Project Title	Carrots: Survey of major growers to promote sustainable methods of nematode control and investigate factors limiting their uptake.
Project number:	FV 278
Project leader:	Sue Hockland, Central Science Laboratory
Report:	Final report, December 2005
Key staff:	Dr Sue Hockland Peter Knight, Vegetable Consultancy Services
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Date project commenced:	25 November 2005
Date completion due:	31 December 2005
Key words:	Carrot, parsnip, Temik, Vydate, control, fanging

The results and conclusions in this report are based on a survey of growers conducted in December 2005. Their replies have been treated in confidence.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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Grower Summary

Headlines

- All growers surveyed are using Temik to control nematodes, but none were using the HDC decision tree as part of their decision strategy.
- Temik has won a following for its effect on crop vigour and apparent yield response, not for consistent control of nematodes.
- There appeared to be no relationship between the use of Temik and incidence of fanging.
- A proportion of growers were using Temik selectively in response to customer pressure
- Growers were likely to use Vydate when Temik is withdrawn from the market
- The role of sampling in nematode control programmes has been questioned and should be reviewed
- Current treatment thresholds recommended in the HDC Decision Tree cannot be related to the incidence of fanging damage in the field, so a new management system is required to assess risk

Background and expected deliverables

The control of plant-parasitic nematodes in carrots has been investigated by the HDC over the last five years (FV 232, 249 and 273). Whilst nematodes are known to affect carrot quality, they have not been proven to be a significant problem in these projects. Despite this there seems to be a reluctance to reduce nematicide use or adopt the HDC Decision Tree (Appendix 1) to decide what are appropriate control measures.

The aim of this survey was therefore to determine the present status of nematode control in carrots and identify factors that restrain the development of a sustainable nematode control strategy. The survey results would be delivered in a report for circulation amongst carrot and parsnip growers; expected benefits could include reduced costs of production and improved competitiveness for quality assured schemes, but also it was hoped the work would help us to understand the reasons for the non-uptake of the R and D recommendations, as well as stimulate ideas for future research.

Summary of the project and main conclusions

Information for ten field crops grown in 2005 was collected from five grower groups during a survey done in early December 2005. Most growers continue to use Temik, not prophylactically for nematode control, but primarily for the increase in plant vigour and resulting yield response, that to them offered some insurance of adequate profit margins. Several growers could confidently predict a yield response where Temik had been used, but none could show a commensurate effect on nematode levels, or the proportion of fanged carrots. Fanging itself was invariably included as a small proportion of general 'misshapes', and its cause was often not confirmed. Thus the survey itself has not shown that nematodes are generally a significant factor in yield or quality losses, but there is pressure to reduce any negative effect on profit margins. The HDC Decision Tree was not well known; where it was, treatment thresholds were regarded as unreliable. There was a universal view that nematode levels recorded in samples bore no relation to the extent of subsequent damage, but as very few growers were confident that all fanging was caused by nematodes, this made comparisons difficult.

The importance of nematodes therefore needs to be put into perspective with all other factors affecting yield loss and quality, but the survey has highlighted that the use of the HDC Decision Tree should be reviewed, along with sampling and subsequent use of results, to help provide a more reliable risk assessment process that growers would use as part of a sustainable pest control programme. A key factor in such a review would be to build on growers' observations about nematode activity during the seedling stage and to monitor closely the soil moisture deficit from drilling to assess when conditions are favourable for nematode activity and hence damage. This would require a cross-commodity approach to further research.

Financial benefits

Financial benefits deriving from this survey will depend on the willingness of growers to forgo or at least review the use of nematicides and the benefits of better understanding the direction of future research.

Action points for growers

- The benefit of using nematicides for nematode control in carrots has yet to be demonstrated. Thus when Temik is withdrawn, or before this, consider the evidence for cost:benefits before applying an alternative product.
- There was variation in the rates of products being used by growers, so these should be reviewed, as financial savings may be possible.
- Consider whether fanging is a significant factor compared to, say, misshapes, and try to ascertain the true cause
- Continue to use sampling to justify the application of chemical treatments and consider whether timing this for the spring in the year before cropping might ease workloads and management decisions.
- Examine whether earlier drilling dates or other cultural practices would increase crop vigour rather than using Temik.
- If not already used, try destoning equipment before drilling and assess its effect on crop quality.

Acknowledgements

We are grateful for the assistance of the growers who gave of their time for this survey. Thanks are also due to information from Colin Allott (DuPont), Eileen Bardsley (Bayer CropScience), John Birkenshaw and Steve Ellis (ADAS), David Martin (Plantsystems Limited) and Tom Will (Vegetable Consultancy Services).

Science Section

Introduction

The development of Assured Produce schemes in field vegetables has stimulated interest in the rationalisation of chemical use for control of pests and weeds. In a previous project funded by the HDC (FV 232) the damage done by plant-parasitic nematodes and their control had been investigated. The efficacy of Temik (aldicarb) had been variable, whilst at the same time the incidence of damage to carrots that could be reliably attributed to nematode activity was minimal. Evidence from HDC trials work since this project (FV 249 and FV 273) has not provided evidence that this observation has changed, but chemicals for nematode control continue to be applied to control fanging, although such symptoms can also be caused by disease, stony soil, herbicide use, water-logged or compacted soils.

The HDC sponsored this grower survey to discover why the HDC decision tree was not being used, why chemicals for nematode control were still being applied and to determine which factors are preventing the sustainable control of plant-parasitic nematodes.

Materials and Methods

Six growers or groups of growers were selected that comprised the majority of the carrot producers in England, also representing the main carrot-growing areas of Lancashire, Norfolk, North Yorkshire, Nottinghamshire and Suffolk. One grower decided not to participate on the day of the visit but additional information on other sites was provided to include as much variation in circumstances as possible.

Growers were provided with a questionnaire about a week before the visit (Appendix 2) and this was completed during the site visit. Separately, action on fields other than the selected field was discussed, as well as any other topics relevant to integrated control of plant-parasitic nematodes. The information collected has not been attributed to any particular grower to ensure confidentiality.

Results

Whilst the survey questionnaire was devised to collect details about a designated field, it formed the basis for discussions involving the nematode control strategy for whole sites (Table 1).

Table 1. Collated replies to the survey questionnaire (numbers in brackets refer to responses where given more than once)

Information requested	**Reply**	**Additional comments**
Counties included	Lancashire, Norfolk, North Yorkshire (2 fields), Nottinghamshire (4 fields), Suffolk (2 fields)	
Cropping fields included in the survey	Carrots 9 Parsnips 1	
Soil type	Loamy Sand with gravel, Loamy Sand (3), Medium Sand, Heavy Sand, Sand (2), Sandy Loam, Peat	
Previous cropping	Potatoes>sugar beet>wheat>carrots Barley>barley>wheat>sugar beet>carrots Wheat>barley>turf>turf>turf>parsnips Cereals or rape>carrots Wheat>sugar beet>peas>lettuce>carrots Grass>grass>grass>leeks/beans>carrots Potatoes>wheat>peas>wheat>barley carrots Wheat>wheat>potatoes>wheat>wheat>carrots (organic). Winter wheat>potatoes>winter wheat>onions>linseed> carrots	
Land rented or owned	Rented (6); Owned (4)	

Information requested	Reply	Additional comments
Criteria for choice of rented land	free-draining suitable soil type (5), not following potatoes because of volunteer problem, 6 years from previous carrots or parsnips (3); access to water (2); general fertility(3); weed risk (2) ; disease risk.	Area most likely selected September/October. Readily available irrigation also important.
Sampling	A selection of fields sampled (2); nematode species not known in this field. Has been disillusioned with sampling because sometimes found no nematodes but had a problem with fanging. No sampling done as counts have been inconsistent (3); fields known to have stubby-root and longidorid nematodes (2). Soil sampling never gives full picture – not done. Soil sampling not done (2). Workload of sampling needs to be reduced, or need to make a choice about the fields to be selected. This done by rotating fields sampled, then at crop mist at risk. Sampling done early April. Considering sampling in May in year before cropping.	Soil too dry in August when need decision in September. Autumn schedule too busy (5);. Spring sampling possible but may be problem with assigned drilling date (2). May/June drilling dates would allow spring sampling and reinforce decision to use Temik (2). Sampling May in previous year might ease workload at critical time. Quality Assurance Schemes recommend sampling but it remains grower's decision (3). Weather forecasts may not be useful as takes time to organise sampling or machinery (2).

Information requested	Reply	Additional comments
Nematode species known to be a problem	Stubby-root nematodes. Root-lesion and root-knot nematodes also present, but carrot cyst nematode not seen	Also problem (spraing) in potatoes. Thus these species are main target for testing. No link between levels of stubby-root nematodes and presence of virus. Most problems in crops under polythene or early open ground, but not much of latter.
Treatment	Vydate (1); Temik (7); no treatment on peat	Temik also used on some fields. Last 10 years Temik on most crops now just potatoes and carrots.
Why use chemical treatments?	Untreated fields have had fanging problems, but about 50% of fields are not treated due to low nematode counts and experience of fields. Temik gives confidence that fanging will be reduced (2); 5% of crop affected by fanging a problem; 15-20% can lead to problems on packing line. Worst 30% of fields treated and acceptable results are achieved. Temik used as a prophylactic (4) and for improved establishment/vigour/quality (10). Need to control stubby-root nematodes in potatoes.	Some customers have a target of no crops treated with Temik, but the position regarding the use of Vydate seems unclear. No Temik or Vydate on Fenland Also good for aphid control (3).

Information requested	Reply	Additional comments
Comparison of treated/untreated areas?	Not recently (2) Yes – on peat but no difference. No (2) Yes – no significant difference in fanging but yield in Temik plots was higher.	Also comparing areas treated with Vydate and Nemathorin.
Why are some areas left untreated	Peat soil – Temik ineffective.	Increasingly political and commercial advantage not to use Temik.
Rates	Temik: 8 kg/ha (3) "Half rate". Temik: 9 kg/ha Temik: 10kgs per ha (3) Vydate: 12.3 kg/ha	Vydate requires more product per unit area and is more expensive. Predominantly 3 bed rows.
Cost	£30 per acre to £75 per ha. £7.80 per kg, with Horstine Farmery machine – fishtails over destoner.	
Cost:benefit of using chemical treatments	Not analysed (5). Untreated fields show 10% increase in yield. £350 per acre yield response.	Benefits for aphid control (2). Fanging assumed greater importance would as profit margins decrease.
Are nematode levels increasing or are they about the same?	Difficult to answer. Static (5)	

Information requested	Reply	Additional comments
Organic fields	Organic for 4/5 years. Fanging less than 2%. Last 2 years incorporated mustard with animal manure in the autumn. Weed control by cultivation and burning. Low fertility and weed burden reason for ceasing next year (1) More cultivations in organic field than conventional fields (2).	Posed question: did weeds attract nematodes away from carrot crop? Not known, but weeds are hosts. Using a cultivator every 7-10 days will also reduce surface moisture.
HDC Decision Tree	Used (1), but science gets lost as other judgements are made. Thresholds are too rigid and too high (still see fanging at lower levels). Invariably own decisions are made based on experience but helps thought process. Not known (2). Not used (3). Decision tree is sometimes superseded by customer demands (3). Need to consider previous cropping, soil type and field history. Thresholds given are too complex, and growers have had damage with lower populations (2), so broader categories might be appropriate. Agronomist makes judgement on whether risk low, medium or high. Not used as no sampling done (2). Temik used prophylactically as nematode damage considered likely (2).	

Information requested	Reply	Additional comments
Pre-drilling cultivations	1 pass disc/harrow, Subsoil (3), plough (7) (March), destoner (5) and bedformer (7) (close to drilling). Organic: rotavate before ploughing once or twice depending on previous crop.	Bed-forming done at drilling. Considers cultivations help control nematodes (2). Destoning not good pre-drilling, especially in wet conditions as will lead to compaction. Can move 10" in depth. Destoning costs £50-60 per acre. Paying for destining by the hour said to lead to more effective job, but weather at destoning is important. Bed tiller immediately in front of drill.
Drilling date	February (under cover) Last week in March 1 April (parsnips) April 20 and 27 April end of April 2 and 3 and 8 May 15 May (organic)	Drilling date determined by required size of carrots and harvest date. Soil temperatures are around 8-10˚C early March. Maybe 4 triples or 3 triples.

Information requested	Reply	Additional comments
Herbicides?	*Pre-drilling* PDQ for nettles *Post-drilling* Several, including PDQ, Linuron, etc. *Pre-emergence* Linuron or Stomp+Linuron after 3-4 days. *Post-emergence* Alpha Linuron, 3 weeks after drilling and again in July Dosaflo/Linuron/Sinorco; Linuron at 5 true leaves. None (3). None on organic field.	
Irrigation	Irrigation dates in June (3), July (3) and August; September. None (parsnips) 1 site: 6 applications of 25mm. First timing at 20%-30% crop cover, about 3-4 weeks after drilling, mid-June (2).	Generally the weather in 2005 enabled most growers to forgo irrigation until late June. Irrigation occurs during dry weather, although the criteria for determining action may vary. Soil moisture monitored by neutron probes. Deficits of 20 or 25mm used, but growing carrots for processing requires less water early in season.

Information requested	Reply	Additional comments
Crop strawed?	No (3) Yes, when ¾ grown (6)	Processing crop is ridged and covered with soil. Polythene (except for 2 sites) and straw are used elsewhere. Polythene and straw (4) – costs £1000 per acre.
Harvest date	Mostly customer led but covered period August to October, December to March.	
% fanging	Less than 2% (2) 3-4%-10% (Temik used prophylactically) (2) 5.22% - 15.9% (Temik use prophylactically). Organic 1.68%	Fanging first noticed when the root is about 15cm or 6" long, but susceptible stage may be the 'pencil' stage, when the seedling root is about 2" long (1). As carrot expands in June/July the damage to the root tip becomes apparent Fortnightly assessments made on one site. Fanging in field with 10-70% damage not seen at 5-leaf stage.

Information requested	Reply	Additional comments
Cause of fanging?	Casual observation that when used more Temik 2/3 years ago had more fanging, which has led to the conclusion that fanging was not caused by nematodes but by herbicide damage, excess nitrogen or water. Nematodes (4) (Temik used prophylactically – sampling not done every year). Stony soils but some caused by nematodes (4). Have had problems with fertiliser, now confident the problem is nematodes, but not confirmed. Not known (2).	
Yield (before losses)	25T/30T/40T/47T per acre; 70T/75T/100T/120T/130T per ha Organic 90 tonnes per ha.	Many site factors may be involved.
Value	£50-£80 per ton	
% Class 1	49%, Vydate used 51.3% (misshapes due to stones; Temik applied). 61.46%; 69.27% (organic), 73 – 77.5% of crop – Temik used Pre-pack assessment is 80% 89.22%	

Information requested	Reply	Additional comments
What are the five most important reasons for losses?	Oversize (2) Undersize (2) Misshapes (includes fanging) (0.3%) (6-7%) (9%) (10-15%) (30%) (6) Disease (9) (Sclerotinia, cavity spot, scab)) Weather (4) Breaks and similar damage (2) On-site management (poor management can lead to high stone content) (3) Market conditions (3)	Misshapes would include fanging but would include other distortions, due, say, to carrots growing too close together.
Is there a field that always produces a good crop?	Yes, virgin land that has never had carrots or parsnips. Those fields that have had sugar beet are rated a higher risk. Very complex subject – noticeably better around old animal rearing sites.	
Is there a field that always produces a poor crop?	Peat – 50% losses due to fanging. Stony fields (4). Poorly draining soils.	

Information requested	Reply	Additional comments
What factors are limiting the use of sustainable control methods?	Cultivations may kill nematodes but cultivating sand when dry pre-drilling could result in a seedbed too dry for good germination (3). Biocidal plants: have tried for nematode control but results worse than expected. Lack of research in to biology of the pests – knowing parameters that can be manipulated commercially. Intercropping would take moisture out of the ground. Garlic tried for carrot fly but no success. No success with garlic for nematode control. Quality Assurance schemes recommend following taken into account: previous cropping, soil type and field history. Stewardship scheme recommends cultivation of headlands after Temik applied (3). Appears to be no science behind quality schemes though. Timing of soil sampling; lack of effective thresholds; cost-effectiveness of treating (5). Pre-drilling sampling would entail testing of 1200 acres before drilling, but would still treat.	Used Caliente mustard; drilled in August and incorporated October/November. Drilled in June this year. Not frost tolerant so cannot be left overwinter. Overwintering crop then incorporation may not be feasible (2). Biocidal could be sown in to stubble, overwintered and incorporated before drilling with front-mounted chopper on plough. Field was tested and found no nematodes but 30-40% fanging (cause not clear – excessive nitrogen release?) An instance was quoted where a high incidence of fanging was recorded in June, so a new crop was drilled in mid-June (the latest date for drilling) which subsequently showed no damage.

Information requested	Reply	Additional comments
What are the reasons for lack of confidence in accepting the prevailing advice that nematodes may have a limited effect on crop losses?	No link between nematode levels and fanging. Are trying to use advice but if not using nematicides will use extra seed to guard against poor germination. Low levels of nematodes found, potatoes in rotation – use of Temik will keep levels at a consistently low level and maintain higher quality.	
What will you use as an alternative control to Temik	Vydate (2); considering Vydate (1)	

Information requested	Reply	Additional comments
Other comments	Fanged carrots: no interest from supermarkets. Mechanical weeding done 3 times with front-mounted equipment may affect nematode levels. Weed control a big issue. Willing to put up with some fanging damage. Cannot change site What plants/weeds are stubby-root nematodes most attracted to? Can technology develop an attractant? Does Vydate produce a yield response? Effectiveness of destoners needs to be examined if misshapes due to stones. Increasing crop vigour by other means, such as green manure, seaweed tonic, etc. needs to be examined. Need to investigate soil moisture and temperature requirements of nematodes, especially stubby-root nematodes, Rate of movement horizontally and vertically? When do they attack carrots and is it at the root tip or elsewhere? Fertiliser goes on at 3-4 true leaf so does this or herbicides have an effect on nematodes?	

Discussion

Sites, Soil Structure and Crop rotation

The selected fields included the major carrot and parsnip growing areas in England and covered the spectrum of different soil types encountered, weather and management practices used so that any major differences in approach to nematode control could be included in this report. Almost without exception the cropping fields had sandy soils. Such soils are composed of relatively large particles which gives an open texture so that they are free-draining and subject to rapid drying during periods of drought. Stubby-root nematodes, one of the prime causes of fanging symptoms, have a preference for such soils (Decraemer, 1995). Four of the fields were owned by the growers and six were rented. Owning the land allows a long-term strategy for nematode control to be developed. Those renting land have limited choices, but do not choose fields on the basis of nematode freedom and are most likely to choose fields with a free-draining light soil and readily available irrigation. Most nematodes attack the whole range of crops included in rotations but chemical control is generally only practised for carrots, potatoes (where stubby-root nematodes are vectors of tobacco rattle virus causing spraing) and sugar beet. For six out of nine carrot rotations these crops were included, so there is a continuing pressure to control the same nematodes in most seasons. This highlights the need to develop a universal nematode control strategy covering both arable and horticultural crops and the need for a cross-commodity approach to research.

Irrigation

Surface levels of all nematodes tend to fluctuate according to the amount of moisture, but whilst stubby-root nematodes are attracted to moist areas they become inactive in dry soils. Movement of these nematodes appears to be greatest when soil pores are half-full of water and is least in waterlogged or dry soil. As stubby-root nematodes are almost entirely restricted to free-draining sandy soils and so are likely to encounter very dry soil conditions, it is not surprising that their numbers in the upper layer of soil are correlated with rainfall or irrigation. Studies of stubby-root nematode damage in sugar beet have shown a close correlation between the area affected by fanging and the total rainfall in May, the month in which most damage to sugar beet takes place

(Cooke & Draycott, 1971), so a similar correlation might exist in carrots or parsnips. If a risk management system for nematode control is to be developed, then more research is required to study the soil moisture conditions for stubby-root nematode activity and the optimum conditions required by the carrot or parsnip crop; it would also be interesting to monitor the damage caused by nematodes in carrots grown for processing, for example, where drier conditions prevail.

Sampling and thresholds

Sampling to estimate nematode activity has formed the basis for making decisions about the need to apply chemical treatments for many years. Unfortunately the results are dependent on soil moisture and temperature at the time of sampling, the method of sampling used and sampling error when small samples are taken from a large field where nematode populations are randomly distributed and aggregated. Sub-samples are again made in the processing laboratory and different extraction methods may be used. The subject of sampling provoked perhaps the most heated debate, especially as most Assured Produce protocols require sampling as part of an integrated control programme. Growers cited the problems of relating sampling results to past experience of fanging and have developed an almost universal belief that the sampling system as a basis for predicting risk of fanging is flawed. Despite this conviction there was also a difficulty of assigning fanging damage to a particular cause. Commercial constraints to developing a more effective sampling system for treatment decisions include the timing of sampling in relation to the choice of field (but sampling in the spring the year before cropping might alleviate this problem) and the pressure to maximise quality and yield which means prophylactic treatments are often chosen.

Growers cited many examples where the levels of nematodes could not subsequently be related to the extent of fanging damage, leading to disillusionment with both sampling and treatment thresholds for plant-parasitic nematodes as a ‘fanging’ risk assessment tool. This lack of correlation might indicate other factors are primarily involved in fanging but it is difficult to distinguish the causes of fanging from symptoms alone. As nematodes are perceived to be the culprits which can be controlled the mere presence of them has often provided justification for the use of nematicide. HDC trials in the last five years have failed to show significant fanging

damage at low levels of nematodes, and indeed, there had been discussion amongst researchers as to whether recognised treatment thresholds might need to be raised.

Difficulties in relating specific levels of nematodes to damage has been encountered in other root crops, such as sugar beet. Much research has resulted in a range of factors being implicated in affecting the incidence of fanging, such as previous cropping, soil structure and moisture, poor establishment, deep drilling, herbicide toxicity and other factors (Jones & Dunning, 1972). Hence there are no well-defined treatment thresholds or risk models in this crop that might facilitate the development of a control strategy in carrots or parsnips. It therefore seems appropriate to reconsider the nematode control strategy on carrots or parsnips, bearing in mind the conflicting evidence of nematode levels and damage.

Perhaps for carrots and parsnips the mere presence of stubby-root nematodes should be considered as the treatment threshold if the aim is to reduce fanging by them, but considering the complexity of other factors that influence nematode activity and the evidence of other contributory causes such as herbicide damage, this approach must be viewed as too simplistic. More research on the interrelationship between nematodes and other environmental factors might help to clarify such issues.

HDC Decision Tree

The HDC Decision Tree, which included advice on treatment thresholds, was seen as a prototype to facilitate management decisions. The lack of grower awareness of the HDC Decision Tree generally was disappointing despite its publication in the report of the HDC project FV 232 and in an item in the HDC News. Alternative means of communication must be considered in the future. Most that did know of it found it useful as an aide to decision-making but none adopted its recommendations regarding treatment thresholds because of the problems of relating sampling results to the incidence of fanging. In addition, it was apparent from the discussions that the treatment decision-making process was more complex than appeared from the Decision Tree. The actual causes of fanging may be difficult to determine so that relating sampling results to fanging damage is also a complicated issue. For most growers this dilemma has been resolved by prophylactic applications of Temik, whilst others, especially those that had built up a knowledge of rented or owned fields, made

selective decisions on which fields to treat based on selected sampling and previous experience. In some cases this decision was strongly influenced by the demands of buyers wishing to be seen to be selling produce that had not been treated with Temik, but in most cases the buyers were leaving treatment decisions to growers or their consultants.

Despite the widespread use of Temik, however, the results of this survey support previous HDC work which concluded that treatment is not a reliable control measure; indeed, the results of this survey showed damage on Temik fields ranged from about 10% to as high as 24%. The reasons for this need to be investigated if chemical control is to continue. It might be that application methods need to be improved, rates reviewed or that enhanced degradation is taking place, though this is thought to be rare. It might also be that nematodes in the surface layers have been affected by cultivations at drilling, and that significant numbers do not return to the root zone until after the chemical has ceased to be effective.

Treatment

Temik was used on all soil types except peat, where control was reported as poor. However, both Bayer CropScience and Dupont advise that carbamates such as Temik and Vydate should perform well on soils with a significant organic fraction, although soils with a high pH can reduce efficacy in some circumstances.

Nematicides were also applied to keep numbers of stubby-root nematodes at low levels for other crops in the rotation, such as potatoes, but there is no evidence that regular use will decrease nematode numbers over time. In fact it could lead to enhanced degradation in some soils.

Whilst Temik will cease to be available from December 2007, there was evidence that its use is beginning to decline as a result of customer pressure. However, there is almost universal agreement amongst growers that Temik produces a significant yield response and may advance the crop by 3 weeks. These factors are very important in the continued use of the product, perhaps more so than any effect on nematode populations.

The range of cropping bed systems being used means that a range of rates for Temik were quoted by growers in this survey, further complicated by different rates being quoted on the product label, namely a low rate of 26g per 100metres of row, a medium rate of 51g per 100metres of row and a high rate of 77g per 100 metres of row. Such a range could lead to as little as 6kg or as much as 17kg being used per ha. Bayer CropScience have used a rate of 38g per 100m length of row in trials work which is approximately equivalent to 8.4kg per ha., compared with the range of 8 to 10kg of Temik quoted by growers in this survey. The rates of nematicide being applied need to be checked as this might account for poor performance or unnecessary expense.

As an alternative to Temik growers are considering using Vydate, which is currently approved for use on carrots and parsnips by a SOLA. DuPont advise a rate of 90g per 100metres of row (compared with the rate of 12.3 kg of Vydate quoted in this survey).

DuPont trials work in 2003-2005 indicate that Vydate use provides a similar level of reduction in fanging to Temik; data from Bayer CropScience appears to support this but they also provide evidence for significantly better yield benefits from the use of Temik compared with Vydate and this is confirmed by growers. Nevertheless, as the levels of fanging appear to vary considerably even when Temik is used justification for chemical application must be a matter for review. As Vydate does not appear to offer any significant improvement in crop vigour compared with Temik, it will become more important for growers to consider the true cost:benefits of chemical treatment.

The nature of fanging

Fig. 1. Typical symptoms of fanging

There were wide-ranging discussions with growers about the nature of fanging and the range of factors that might cause it, such as compaction, herbicides, nitrogen, nematodes and waterlogging (Fig. 1). It is difficult to assign symptoms to a particular cause. Fanging is often not noticed until assessments on quality are done in the summer, but the damage may be initiated earlier. The influence of herbicides and other soil-related factors must be greatest during the seedling stage. For crops that are attacked by stubby-root nematodes this period is also a critical one, as the nematodes seem to favour feeding in the elongation zone of the root tip. When root growth declines the attack may be transferred to the apical meristem (Pitcher, 1967). The general opinion was that drilling produced a loss of moisture in the surface layers which, combined with the physical effects of cultivation, would probably result in a delay of stubby-root nematode activity for a couple of weeks. One grower considered that nematode damage could be detected at the "pencil" stage, when a tuft of roots could be seen at the root tip. Such "tufts" might represent attempts by the plant to develop a new "leader" root after the original one had been destroyed by nematode feeding. Re-drilling once significant levels of damage had been seen usually resulted in a crop with little or no fanging, so such monitoring of early signs of damage is probably critical. Clearly, whilst such observations need to be investigated and

supported by research, monitoring the crop closely at such a susceptible stage may offer growers an early warning of likely damage and present an opportunity to re-drill the crop if necessary; this was thought to have had economic benefits in one case discussed.

The importance of fanging was illustrated when the percentage of Class 1 roots per crop and proportion and importance of misshapes was discussed. Percentage Class 1 carrots varied from 51% to 89% with no particular reason other than site differences emerging. Misshapes, which includes carrots with unacceptable distortions as well as fanged carrots, was the second most important reason for losses (disease being the most important). The proportion of 'fanged' carrots varied from site to site, but also the cause of the fanging was not confirmed as nematodes in most fields.

Sustainable methods of nematode control

As the main nematode species attacking carrots and parsnips have a wide range of hosts, the use of crop rotation as a means of control is limited, especially as most nematode species can also survive on an equally wide range of weed species.

Several growers considered that cultivations offered a cultural means of control, especially, but not exclusively, when destoners were used. HDC results on cultivations to date have been inconclusive but their effects seem short-lived; they may, however, disrupt nematode activity at the crucial susceptible early stages of plant growth. During discussions with growers it became apparent that the quality of the destoning process was very variable, and if used to reduce the incidence of misshapes, or more specifically fanging, then attention should be given to the quality of destoning, i.e. the depth, the amount of soil moved and the size of stone removed. Soil moisture also needs to be quite high for the optimum performance of the machine.

Drilling dates for uncovered crops ranged from the end of March to the middle of May. There has been no recent study of nematode activity in the spring, but it would clearly be influenced by the weather and by irrigation. The effect of crop advancement attributed to Temik could also be achieved in the absence of treatment

by earlier drilling, but it is not known whether such practice would control nematodes, especially in cool, wet springs.

Animal manures have been associated with increased vigour of plants, but may also affect the pH of the soil; in Britain, the majority of stubby-root nematodes (16.9%) are found in soils with a pH of 6.5 or higher, whereas in soils with a pH lower than 5.5 these nematodes were less common (6.5% of soils) (Alphey & Boag, 1976). Although carrots are tolerant of pH at 5.5, they are usually grown in soils of at least 6 - 6.5 to avoid problems of disease, so there is probably little point in manipulating levels purely for nematode control.

Incorporation of biocidal plants occurred on one site. Mustard belongs to a group of plants that release isothiocyanates when plant tissue (foliage or roots) is broken. However, Caliente mustard, one of the commercially available biocidal crops, is not frost tolerant, so has to be incorporated in the autumn whilst there is still active growth. If a biocidal crop could be found that could be grown overwinter and incorporated in the spring before pre-drilling cultivations, this might improve nematode control. The development of pellets of biocidal crop material for incorporation in the spring needs to be investigated.

Conclusions

- Sampling prospective cropping fields should be continued to provide information on nematode activity but the timing of sampling and integration with commercial practices, as well as the role of sample results in treatment guidelines should be reviewed.
- Carrot and parsnip growers are under increasing pressure to reduce the use of nematicides, so a clear management decision process needs to be developed for every site.
- Growers should review the rate of products they are using for nematode control as financial savings could be made.
- The HDC Decision Tree is not being used because of a lack of confidence in the use of treatment thresholds and these need to be reviewed. The

Decision Tree should be reviewed or replaced by a set of management guidelines.

- There appears to be no correlation between nematicide use and the incidence of fanging, suggesting either ineffective nematode control or other, non-nematode factors, are involved. If growers are to choose Vydate to control nematodes then on-farm trials are required to assess its effectiveness.
- Experimental work should be done to assess the symptoms produced by stubby-root nematodes and relate them to those produced by other causes, such as herbicides.
- In order to refine new strategies for sustainable control of nematodes, especially stubby-root nematodes, the relationship between the seedling carrot, nematode activity, moisture, temperature and soil type should be investigated.
- The role of cultivations remains unclear, although most growers believe it offers some benefit for nematode control. It may offer a reduction in nematode numbers at drilling.
- Biocidal plants may play a role in nematode control but their effectiveness has yet to be proven. The use of biocidal plants is gaining interest worldwide and the Second International Biofumigation Symposium takes place in Idaho, USA 25-29 June. The Proceedings from this conference should be a useful indicator of current progress.

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Technology Transfer

An article for HDC News, based on the findings of this report.

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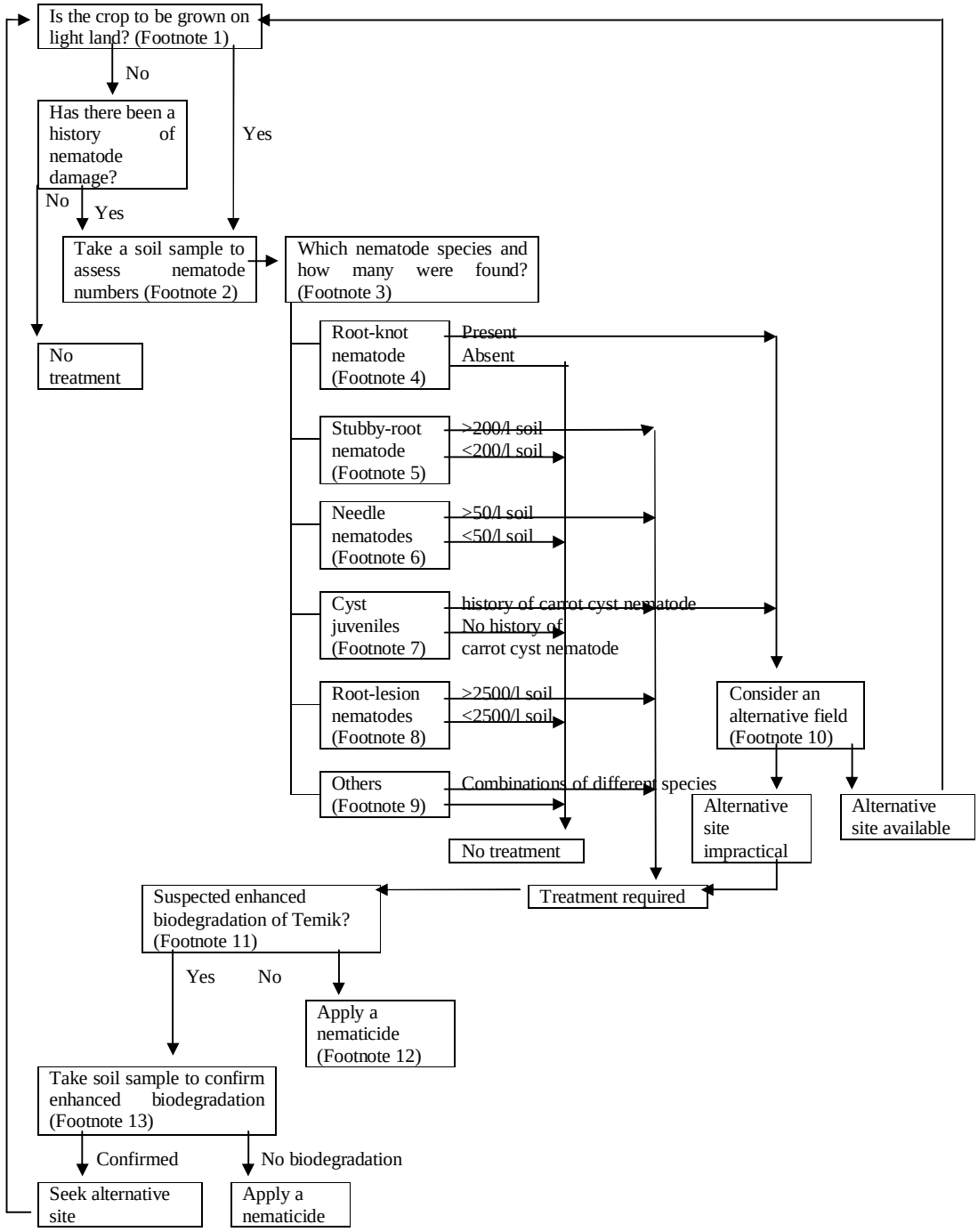
Jones, F.G.W. and Dunning, R.A. (1972). Sugar Beet Pests. MAFF Bulletin 162. HMSO.

Pitcher, R.S. (1967). The host-parasite relations and ecology of *Trichodorus viruliferus* on apple roots, as observed from an underground laboratory. *Nematologica,* 13, 547-557.

APPENDIX 1. HDC Decision Tree to assess the risk of nematode damage in carrots and parsnips (adapted from HDC Project FV 232) (with footnotes)



Footnote 1
The risk of nematode damage is greater in light than heavy land.
Footnote 2
Soil cores should be taken with a cheese corer at regular intervals and as evenly spaced as possible. This is best achieved by zigzagging across the area in an extended "W" path. Take approximately 50 cores to a depth of 15 cm from an area to obtain a representative soil sample. This will provide a bulked sample of approximately 1.5-2 kg. One sample should be taken from an area not exceeding 4 ha. Samples should be handled carefully and stored at approximately 5ºC (in a refrigerator) prior to despatch. Both ADAS Pest Evaluation Services, ADAS High Mowthorpe, Duggleby, Malton, North Yorkshire, YO17 8BP and CSL Diagnostics, Central Science Laboratory, Sand Hutton, York, YO41 1LZ will process these samples.
Footnote 3
The results of nematode extractions are provided in terms of the number of nematodes/l soil, or per 200g soil (multiply the latter by 5 to get the litre figure).
Footnote 4
Root-knot nematode can be very damaging to carrots and parsnips but is a localised problem.
Footnote 5
Stubby-root nematodes are generally considered to be damaging if numbers exceed 200/l or 40 per 200g soil but further research is required to re-evaluate the threshold for these species.
Footnote 6
Needle nematodes are one of the larger free-living species and consequently are thought to be damaging if numbers exceed about 50/l or 10 per 200g soil.
Footnote 7
Cyst juveniles cannot be identified to species in the free-living state and a cyst extraction would be needed to determine which species is present. Carrot cyst nematode would be damaging to carrots (but not parsnips). However, it is usually a localised pest.
Footnote 8
Root-lesion nematodes damage carrot crops in Europe, but this has not been substantiated in the UK; as a guideline a nematicide may be worthwhile where numbers exceed 2500/l soil.
Footnote 9
Stunt and spiral nematodes are frequently found but are unlikely to damage a carrot or parsnip crop. Pin and sheath nematodes are also sometimes recovered but invariably in low numbers that pose little threat to carrots or parsnips.
The combined effect of a number of different nematode species could also justify nematicide treatment. For example, if a sample contains both stubby-root and needle nematodes and numbers are just below treatment guidelines for both species, a nematicide or nematistat would probably still be worthwhile.
Footnote 10
Temik is only likely to protect carrot and parsnip crops for about six weeks. Thus second generations of the carrot cyst and root-knot nematodes may still cause damage. Even if low numbers of these nematodes are found it may be wise to avoid growing carrots or parsnips in the affected field. If there is no alternative but to grow the crop, a nematicide should be applied but some damage could still occur. Remember that carrot cyst nematode will not affect parsnips.
Footnote 11
If enhanced biodegradation of Temik does occur (not yet recorded in the UK) then the product should not be applied. Reduced efficacy of Temik could also be due to low levels of soil moisture so that the active ingredient is not released or problems with the application equipment so that the full rate of the product is not applied. Both these factors should be considered before taking soil samples to check for enhanced biodegradation.
Footnote 12
Even where a nematicide is applied it is still possible for crop damage to occur. Nematicide efficacy is affected by a range of factors including soil moisture, and can only be expected to reduce the level of pest attack.
Footnote 13
It is possible to sample soil and analyse for enhanced biodegradation of pesticides. If this is suspected, Bayer CropScience should be consulted to determine whether they have any experience of the problem. Preliminary enquiries suggest that an independent laboratory, Chemex Environmental International Ltd, are prepared to undertake the laboratory analysis for enhanced biodegradation. However, a

controlled study would be needed in order to develop the testing procedure, before routine samples could be accepted from growers. A controlled study would cost in the region of £3000 but once completed subsequent grower samples could be processed for approximately £320.

APPENDIX 2. HDC FV 278 – Carrot: Survey of major growers to promote sustainable methods of nematode control and investigate factors limiting their uptake. To collate current nematode control strategies and make recommendations for future research.

Thank you for agreeing to complete this questionnaire. If you can complete most of it and send it to me before our meeting then that will save time on the day, but I do wish to take the opportunity to discuss those factors limiting the use of sustainable methods. If you have any questions before my visit please contact me via s.hockland@csl.gov.uk, or 01904 462214.

I have not produced this form in a .pdf format so that you can enter as much information as you like electronically. This may, however, result in an overlapping of sections from one page to another, but this won't be a problem.

Questionnaire	Reply	Other comments
Data to be collected for 2005 season, but details for previous two seasons to be included if available.		
County		
Number of fields/farms included in survey. Please complete a form for each site if necessary.		
Soil type		
Previous cropping for last 5 years (to see if any trends apparent with nematode problems)		

Questionnaire	Reply	Other comments
Own or rented land?		
Criteria for choice of rented land		
Pre-drilling sampling:		
When are samples taken?		
Nematode groups and numbers per 200g identified		
stubby-root		
root-lesion (species?)		
root-knot		
carrot cyst nematode		
other:		
Treatment; which products and why used?		
Prophylactic/feel good factor? Proven or heresay?		
Evidence for benefits? Evidence for nematode reduction? Crop vigour?		
If products are used primarily for insect control rather than nematodes e.g. aphids, are they successful?		
Rates		
Costs of nematicide and application.		
Please enter cost-benefit ratio of using nematistats/nematicides.		

Questionnaire	Reply	Other comments
Has a comparison of treated/untreated areas been done?		
Are nematode levels increasing in carrot fields or remain about the same or decreasing – need to distinguish between treated and untreated fields.		
Untreated – why?		
Organic farms: what are differences in production, apart from no pesticides?		
Composts incorporated?		
Particular problems (may increase over time?)		
Pre- and post herbicides used?		
Used HDC decision tree?		
Helpful/Not used – why?		
Is decision tree superceded by quality assurance or stewardship schemes?		
Detail treatment guidance from Quality Assurance scheme		

Questionnaire	Reply	Other comments
How does this compare with Stewardship schemes? Are the two compatible?		
Pre-drilling cultivations		
Particularly use of destoner		
Drilling date (each year if several years' data)		
Harvest date		
Crop strawed?		
How is this done? e.g. polythene base layer then straw?		
% fanging		
Cause confirmed this year? Previous years? Herbicide/Flooding/Nematodes/Disease/Stony soil, etc.		
Obtain details not included in this questionnaire of any fields where nematodes shown to cause losses.		
Yield (tonnes /ha)		
Is there a field that always produces a good crop?		

Questionnaire	Reply	Other comments
Is there a field that always produces a poor crop?		
Quality		
% Class 1		
Other quality comments		
e.g. what are 5 most important factors in losses? e.g. disease/market conditions/weather/on-site management?		
Are you sure fanging/damage was caused by nematodes?		
(digital photos very welcome)		
What factors are limiting the development of a sustainable nematode control strategy?		
i.e factors which cannot be influenced, e.g. field used		
lack of confidence in accepting limited/localised influence of nematodes on quality?		
Any other comments?		