4.1.1 below) illustrates the variability of the FLN populations at trial sites in each season

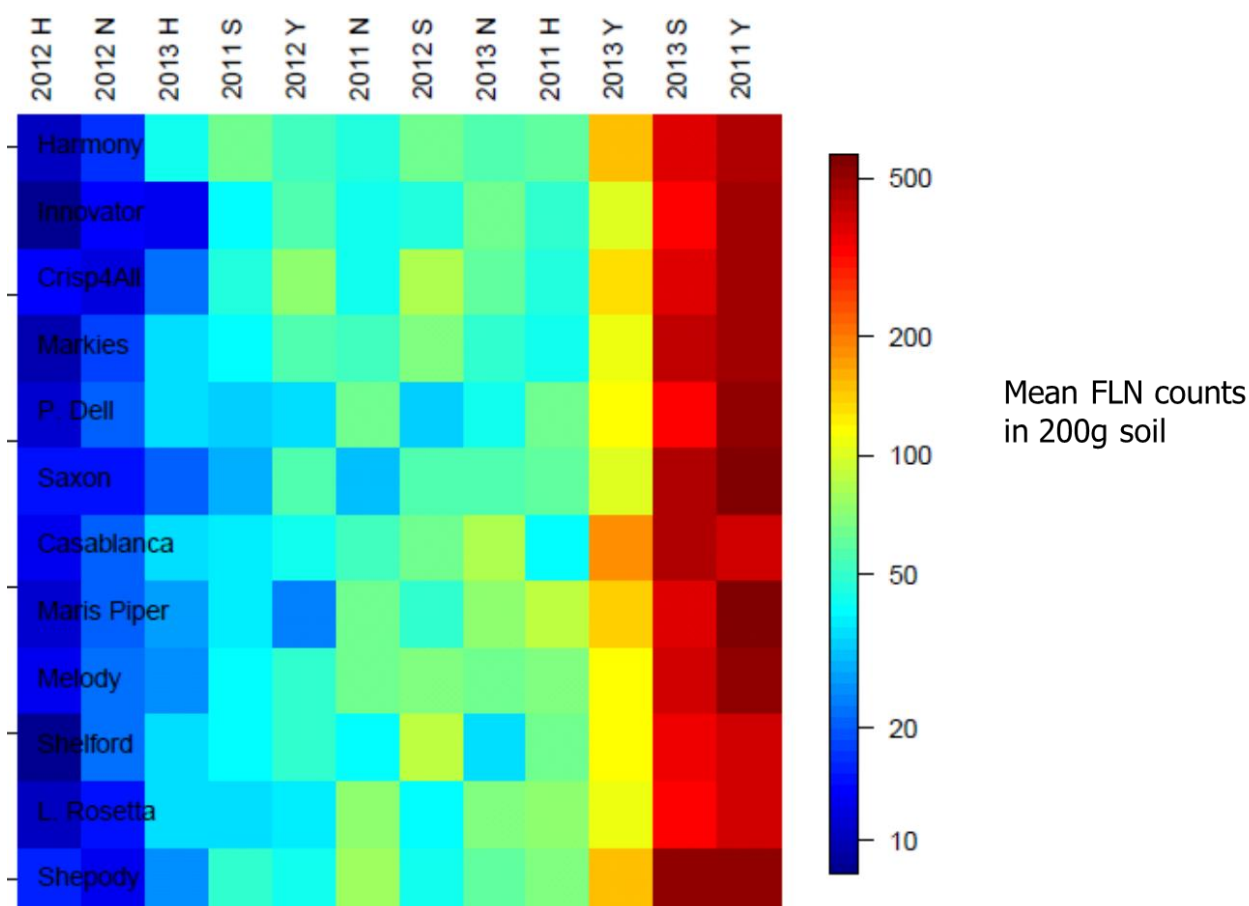


Fig. 4.1.1. 'Heatmap' illustrating the mean FLN counts at each of the 4 trial sites and within each variety across the 3 years of trials. H refers to Harper-Adams (Shropshire), S refers to Scotland, Y refers to Yorkshire, and N refers to Norfolk.

4.1.2. Explanation of the 'heatmaps':

The colour of each square grid relates to the mean FLN count (FLN being *(Para)trichodorus*) in 200g of soil for the trial site listed along the top axis, and the potato variety along the vertical axis on the left.

So, for example, the darker blue squares indicate relatively low mean FLN counts (<20 in 200g of soil) and these counts were at the 2012 H (Harper-Adams trial in 2012) and 2012 N (Norfolk 2012 trial) and were representative across all the trial plots for the different varieties at those sites. The darker red squares indicate the relatively high mean FLN counts (>200 in 200g of soil), and these counts were at the 2011 Y (Yorkshire 2011 trial) and 2013 S (Scottish 2013 trial), and these high FLN counts were consistent across all the trial plots for the different varieties at those sites.

Note that at some trial sites such as 2012 Y (Yorkshire 2012 trial) there is a degree of variability in the 'heatmap' colours in terms of the FLN counts – ranging from a mean of between 10-20 in the Maris Piper plots (dark blue) to >50 in the Saxon, Markies and Crisp4All plots (green).

Analysis of the data obtained from the 3 seasons' trials (12 trials in total) in relation to *(Para)trichodorus* population and variety response is summarised below (Table 4.1.1).

The significant P values in Table 4.1.1 (in **red**, $P < 0.05$) indicate a significant effect of *(Para)trichodorus* on that variable (e.g. mean marketable yield, tuber count, tuber size etc). NA are non-significant, they correspond to fits where the data sufficiently fails to show an improvement by inclusion of *(Para)trichodorus* effect, consequently a reasonable test statistic cannot be calculated.

Table 4.2.1. Significance values of the combined data analysis across 3 seasons of trials. P values below (in **red**, $P < 0.05$) indicate a significant effect of *(Para)trichodorus* on that variable

Variety	No. of tubers/ha	Mean total yield/ha	Mean tuber size	Mean marketable yield/ha	Standardised (23%) dry matter marketable yield/ha	Standardised (23%) dry matter yield/ha
Maris Piper	0.413	0.784	0.446	0.202	0.713	0.863
Pentland Dell	0.003	0.005	0.009	0.005	0.059	0.069
Shepody	0.058	0.483	0.848	0.518	NA	NA
Markies	0.473	0.852	0.310	0.809	NA	NA
Innovator	NA	0.136	0.667	0.087	0.265	0.653
Lady Rosetta	0.904	0.001	NA	0.0001	NA	0.651
Shelford	0.501	0.468	0.614	0.566	0.954	0.982
Crisp4All	0.308	0.106	0.275	0.107	0.008	NA
Casablanca	0.431	0.605	0.446	0.670	0.971	0.092
Saxon	0.880	0.425	NA	0.438	NA	0.001
Melody	0.560	0.215	0.056	0.145	0.352	0.461
Harmony	0.034	NA	0.170	NA	NA	NA

Only one variety (Pentland Dell) has a consistent reduction in tuber count, total yield, average tuber size and marketable yield due to *(Para)trichodorus* population. This is not seen with the standardised dry matter (23%) yield though.

Other varieties have some significant associations with *(Para)trichodorus* population: Harmony and reduction in tuber count; Lady Rosetta reduction in marketable yield and total yield; Crisp4All reduction in standardised marketable dry matter (23%) yield; Saxon reduction in standardised dry matter (23%) yield.

4.1.3. Effects of Vydate 10G treatment

Fig. 4.1.2 shows the FLN levels in relation to the total yield. Reading the heatmap in Fig. 4.1.2 from left to right shows the least beneficial site/year to the most beneficial site/year in terms of yield response to the use of Vydate 10G.

If there was a direct relationship between the use of Vydate 10G benefit on total yield and high FLN count, we would expect to see more red colours to the right, and blues

to the left. However, we see instead that the two highest FLN site/years (2013S [red], 2011Y [red], where FLN counts were well in excess of 200/200 g of soil) are below average for the Vydate 10G benefit, while the three low FLN trial sites (2012N [dark blue-blue], 2013 H [dark blue-turquoise], 2012H [dark blue-blue]) show average to high Vydate 10G benefit (they are on the middle to right hand side of the heatmap Fig. 4.1.2) The sites with the lowest yield response to Vydate 10G (2011S, 2012Y, 2011N) all have average FLN counts in the range 50-100/200g of soil.

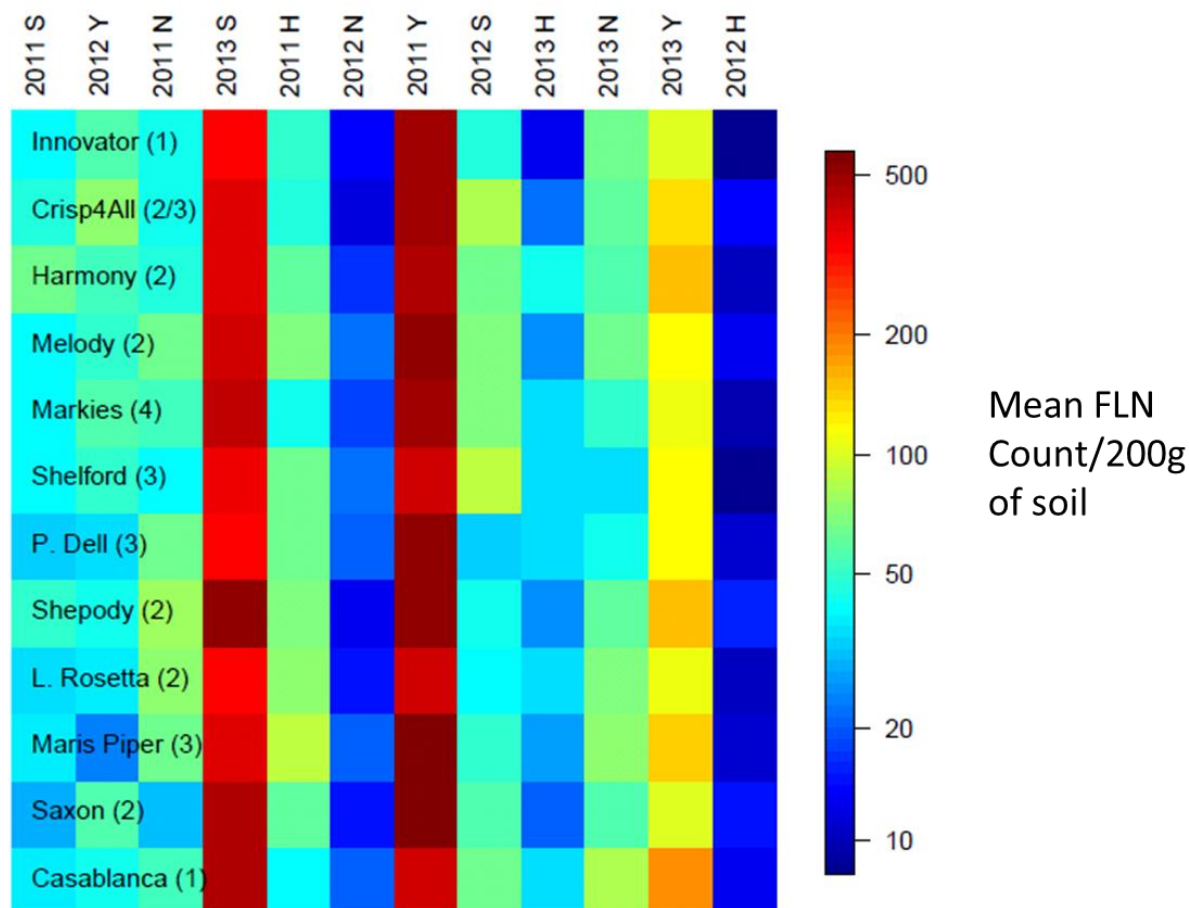


Fig. 4.1.2. 'Heatmap' illustrating the mean FLN count (in 200g of soil) at the 4 trial sites and within each variety across the 3 years of trials. Varieties ranked by their mean total yield response. Numbers in parentheses indicate determinacy rating for that variety (**1= determinate (short haulm longevity)**, **4 = very indeterminate (very long haulm longevity)**). S = Scotland, Y = Yorkshire, N = Norfolk and H = Harper-Adams. Year and trial sites moving from left to right indicate the ranking from least to most benefit from the use of Vydate 10G.

Similarly, Fig. 4.1.3 shows the FLN levels in relation to the marketable yield, where reading the heatmap in Fig. 4.1.3 from left to right shows the least beneficial site/year to the most beneficial site/year.

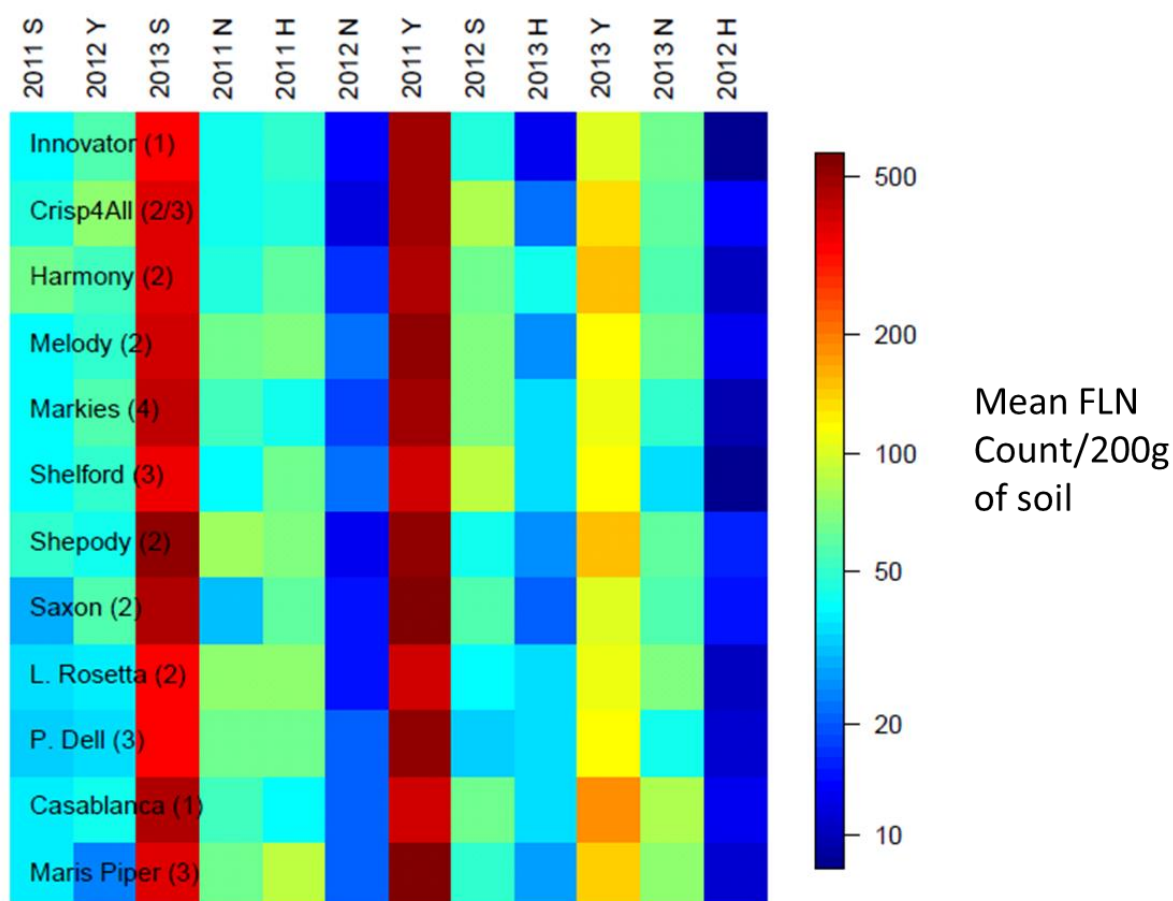


Fig. 4.1.3. 'Heatmap' illustrating the mean FLN count (in 200g of soil) at the 4 trial sites and within each variety across the 3 years of trials. Varieties ranked by their mean marketable yield response. Numbers in parentheses indicate determinacy rating for that variety. S = Scotland, Y = Yorkshire, N = Norfolk and H = Harper-Adams. Year and trial sites moving from left to right indicate the ranking from least to most benefit from the use of Vydate 10G.

As with the total yield heatmap (Fig. 4.1.3), if there was a direct relationship between the use of Vydate 10G benefit on marketable yield and FLN count, we would expect to see more red colours to the right, and blues to the left. However, we see instead that the two highest FLN site/years (2013S, 2011Y) are below average or average respectively, for Vydate 10G benefit, while the three low FLN trial sites (2012N, 2013H, 2012H) show average or very high Vydate 10G benefit (they are on the middle to right hand side of the heatmap Fig. 4.1.3).

The heatmaps above and the response of varieties to the use of Vydate 10G with differing FLN counts suggests that there is no clear indication of a FLN threshold population for impact on total yield or marketable yield. This is also confirmed by the statistical analyses (Table 4.1.2) below.

Analysis of the data obtained from the 3 seasons' trials (12 trials in total) in relation to Vydate 10G treatment and variety response is summarised below (Table 4.1.2). The significant P values below (in **red**, $P < 0.05$) indicate a significant effect of Vydate 10G treatment (and by inference FLN management) on that variable (e.g. total yield, tuber count, tuber size etc...). Note that negative P values indicate a reduction in that response variable to the use of Vydate 10G compared to the Untreated.

Table 4.1.2. Significance values of the combined data analysis across 3 seasons of trials. P values below (in **red**, $P < 0.05$) indicate a significant effect of use of Vydate 10G on that variable

Variety	No. of tubers/ha	Mean total yield/ha	Mean tuber size	Mean marketable yield/ha	Standardised (23%) dry matter marketable yield/ha	Standardised (23%) dry matter yield/ha
Maris Piper	0.008	0.160	-0.031	0.965	0.947	0.409
Pentland Dell	0.009	0.109	-0.000	0.423	-0.690	-0.919
Shepody	0.001	0.623	-0.042	0.745	-0.736	-0.813
Markies	0.003	0.341	-0.100	0.660	0.736	0.602
Innovator	0.000	0.040	-0.009	0.138	0.033	0.015
Lady Rosetta	0.005	0.619	-0.417	0.867	0.019	0.005
Shelford	0.055	0.160	-0.334	0.595	0.580	0.390
Crisp4All	0.000	0.060	-0.036	0.270	0.250	0.104
Casablanca	0.066	0.191	-0.297	0.381	-0.791	0.931
Saxon	0.530	0.292	0.010	0.266	0.315	0.331
Melody	0.142	0.551	-0.571	0.716	-0.845	-0.713
Harmony	0.001	0.014	-0.039	0.062	0.199	0.121

Use of Vydate 10G affects most varieties through significantly increasing tuber count. Vydate 10G significantly increases total yield (Innovator and Harmony only); increases average tuber size (Saxon only). Note that several varieties (Maris Piper, Pentland Dell, Shepody, Innovator, Crisp4All and Harmony) have significant reductions in average tuber size in response to the use of Vydate 10G. Vydate 10G significantly increases standardised (23% dry matter) total yield and marketable yield in Innovator and Lady Rosetta only.

4.1.4. Effects of Vydate 10G treatment and FLN counts

A 'heatmap' of the total yield increase across the trials through the use of Vydate 10G in relation to FLN populations at each trial site is shown below (Fig. 4.1.9), with the varieties ranked by their mean total yield response.

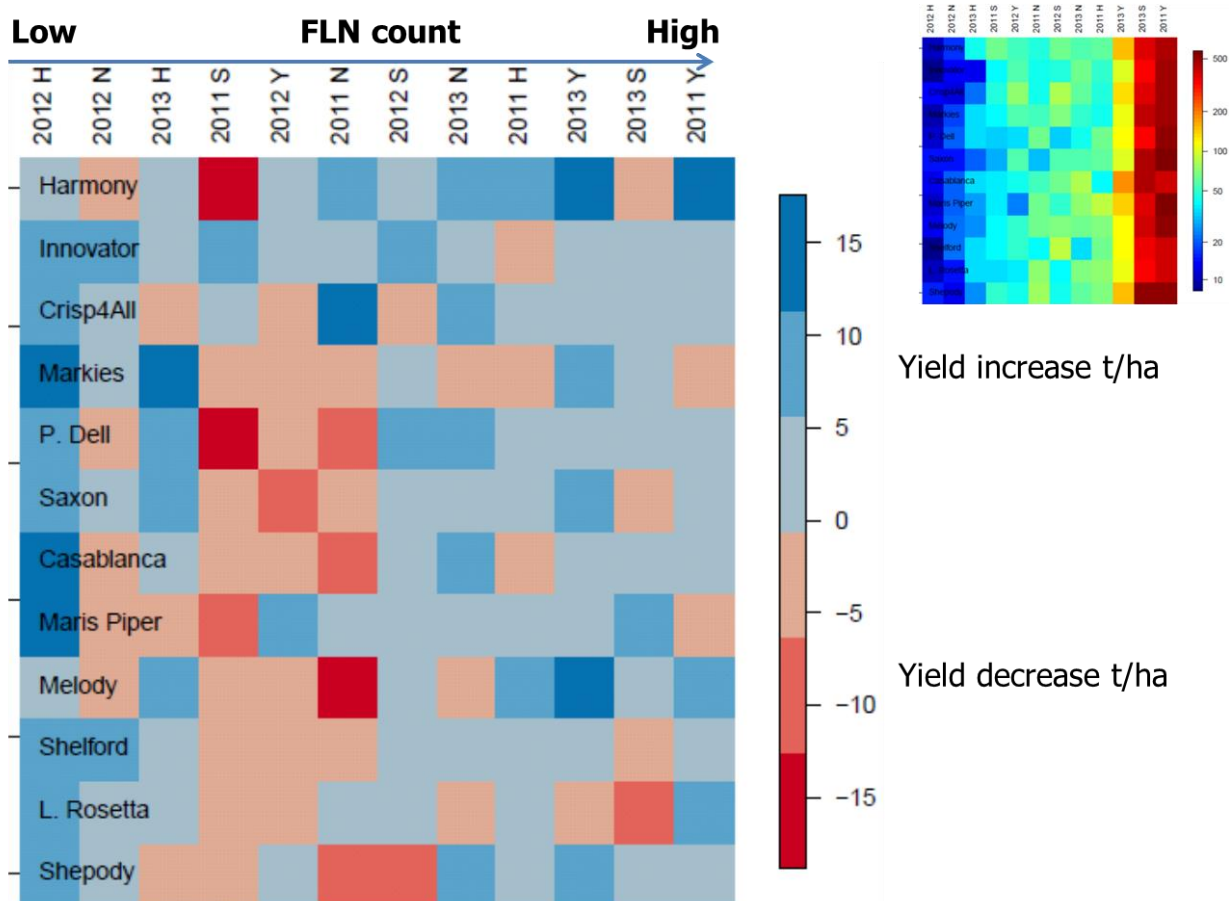


Fig. 4.1.9. 'Heatmap' illustrating the total yield increase/decrease across the trials through the use of Vydate 10G in relation to FLN populations at each trial site, with the varieties ranked by their mean total yield response. Top right is a 'heatmap' illustrating the corresponding FLN counts (Blue = low FLN counts: see Fig. 4.1.1 for more detail).

What this 'heatmap' indicates is that even when there are relatively low FLN counts (to the left of the 'heatmap'), the 'blue' squares indicate a mean total yield increase through the use of Vydate 10G.

Most of the 'red' squares which indicate a mean total yield decrease through the use of Vydate 10G are clustered to the left-middle of the 'heatmap', indicating that at moderate FLN counts there can still be some total yield loss even with the use of Vydate 10G. At high FLN counts to the middle-right of the 'heatmap' there tends to be more 'blue' squares indicating a total yield benefit through the use of Vydate 10G when FLN populations are high.

There are some potato varieties that show a propensity to increase total yield in response to the use of Vydate 10G regardless of the FLN count – e.g. Harmony, Innovator, Crisp4All, whilst there are others where the response is variable – e.g. Melody, Shelford, Lady Rosetta and Shepody.

A 'heatmap' of the total marketable yield increase across the trials through the use of Vydate 10G in relation to FLN populations at each trial site is shown below (Fig. 4.1.10), with the varieties ranked by their mean marketable yield response.

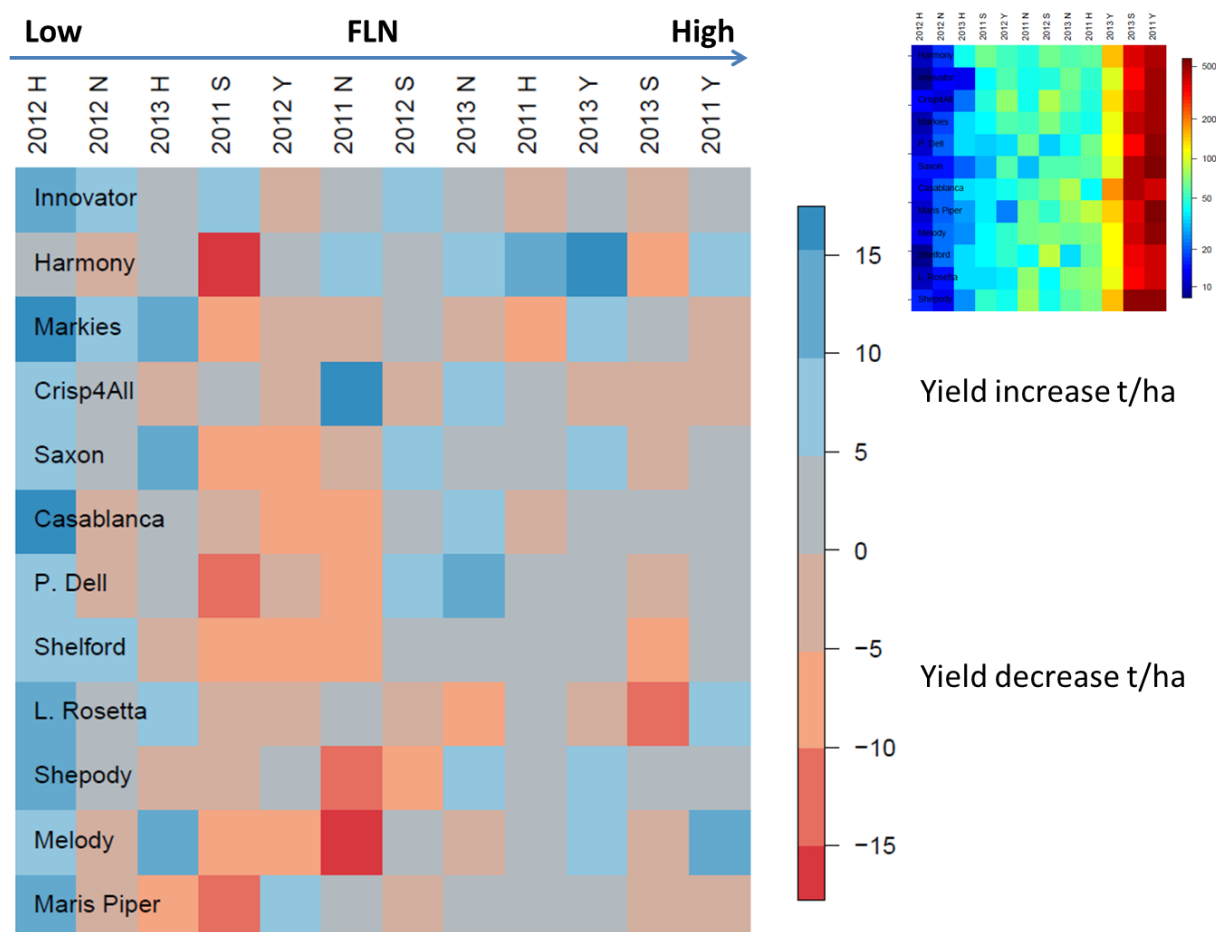


Fig. 4.1.10. 'Heatmap' illustrating the mean marketable yield increase/decrease across the trials through the use of Vydate 10G in relation to FLN populations at each trial site, with the varieties ranked by their mean marketable yield response. Top right is a 'heatmap' illustrating the corresponding FLN counts (see Fig. 4.1.1 for more detail).

What this 'heatmap' (Fig. 4.1.10) indicates is that even when there are relatively low FLN counts (to the left of the 'heatmap'), the 'blue' squares indicate a tendency for mean marketable yield to increase through the use of Vydate 10G.

Most of the 'red' squares which indicate a mean marketable yield decrease through the use of Vydate 10G are clustered to the left-middle of the 'heatmap', indicating that at moderate FLN counts there can still be some marketable yield loss even with the use of Vydate 10G.

At high FLN counts to the middle-right of the 'heatmap' there is a mix of coloured squares indicating an inconsistent marketable yield benefit through the use of Vydate 10G when FLN populations are high.

There are some potato varieties that show a propensity to increase marketable yield in response to the use of Vydate 10G regardless of the FLN count – e.g. Innovator and Harmony, whilst there are others where the response is variable.

A 'heatmap' of the total tuber number (000)/ha increase across the trials through the use of Vydate 10G in relation to FLN populations at each trial site is shown below (Fig. 4.1.11), with the varieties ranked by their mean tuber number (,000)/ha response.

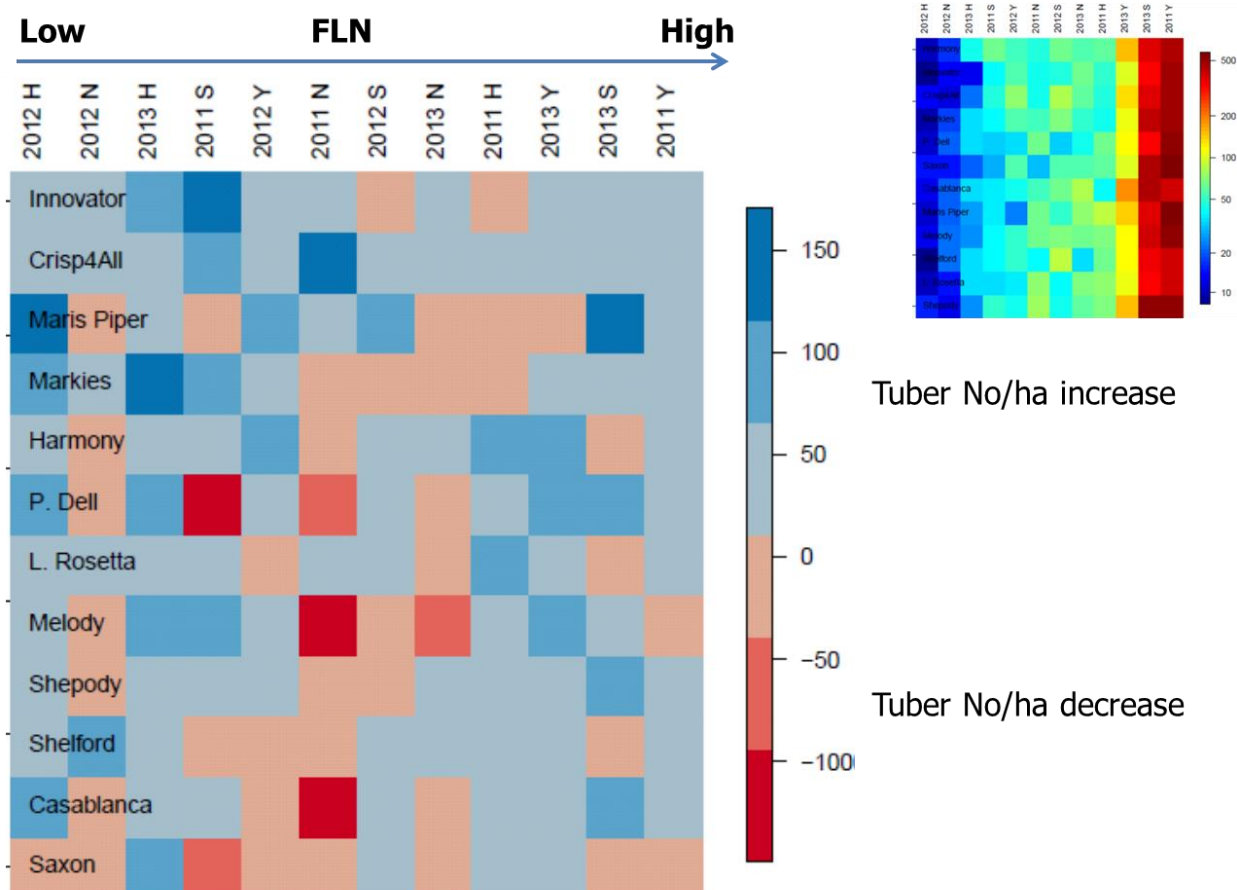


Fig. 4.1.11. 'Heatmap' illustrating the Tuber number increase/decrease across the trials through the use of Vydate 10G in relation to FLN populations at each trial site, with the varieties ranked by their increase in mean tuber number/ha. Top right is a 'heatmap' illustrating the corresponding FLN counts (see Fig. 4.1.1 for more detail).

What this 'heatmap' indicates is that even when there are relatively low FLN counts (to the left of the 'heatmap'), the 'blue' squares indicate an increase in mean tuber number/ha through the use of Vydate 10G in most varieties apart from Saxon. Saxon tends to respond negatively to the use of Vydate 10G in terms of tuber number (8 out of 12 trials).

There are some potato varieties that show a propensity to increase tuber number in response to the use of Vydate 10G regardless of the FLN count – e.g. Innovator, Crisp4All, whilst there are others where the response is variable.

4.1.5. Effects of Vydate 10G treatment on crop emergence and ground cover

Analysis of the data obtained from the 3 seasons' trials (12 trials in total) in relation to Vydate 10G treatment and crop emergence (days to 50% emergence) is summarised below (Fig. 4.1.12).

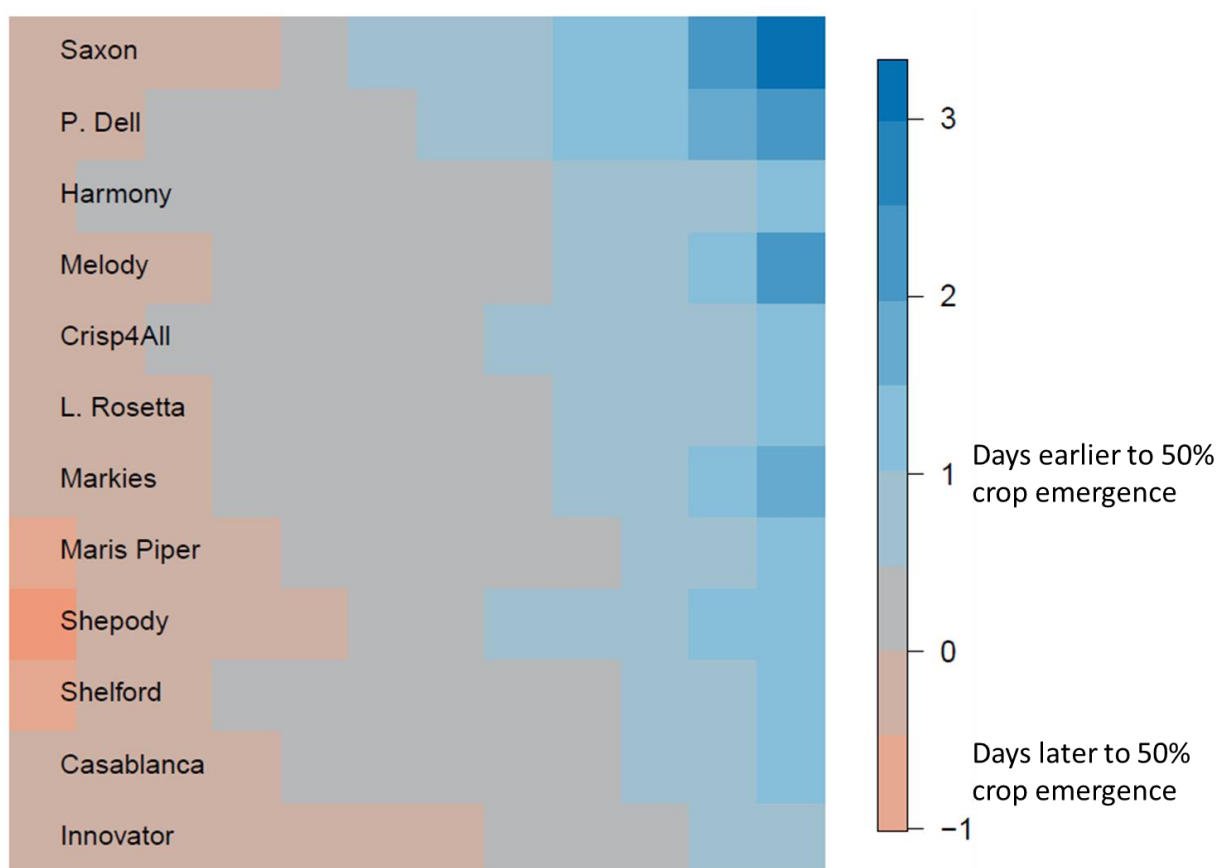


Fig. 4.1.12. 'Heatmap' illustrating the difference in days to reach 50% crop emergence through the use of Vydate 10G at each of the 4 trial sites and within each variety across the 3 years of trials. Varieties are ranked by their mean days to 50% emergence response.

The 'heatmap' (Fig. 4.1.12) shows that Saxon, Pentland Dell and Harmony in particular tend to show a propensity for reaching 50% crop emergence more rapidly when Vydate 10G is used – the greater the amount and intensity of 'blue' squares in the 'heatmap'. However, most varieties tend to be slightly faster at reaching 50% crop emergence when Vydate 10G is used, with the differences being measured in +3 days at best, and -1 day at worst compared to the Untreated.

Analysis of the data obtained from the 3 seasons' trials (12 trials in total) in relation to Vydate 10G treatment and area under the growth cover curve (AUGCC) is summarised below (Fig. 4.1.13).

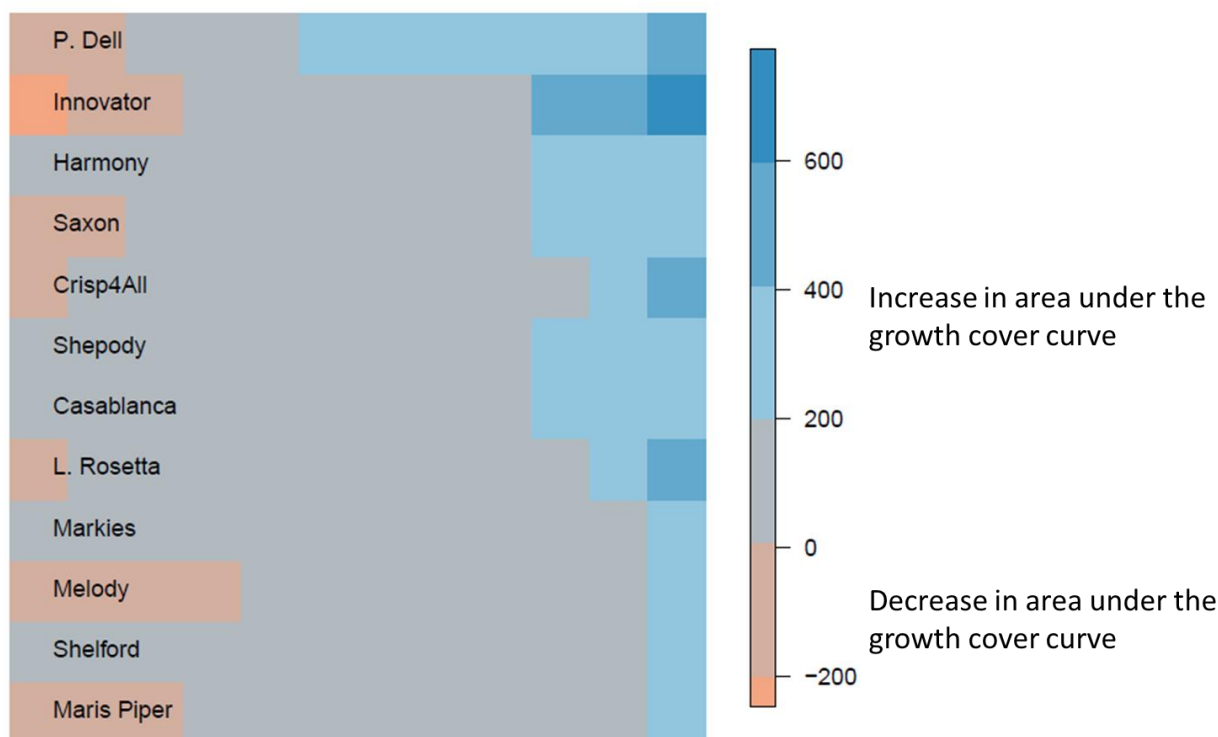


Fig. 4.1.13 'Heatmap' illustrating the difference in area under the growth cover curve (AUGCC) through the use of Vydate 10G at each of the 4 trial sites and within each variety across the 3 years of trials. Varieties are ranked by their mean AUGCC response.

The 'heatmap' (Fig. 4.1.13) shows that most varieties tend to show a propensity for having an increased AUGCC when Vydate 10G is used – the greater the amount and intensity of 'blue' squares in the 'heatmap'.

4.1.6. Spraing symptoms

The use of Vydate 10G significantly reduced spraing symptoms in the trials where Tobacco Rattle Virus (TRV) was present. The mean percentage of tubers with spraing symptoms across the 6 trials are summarised in Fig. 4.1.14 below.

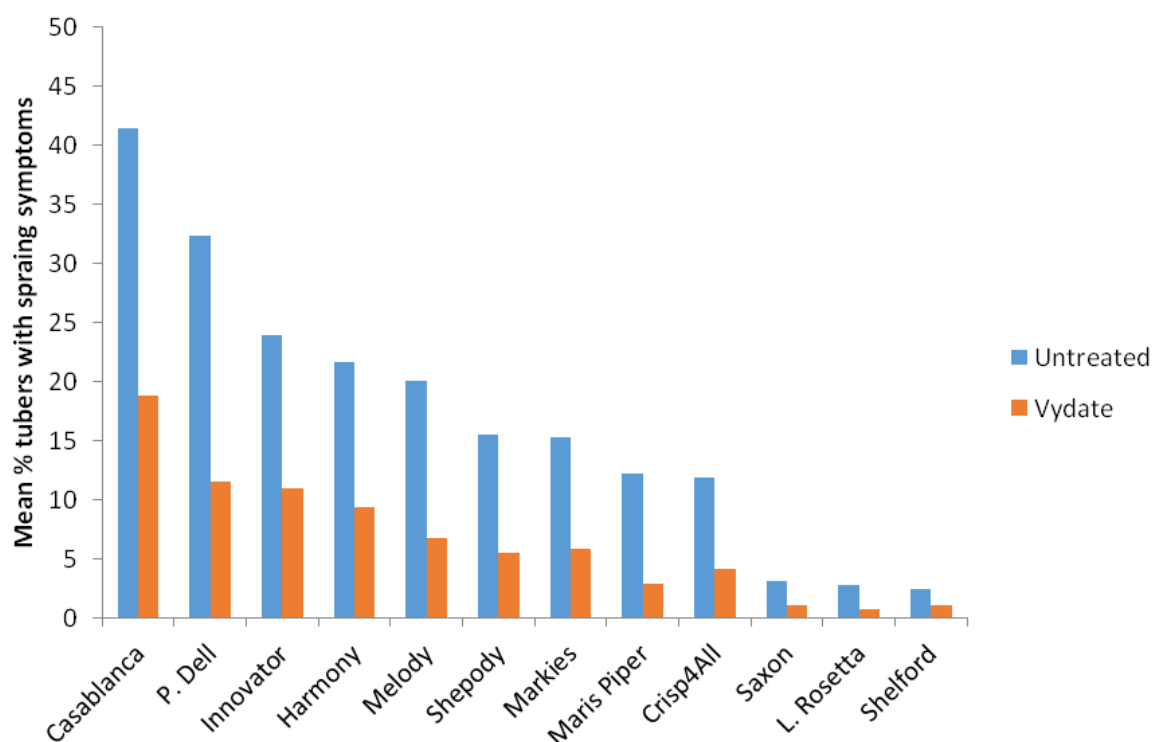


Fig. 4.1.14. Mean % of tubers with spraing symptoms from the 3 trials at Harper-Adams and the 3 trials in Scotland (2011-2013), Untreated and Vydate 10G treated.

All varieties responded to the Vydate 10G treatment by exhibiting a reduction in spraing symptoms. The varieties Shelford, Lady Rosetta and Saxon demonstrated the lowest incidence of TRV spraing (<4% in the absence of Vydate 10G), with further reductions in symptoms when Vydate 10G was applied.

4.2. Work Package 2: Alternative trials

4.2.1.1. Total yield

The total yields obtained from the Alternative Treatments trials at Harper Adams (Shropshire) and Scotland (Meigle) across 4 trials are summarised in Fig. 4.2.1 (Pentland Dell) and Fig. 4.2.2 (Harmony).

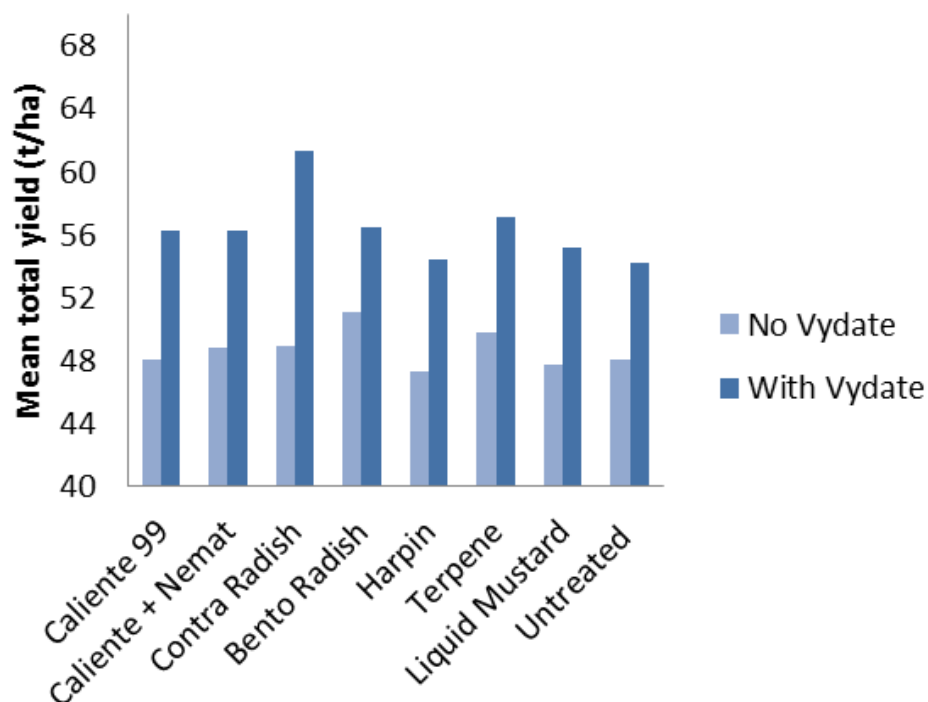


Fig. 4.2.1. Mean total yield t/ha (with and without Vydate 10G treatment) - Pentland Dell – from the alternative treatments trials at Harper-Adams and Meigle.

There were no significant differences between any of the different alternative treatments in terms of the total yield (t/ha) of Pentland Dell compared to each other and to the Untreated (Fig. 4.2.1). On average only 4 t/ha separated the lowest from the highest yielding treatments in the absence of Vydate 10G. The addition of Vydate 10G to the above treatments led to significant increases in total yield (Fig. 4.2.1), although there were no significant differences between treatments.

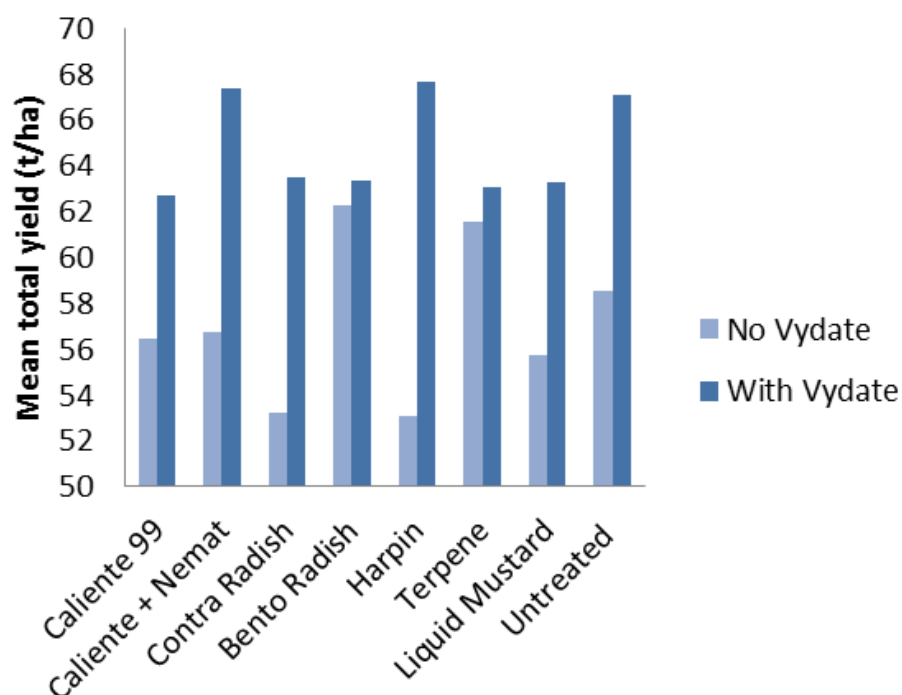


Fig. 4.2.2. Mean total yield t/ha (with and without Vydate 10G treatment) - Harmony – from the trials at Harper-Adams and Meigle.

There were no significant differences between any of the different alternative treatments in terms of the total yield (t/ha) of Harmony compared to each other and to the Untreated (Fig. 4.2.2). The addition of Vydate 10G to the above treatments led to increases in yield (Fig. 4.2.2), although there were no significant differences between treatments.

4.2.1.2. Marketable yield

The marketable yields (>45mm) obtained from the Alternative Treatments trials at Harper Adams (Shropshire) and Scotland (Meikle) across 4 trials are summarised in Fig. 4.2.3 (Pentland Dell) and Fig. 4.2.4 (Harmony).

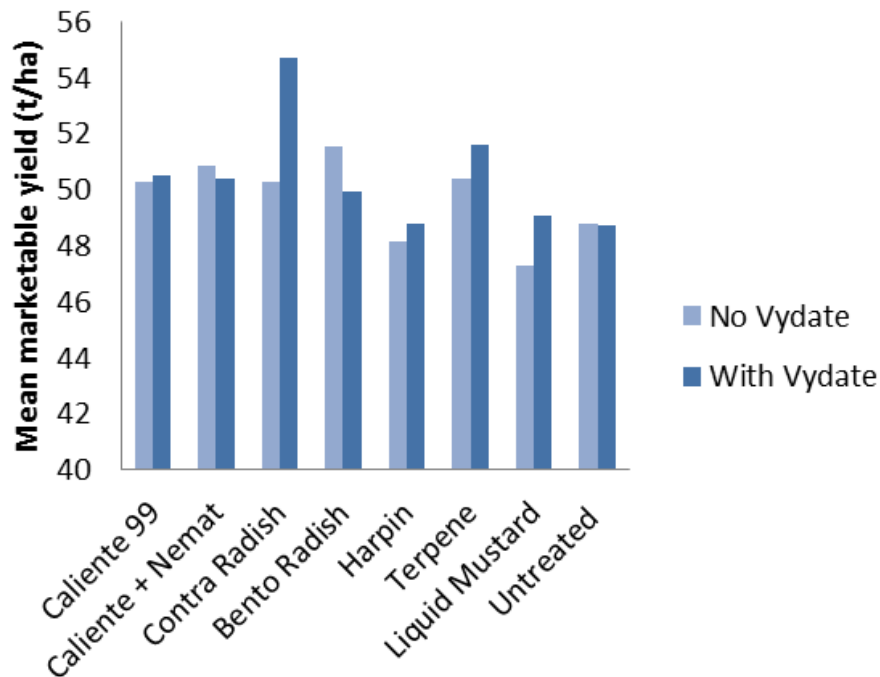


Fig. 4.2.3. Mean marketable yield t/ha (with and without Vydate 10G treatment) - Pentland Dell – from the alternative treatments trials at Harper-Adams and Meikle.

There were no significant differences between any of the different alternative treatments in terms of the marketable yield (t/ha) of Pentland Dell compared to each other and to the Untreated (Fig. 4.2.3). The addition of Vydate 10G to the above treatments led to increases in marketable yield in some treatments (Fig. 4.2.3), although there were no significant differences between treatments.

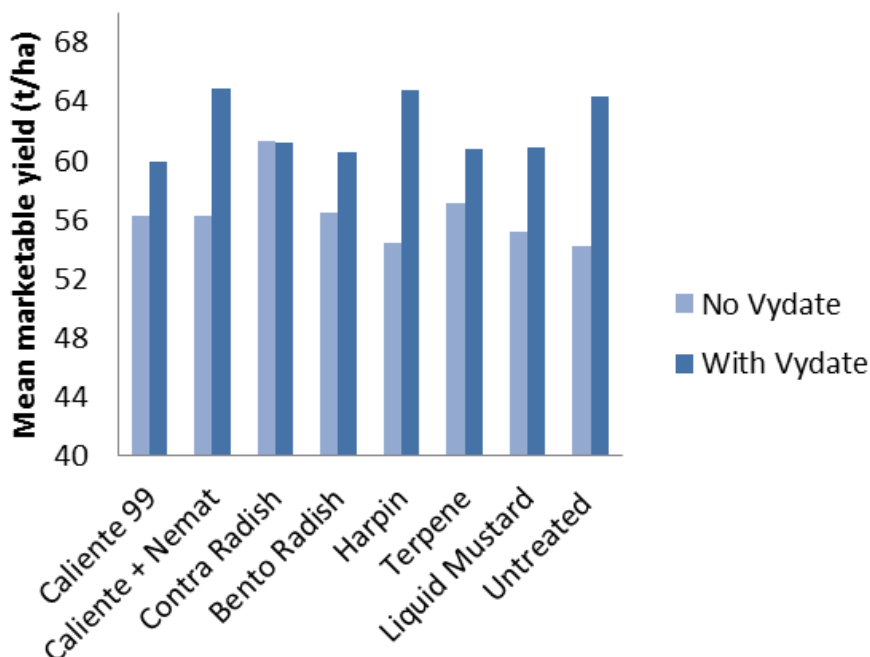


Fig. 4.2.4. Mean marketable yield t/ha (with and without Vydate 10G treatment) - Harmony – from the alternative treatments trials at Harper-Adams and Meikle.

There were no significant differences between any of the different alternative treatments in terms of the marketable yield (t/ha) of Harmony compared to each other and to the Untreated (Fig. 4.2.4) in the absence of Vydate 10G. The addition of Vydate 10G to the above treatments led to increases in marketable yield in most treatments (Fig. 4.2.4), although there were no significant differences between treatments.

4.2.1.3. Tuber Number

The tuber numbers (,000/ha) obtained from the Alternative Treatments trials at Harper Adams (Shropshire) and Scotland (Meigle) across 4 trials are summarised in Fig. 4.2.5 (Pentland Dell) and Fig. 4.2.6 (Harmony).

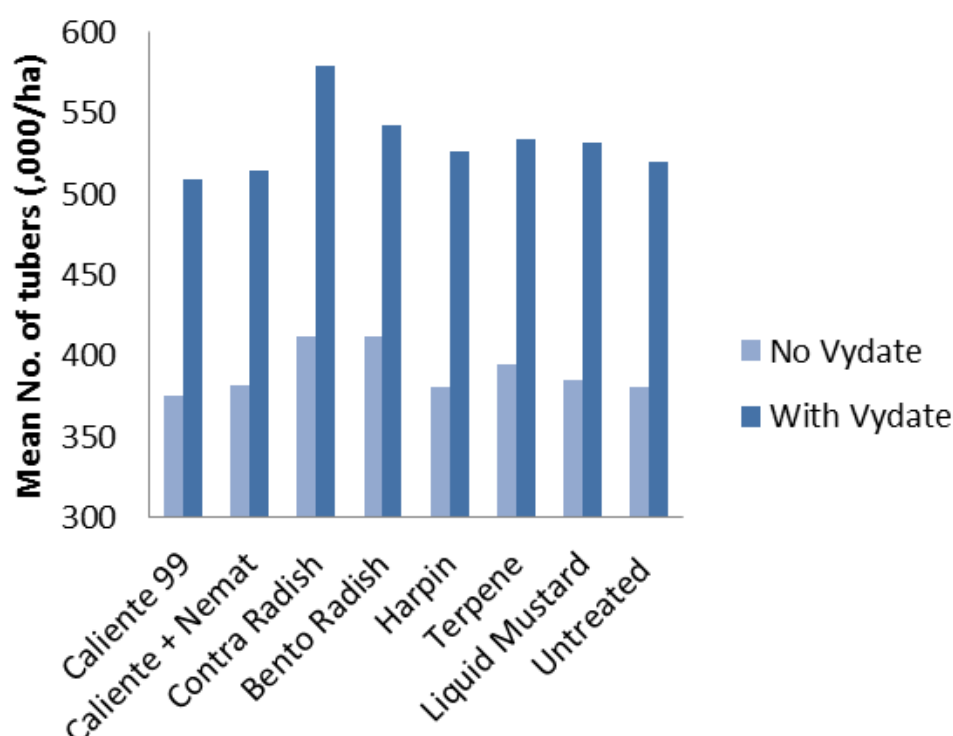


Fig. 4.2.5. Mean tuber number (with and without Vydate 10G treatment) - Pentland Dell – from the alternative treatments trials at Harper-Adams and Meigle.

There were no significant differences between any of the different alternative treatments in terms of the number of tubers (,000/ha) of Pentland Dell compared to each other and to the Untreated (Fig. 4.2.5). The addition of Vydate 10G to the above treatments led to significant increases in tuber number in all treatments (Fig. 4.2.5), although there were no significant differences between treatments.

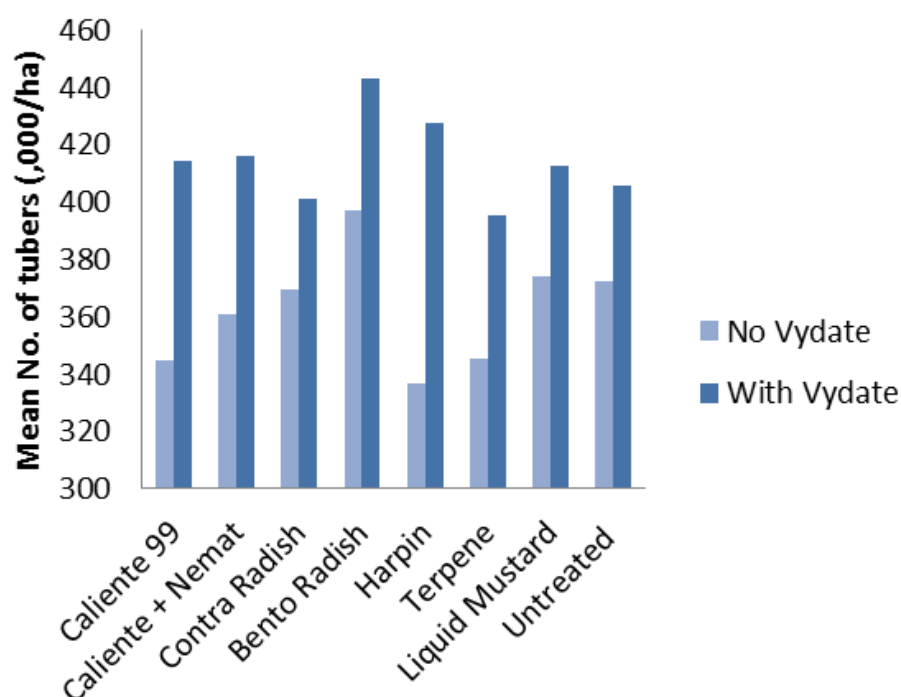


Fig. 4.2.6. Mean number of tubers (with and without Vydate 10G treatment) - Harmony – from the alternative treatments trials at Harper-Adams and Meigle.

There were no significant differences between any of the different Alternative Treatments in terms of the number of tubers (,000/ha) of Harmony compared to each other and to the Untreated (Fig. 4.2.6). The addition of Vydate 10G to the above treatments led to significant increases in tuber number in all treatments (Fig. 4.2.6), although there were no significant differences between treatments.

4.2.1.4. *Spraying*

The % of tubers with spraing symptoms obtained from the alternative treatments trials at Harper Adams (Shropshire) and Scotland (Meigle) across 4 trials are summarised in Fig. 4.2.7 (Pentland Dell) and Fig. 4.2.8 (Harmony).

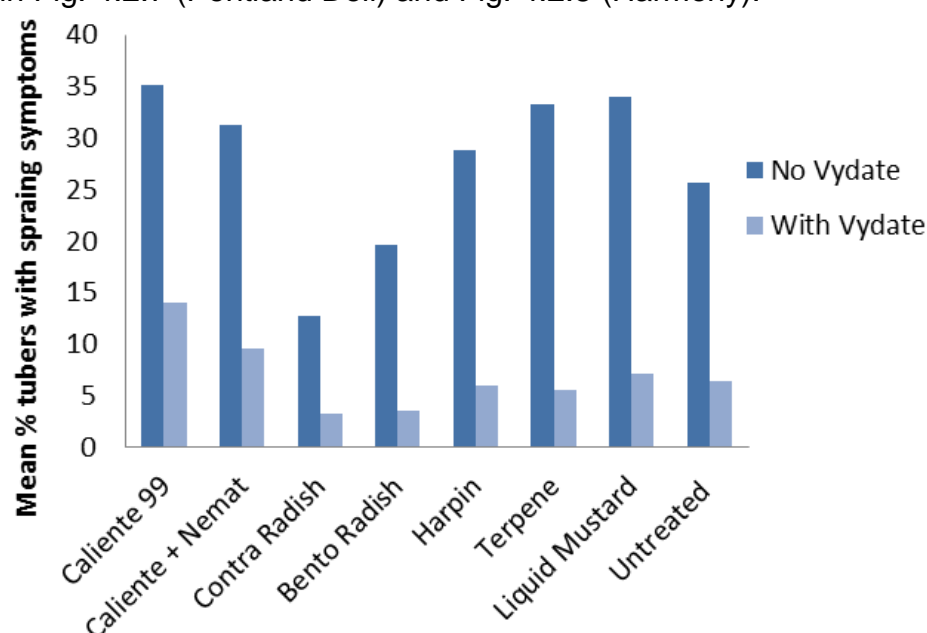


Fig. 4.2.7. Mean % of tubers with spraing symptoms – Pentland Dell – from the alternative treatments trials at Harper-Adams and Meigle.

The Contra radish treatment had significantly less spraing symptoms in Pentland Dell compared to the Untreated and Caliente + Nemat treatments (Fig. 4.2.7). The addition of Vydate 10G to the above treatments led to significant reductions in spraing symptoms (Fig. 4.2.7).

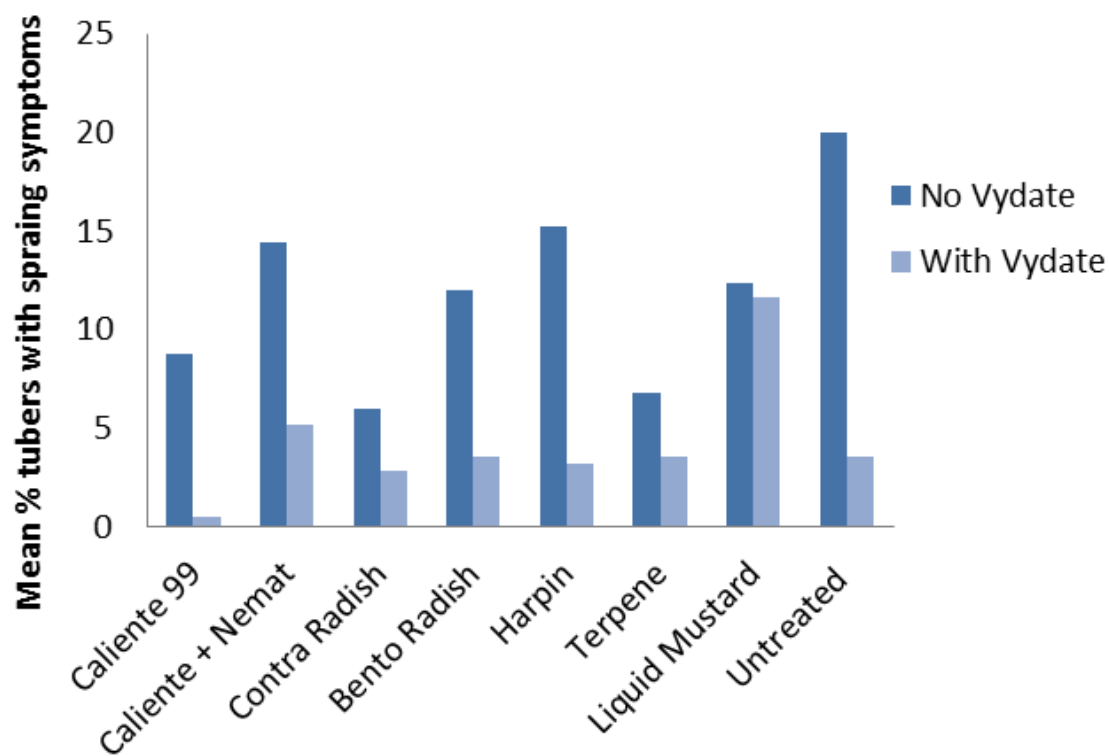


Fig. 4.2.8. Mean % of tubers with spraing symptoms – Harmony – from the Alternative Treatments trials at Harper-Adams and Meikle.

There were no significant differences between any of the different alternative Treatments in terms of the % of tubers with spraing symptoms in Harmony compared to each other and to the Untreated (Fig. 4.2.8). The addition of Vydate 10G to the above treatments led to significant reductions in spraing symptoms (Fig. 4.2.8).

5. DISCUSSION

5.1. Work Package 2: Field Trials

5.1.1. Variety Trials

The statistical analysis of the cross site and years data provides an overview of the impacts of FLN (primarily *(Para)trichodorus*) populations and the use of a nematicide (Vydate 10G) on a range of potato varieties. This cross year and site analysis was undertaken to attempt to offset the different environmental conditions, site effects and FLN populations at (and within) each of the trial sites. Analysis of individual trials provided a great deal of variability in the results from the field trials.

There was a significant variation in FLN populations between and within trials. For example, Fig. 5.1.1 shows the *(Para)trichodorus* counts as a contour map spatially across one of the trials. Nematode counts vary widely in the trial plots, and this spatial variability in nematode counts was present at all of the trial sites.

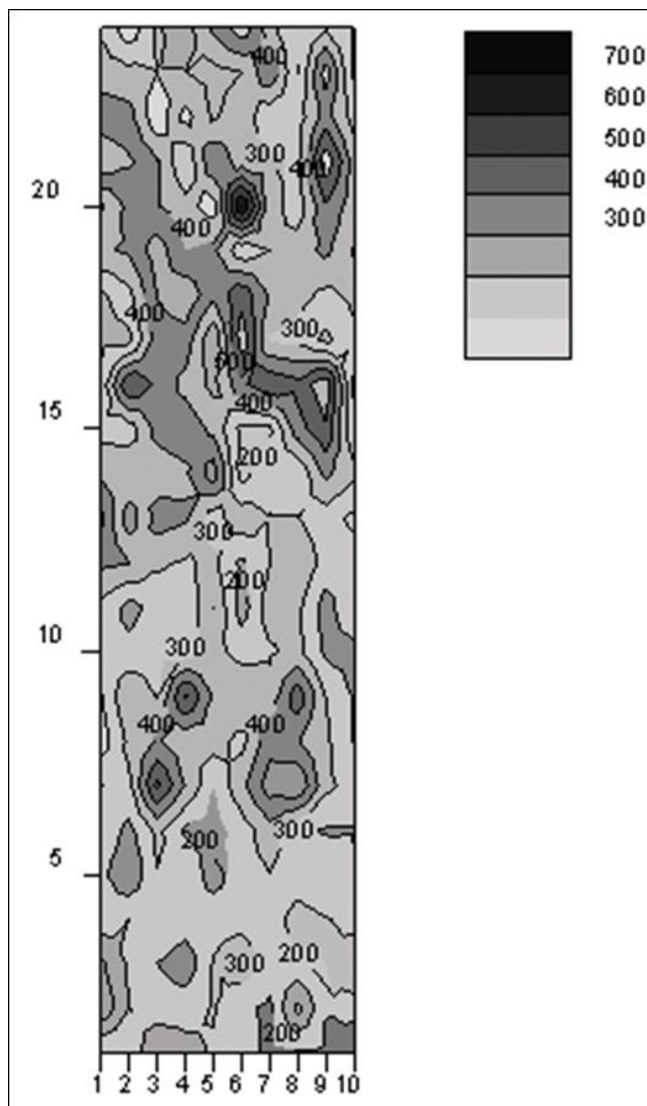


Fig. 5.1.1. *(Para)trichodorus* spatial distribution within one of the trial areas just prior to potato planting. No. of nematodes in 200g of soil.

The statistical analyses undertaken took into account this spatial and site variability so that the data from all 12 variety trials over 3 seasons could be analysed as a whole.

As expected each site varied in terms of its climate, planting date and burning off date and some of these have an influence on whether FLN have a significant impact or not on the crop. For example, cool, damp conditions at or subsequent to planting will naturally slow down crop emergence and establishment, and this benefits FLN by providing conditions for their movement through soil (moisture) and a longer period for them to feed on the roots of the mother tuber, subsequently affecting crop emergence.

Previous work (Evans unpublished) in pot trials and field trials has shown that FLN feeding on the roots stunts plants, leads to thickening and proliferation of the roots at the expense of top growth, effects which are not seen in the absence of FLN from soil or in the presence of a nematicide. The use of a nematicide in these trials had a positive impact on crop emergence and subsequent crop canopy.

The negative effect of FLN feeding damage on the crop canopy did not translate into consistent differences in total yield, marketable yield, tuber numbers or tuber size. Only Pentland Dell showed a consistent negative impact across all these variables. Lady Rosetta also shows a significant reduction in total yield and marketable yield due to FLN damage.

With the use of the nematicide Vydate 10G, varieties tended to increase tuber numbers, although this did not always translate into a significant increase in yield (except with Innovator and Harmony). This can be partially explained by the fact that varieties within each trial were burnt off and harvested at the same time, when ideally some varieties would normally have been allowed to bulk up for longer and potentially lead to larger tubers and increased yields.

Spraying symptoms (confirmed as being TRV) were seen in all varieties. Shelford, Lady Rosetta and Saxon tended to show the lowest incidence of spraying and Casablanca and Pentland Dell the highest incidences. Use of the nematicide Vydate 10G significantly reduced TRV spraying symptoms in all varieties by around 50% or more, indicating that for preventing spraying symptoms in potato a nematicide is necessary when growing spraying sensitive cultivars in land where TRV is present.

5.1.2. Alternatives trials

Use of crops with a biofumigant potential such as Indian mustards and oil radish is being mooted as a potential solution to a reduction in available nematicides for FLN and potato cyst nematode (PCN) management. Whilst the focus in the UK has tended to be on PCN, there is some evidence (Evans, Unpublished; Anon, 2001, Smallwood, pers. comm.; Manduric, 2008) for effects on FLN and TRV. The planting of biofumigant crops in the season prior to planting potatoes was undertaken to see if there was an impact on potato yields, tuber numbers and spraying symptoms in the potato crop. In most cases yields were as good as or slightly higher than an Untreated crop of Harmony or Pentland Dell.

In our trials, we attempted to compensate for the 'green manure' effect of the incorporation of the biofumigant crops by adding additional Nitrogen to the non-biofumigant treatments including the Untreated. This *ad hoc* compensation across the board may have had an impact on the yields seen and evened out any potential

differences between the treatments. For example Bento Radish had an average total yield across the trials in Pentland Dell of around 51 t/ha compared the 48 t/ha of the Untreated, however the variability between the plots and trials did not make this a significant difference. In all cases, addition of a nematicide (Vydate 10G) led to increases in yields and tuber numbers.

Contra radish followed by Pentland Dell had a significantly lower incidence of spraing symptoms compared to the Untreated. Contra radish is claimed to have an impact on nematodes and subsequent reduction in TRV, which is borne out by the results of this trial in Pentland Dell at least. When the nematicide Vydate 10G was used this significantly reduced spraing symptoms in all treatments as expected. There was not a significant difference between treatments in Harmony, although the Contra Radish plots had the numerically lowest levels of spraing.

It should be noted that the biomass of the biofumigants at the time of incorporation was lower than hoped, particularly compared to biomass achieved in whole fields (Roberts, pers. comm) which will have had an impact on any biofumigant activity due to the breakdown of the incorporated plant material. An issue, particularly from a Scottish perspective, is finding a 12 week slot between crops to sow a biofumigant crop and incorporate it. Crops sown towards the end of August were not able to achieve a suitable biomass, whereas crops sown in June were more productive in terms of biomass.

The 'in season' treatments of liquid mustard, harpin and terpene had no significant effects on potato yields or on symptoms of spraing compared to the Untreated potatoes in these trials.

6. CONCLUSIONS

6.1. Work Package 2: Field Trials

The spatial distribution of FLN can vary significantly across a field, and this was demonstrated in our trials where numbers did vary significantly between the individual plots. When fields are sampled for FLN prior to potato planting, growers should be aware that there is likely to be a large degree of variability in FLN populations across the field, and that a single FLN count for the field is an average of all the sampling points only.

The impact of FLN on the potato crop is dependent on soil conditions and the rate at which the crop can get established. Trials over 3 seasons at 12 locations have shown that if crops can emerge rapidly, they can 'grow away' from even relatively high FLN populations without any significant reduction in yield and quality.

Pentland Dell responds negatively to the presence of FLN, with significant reductions in yield (total and marketable), tuber number, and average tuber size. Other varieties such as Harmony (tuber number), Lady Rosetta (total and marketable yield), Crisp4All (standardised marketable dry matter 23% yield) and Saxon (standardised dry matter 23% yield) were significantly affected in a negative way by FLN.

Previous research has shown that varieties differ in their response to TRV infection and have been categorised as:

- **Resistant:** the varieties do not show any symptoms and virus particles cannot be detected in the plant, including in the tubers.
- **Spraing sensitive:** varieties which exhibit spraing symptoms in the tubers and surface lesions and malformations. Virus particles are rarely found in the plants, including the tubers.
- **TRV susceptible:** varieties which show few if any symptoms in the tuber flesh but become systemically infected so that virus particles can be detected throughout the plant. After several generations such potato plants produce smaller and more irregular tubers. There may also be effects on quality (e.g., after cooking blackening).

Where the presence of TRV is confirmed either through past history in the field or via a diagnostic test, use of a nematicide and/or the use of a resistant variety is strongly recommended.

6.2. Work Package 2: Alternatives trials

The results from the trials carried out in Shropshire and Scotland suggest that getting the agronomy of the biofumigant crops (weed management, seed rate, fertiliser input, sowing date and incorporation) right is crucial to get the best nematicidal effects from these crops. In the trials carried out as part of this project, issues with finding a 12 week window for planting were highlighted, as well as latest dates for planting – beyond mid-August is a risk.

Potato crops following incorporation of biofumigant crops did occasionally have an increase in yield but not significantly so compared to untreated crops, a consequence of insufficient biomass, the spatial variability in FLN populations at each trial and between the trials. Variability was mitigated by the number of replicates and trials over several years over two sites.

Growing Contra radish prior to Pentland Dell led to a significant reduction in TRV spraing symptoms compared to the untreated crop. However, use of a nematicide, whether a biofumigant treatment was used or not, was the most effective approach at reducing spraing symptoms. Use of novel 'in season' treatments such as harpin, terpene and liquid mustard did not significantly improve yields or reduce spraing symptoms.

6.3. Further research and development

This research has highlighted several issues that 'muddy the waters' when it comes to the interpretation of the results using field trials and FLN.

The spatial and temporal variability of FLN populations makes the determination of significant responses of treatments and varieties a difficult process. No individual plot is the same when it comes to the FLN population, and the conditions during which soil samples are taken for FLN population analysis dictate the 'true' measure of the actual FLN population present.

During this project two trials were sampled at planting and again at two different timings during crop emergence (see Figures 3.18 & 3.19 in the work package 1 final report), and FLN population estimates from individual plots could vary by $\pm 20\%$,

which whilst reinforcing the relative accuracy of the initial FLN count, does indicate that there is variability depending on conditions at sampling.

Spatial variability of FLN populations within a field prior to planting can significantly influence the overall FLN 'count' that growers and agronomists currently receive from an 'FLN test'. A study of FLN spatial variability combined with identifying the ideal conditions at which to sample would benefit the industry and provide increased confidence in the FLN count obtained.

The 'spraing' symptoms seen in this trial were confirmed as being due to TRV rather than potato mop top virus (PMTV). However, in reality the virus causing symptoms is often not identified, and a TRV and PMTV risk assessment should be undertaken prior to planting. As mentioned above, spatial variability of TRV (and PMTV) may be present in a field, and improved sampling will only be able to address this. PMTV is transmitted by a soil-borne plasmodiophorid (*Spongospora subterranea*) that also causes powdery scab on tubers. Soil samples taken for TRV risk assessment can in practice be assessed for both these viruses and FLN counts.

The effect of environmental conditions on FLN feeding behaviour and movement is poorly studied, but plays a crucial role in their impact on the crop, as does the impact of environmental conditions on the crop itself, especially during crop establishment. Rough rules of thumb regarding a higher risk of FLN damage if planting into cold wet soils can be provided currently, but could be linked in with more data on how varieties themselves respond to these environmental conditions: i.e. do some varieties have a propensity to do worse when planted in cold wet soils?

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