Project Title	Carrots: A cost-benefit study in the control of free-living nematodes, cavity spot and volunteer potatoes by comparing specific management systems before and during cropping.
Project number:	FV 249
Project leader:	Mr P Knight, VCS Ltd
Report:	Final report, June 2005
Previous reports	Annual reports, December 2004 & December 2005
Key staff:	Dr Sue Hockland Tony Prickett Tom Prior Clinton Grey
Location of project:	CSL York and four trial sites on commercial farms in Yorkshire, Nottinghamshire and Suffolk.
Project coordinator:	Martin Evans, Fresh Growers Ltd, Inkersall Grange Farm, Bilsthorpe, Newark, Notts, NG22 8TN
Date project commenced:	1 April 2003
Date completion due:	30 June 2005
Key words:	Biofumigation, carrot, cultivations, fallow, free-living nematodes, nematode, nematicide, nematistats, parsnip, pest, pesticide, *Pythium*, Sudangrass, volunteer potatoes, pesticide.

The results and conclusions in this report are based on a series of experiments conducted over a 2-year 3 month period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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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CONTENTS

Grower Summary

Headlines

- Fallow year cultivations (preceding carrots) did not result in a long-term reduction in nematodes, adequate control of volunteer potatoes or an improvement in marketable yield. Therefore they should not be considered.
- The effect of green manure crops on nematode dynamics may not always be beneficial
- On-site factors may play a more important role in crop quality than pests and diseases alone
- In the absence of Temik (aldicarb), the standard commercial practice of pre-drilling cultivations (in 2004) resulted in a dramatic overall reduction in nematode numbers.
- A link between numbers of stubby-root nematodes and fanging was demonstrated at two sites, but not at others, where symptoms were most likely caused by other factors such as soil compaction, waterlogging, stony soil, disease or herbicide use.
- A link between numbers of root-lesion nematodes and cavity spot was not proven.
- Sudangrass should only be considered as a biofumigant crop during frost-free months.

Background and expected deliverables

Over 50% of the UK carrot and parsnip crop is treated with Temik (aldicarb) at a cost of up to £132 per hectare. Its use is generally prophylactic, contrary to the requirements of the Assured Produce Scheme. Recent HDC work has suggested that Temik may not be effective for nematode control. As a carbamate its use is likely to be reduced 'voluntarily' over the next 2½ years, prior to the product use being revoked on 31 December 2007. Temik is currently used to control plant-parasitic nematodes, certain species of which are considered a potential risk to carrot crops as high populations are thought to cause root fanging.

The use of Dosaflo (Metoxuron) on parsnips is to be revoked as of 31 December 2007 leaving no agro-chemical control for volunteer potatoes in that crop.

Intensive root crop rotations, on light/medium soil types with irrigation, are leading to higher levels of soil-borne fungal pathogens. The effect of cultivations on the incidence of *Pythium* sp. and cavity spot has been a specific objective for this project.

The project aimed to quantify the effects of various cultivation regimes both in the fallow year and immediately pre-drilling and also the cultural potential of Sudangrass as a green crop-cover or bio-fumigant in reducing crop pathogens/cavity spot and weeds/volunteer potatoes prior to cropping with carrot and parsnip, as well as their impact on plant-parasitic nematode populations and fangy roots.

The treatments are expected to affect yield, saleable percentage and therefore marginal costs of production, which will provide an opportunity to review actual costs and possible cost:benefits.

A consequence of the project will be a better understanding of non-chemical controls, helping to develop the principles of an integrated crop management system, which offers a more sustainable option for the future control of the targeted problems.

Summary of the project and main conclusions

The project showed that the effect of fallow year cultivations on nematodes, disease and weeds, including potato volunteers, varied across the four sites sampled and may be short-lived. The incorporation of green manures may result in an increase of some nematode types and not others. Neither fallow year cultivations nor green manure crops had any significant influence on crop quality overall. There were several specific conclusions from this investigation:

- The effect of fallow year cultivations seems to be short-lived on nematode populations overall. There were no obvious effects on carrot quality but the weed bank was reduced.
- Root-lesion nematode numbers overall were reduced by fallow year cultivations, but stubby-root nematodes were not affected.
- The benefits of green manure cannot be guaranteed and need to be investigated further.
- The green manure crop Sudangrass is not frost tolerant. If it is to be tested and used growers will need to use it in another way (under covers or at a different drilling date).
- As a biofumigant, oilseed rape did produce some significant but variable effects that need to be investigated further.
- Root-lesion nematode numbers overall were not reduced by green manure.
- Stubby-root nematode numbers overall were significantly increased by green manure treatments.
- No root-lesion nematodes of economic importance were found during this investigation, and an association between them and the incidence of cavity spot was not proven.
- There was a correlation between numbers of stubby-root nematodes and fanging at pre-drilling and at the two-leaf stage on two sites. However, by observations and growers' comments it was concluded that fanging may also be caused by herbicide damage, compaction or waterlogged soils.
- Treatment guidelines for plant-parasitic nematodes need to be reviewed, especially in light of the current industry practice of a range of pre-drilling operations. Whilst numbers of plant-parasitic nematodes remained below treatment guidelines damage still occurred but set against usual industry losses the damage attributed to nematodes was deemed insignificant.

- Carrot cyst nematodes, root-knot nematodes and longidorid nematodes (needle and dagger nematodes), were not found or were uncommon in this study, reinforcing previous findings that these species tend to be localised problems, and should not be a cause for concern nationally.
- Site-related factors appear to be more significant and perhaps more influential in crop quality than nematodes alone.
- Increasing the intensity of the fallow year cultivations led to increasingly significant reductions in numbers of potato volunteers where these were present in high numbers, but the overall reduction was not acceptable commercially.
- Benefits from using Temik for control of plant-parasitic nematodes and improvement in quality were not proven in this study.
- The dramatic reduction in nematode numbers overall recorded in June 2004 after pre-drilling cultivations (at the two-leaf crop stage) was consistent with previously observed effects of Temik treatment.

Financial benefits

Fallow year cultivations did not result in long-term reduction of nematode numbers, or control of volunteer potatoes, nor was marketable yield affected. As they were ineffective a financial benefit from their use cannot be demonstrated.

However the pre-drilling cultivations, utilised in 2004, are in part or in total, the practise adopted in commercial carrot production. In this project, following discing, primary cultivations were undertaken by either sub-soiling or ploughing. All sites were then deep-ridged, de-stoned (Web type used on all sites), and finally bed-formed prior to drilling.

The total cost of these cultivations would normally be in the region of £315/325 per ha.

Following this cultivation regime a dramatic overall reduction in nematode numbers was measured at the next sampling. As Temik was not applied to the trial areas, it is probable that the reduced population is, in part, the result of these rigorous cultivations.

The cost of Temik per ha varies, depending on the rate of application, from £66-£132. If not used, this represents a saving of £1.25 -£2.50 per lifted tonne.

The cultivation cost is, on some stone-free sites, reduced by £200 per ha to £115/£125 per ha because the destoner is not used. If, as already discussed, the pre-drilling cultivations are reducing nematode numbers, it is thought the destoner may be a critical element in nematode control, so to leave it out may be false economy.

Fanging affects approximately 7.5% of the UK carrot crop, which is estimated currently to be in the region of 900,000 tonnes. If a farm gate value of £70 per tonne is assumed, then the cost to the industry of fanging is estimated at £4.7 million. Fanging may result from a variety of factors, however, so growers should think carefully about nematode control to reduce it, as this might be an unnecessary expense.

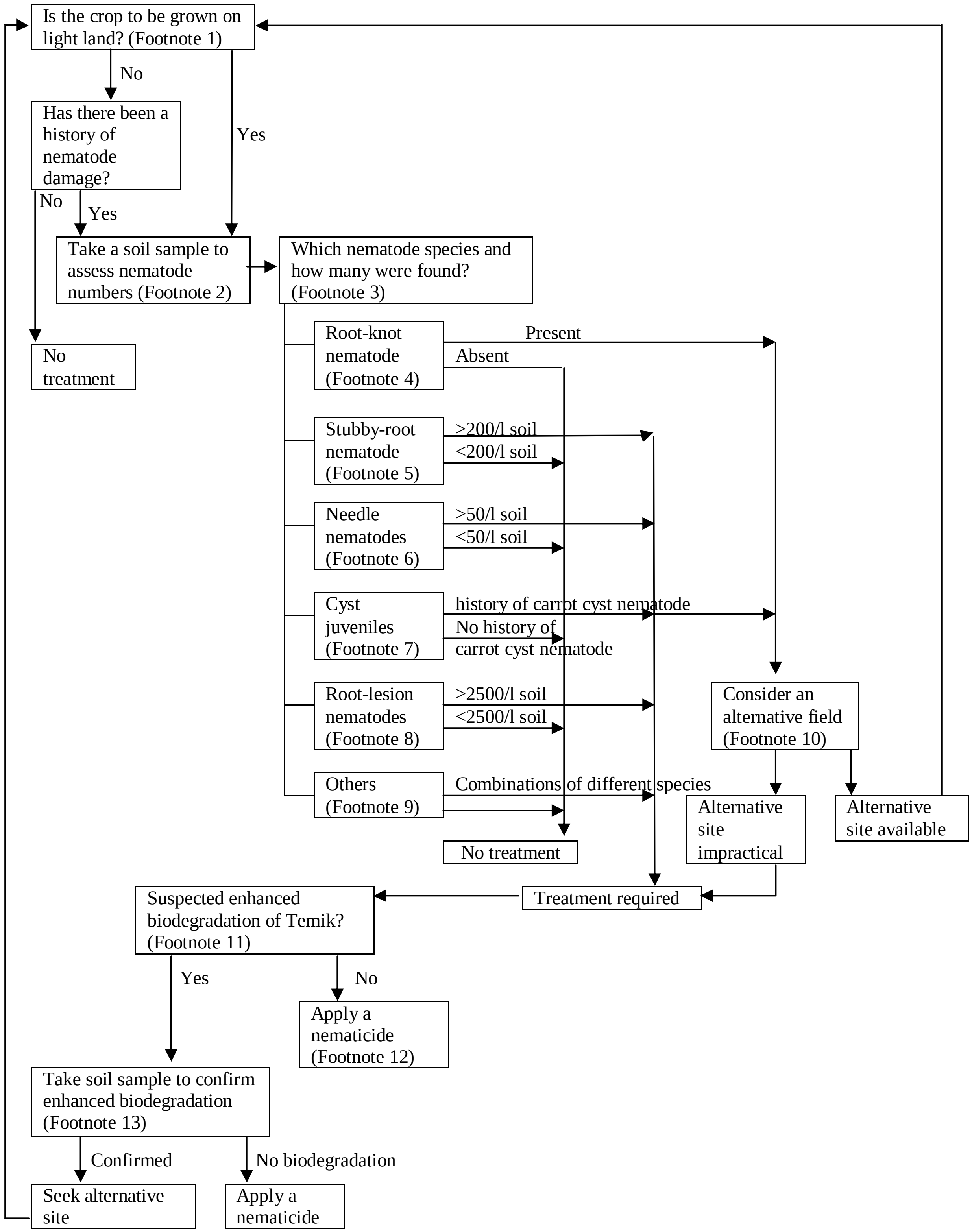
Action points for growers

- Continue to take soil samples pre-cropping to assess the risk of damage from plant-parasitic nematodes.
- Use thresholds (treatment guidelines) to determine the need for a nematistat (products that stun, rather than kill outright, such as Temik) or a nematicide but be aware of particular on-site factors that might affect fanging. At present the treatment guideline for stubby root nematodes is in excess of 40 per 200g or 2000 per litre soil. For other species use the FV 232 Decision Tree (Fig. 1)
- If treatment guidelines are exceeded, consider whether the potential losses make cropping with carrots or parsnips uneconomic.

- Undertake a commercial trial to assess the effect of de-stoning and bedforming operations (industry standard) pre-drilling, without Temik and with Temik on a known nematode population. Bear in mind that the use of Temik on carrots or parsnips will be revoked on 31 December 2007.

- Consider the findings of this report for their own particular sites and compare final crop quality, rather than vigour, from sites with and without Temik.

Fig 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.

Acknowledgements

We are grateful for the assistance of the following companies for the use of their sites and assistance with ground work:

Elveden Estates, The Estate Office, Elveden, Thetford, Norfolk IP24 3TQ

R H Hardstaff & Sons, Hall Farm, Linby, Nottinghamshire NG15 8AE

Hunterpac Yorks/E H Marsland & Sons, Bar Farm, Holme-on-Spalding Moor, Yorkshire YO43 4ED

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 nematodes was minimal. A Knowledge Review produced for the same project highlighted several alternative methods of control, including cultural techniques as well as the use of antagonistic products and green manures.

Thus in 2003, project FV 249 was established. There remains an assumption that plant-parasitic nematodes need to be controlled by chemical means to reduce the incidence of fanging, although such symptoms can also be caused by disease, stony soil, herbicide use, water-logged or compacted soils. The need to investigate and understand non-chemical controls for pests, diseases and weed control for both conventional and organic systems is very real and urgent, as a result of the EU review programme and customer/grower preference to reduce pesticide use. Approval for the use of Temik (aldicarb) for plant-parasitic nematode control and Dosaflo (metaxuron H) for control of volunteer potatoes is due to be revoked 31 December 2007. Thus this project aimed to quantify the effects of frequency of cultivations during a fallow year and assess the more rigorous pre-drilling cultivations on the populations of plant-parasitic nematodes as well as volunteer potatoes. Additionally, at the beginning of September 2003, when the fallow year cultivations were complete, 50% of the area was due to be sown with Sudangrass SUSU to assess its biofumigation / green manure potential.

The project will include a cost:benefit study if applicable. If successful, the system could be applied to organic as well as conventional growing systems.

The effect of cultivations on the incidence of disease (specifically *Pythium* spp.), the percentage of carrots in Class 1 and carrots with other problems would also be assessed at harvest.

Materials and Methods

Experimental design and treatments

At each site the same randomised plot trial design was used. Three sites EC, ED and YK utilise 1.818m beds (distance between tractor wheels). This equates to treatment strips of 10.9m with 12 strips, making total site width of 130.8m. At the NO site the bed width employed is 2m so strips are 12m and total site width 144m. Total strip length is 100m for EC, ED and NO, with YK being shorter at 60m. The resultant plot sizes ensure that on each site, despite different machinery, there will be six blocks of carrots per plot. Each plot was divided in half, with each being designated random as either due to grow a green manure crop (Sudangrass) (marked with an 'X' on trial plans) or not. This dividing line was also marked with a white post at each end of the block. The four corners of the experimental block were clearly marked and the grid reference for each was established using GPS. No nematicides are to be applied to the trial site for the duration of the project.

The trials were laid out by the end of April 2003. The treatments are summarised in Table 1. Each treatment was replicated three times.

Table 1. Treatments used in trial sites.

Designated Treatment Number	Treatment description
1	Control: No cultivations except prior to establishment of green crop cover
2	2 cultivations June and August (1st week of month)
3	1 cultivation per month May to August inclusive (1st week of each month)
4	2 cultivations per month May to August inclusive (1st & 3rd week of each month)
X	Green crop to be sown at beginning of September in half of strip marked with X

Cultivations were at a depth of 6–8” (15 cm–20 cm approximately) with tine spacings of no more than 12” (30.5cm approximately). Cultivations are at a depth of 6 – 8” (15cm – 20cm approximately) with tine spacings of no more than 12” (30.5cm approximately). All sites were ploughed across the line of the treatment strips to remove surface trash immediately before the Sudangrass was drilled in 2003. There was minimal contamination of plots caused by this action. The sowing rate was 30kg per hectare utilising cereal drills with standard row spacing.

In 2004, soil sampling for nematodes was timed to record data pre-discing, pre-ploughing and at the two-leaf stage of seedling development (Table 2.). A summary of the critical operations and their timings are also listed in Table 2.

Table 2. Critical Operations Dates 2003 - 2005.

Operation	**Elveden Contract (EC)**	**Elveden Dryer (ED)**	**Notts (NO)**	**York (YK)**
2003				
Trial laid out	April 2003	April 2003	April 2003	April 2003
1st sampling	**04.07.03**	**04.07.03**	**03.07.03**	**01.07.03**
Sudangrass drilled	03.09.03	03.09.03	01.09.03	29.08.03
2nd sampling	05.09.03	05.09.03	04.09.03	04.09.03
2004				
1st Sampling	**25.02.04**	**25.02.04**	**26.02.04**	**26.02.04**
Roundup				05.03.04
Disc	06.04.04	22.03.04	08.03.04	01.04.04
2nd Sampling	**21.04.04**	**21.04.04**	**22.04.04**	**22.04.04**
Plough/Subsoil	Subsoil 26.04.04	Subsoil 24.03.04	None	Plough 15.05.04
Operation	**Elveden Contract (EC)**	**Elveden Dryer (ED)**	**Notts (NO)**	**York (YK)**
Ridge	29.04.04	25.04.04	24.04.04	16.05.04
De-stone	29.04.04	08.05.04	01.05.04	16.05.04
Bed form	10.05.04	12.05.04	06.05.04	20.05.04
Drill	11.05.04	13.05.04	06.05.04	21.05.04
Spray Pre Em	17.05.04	13.05.04		25.05.04
3rd Sampling	**10.06.04**	**10.06.04**	**14.06.04**	**30.06.04**
2005				
Harvest				

Sampling methods and processing of soil samples for plant-parasitic nematodes

Sampling methods and soil processing was the same on each sampling occasion. Each trial has 24 sample zones. Each zone is a minimum of 10.8m wide and between 30m and 50m long. To minimise inter-plot effects, a 1.5m border for each and every zone was not sampled. Each soil sample was placed in a plastic bag and labelled with the sampling date, plot location and treatment strip (e.g.111 x or 111, 212 or 212x etc). Samples were kept in a cool box and delivered to CSL within two days of sampling.

Soil was sampled along a W-shaped path across a selected field (during site selection) or in a pre-determined central area of each plot, using a corer 20cm long and 6cm in diameter to produce an accumulation of soil of approximately 10kg, which was then sub-sampled for a final sample with a minimum weight of 500g. The soil was processed at CSL using both the Flegg and Whitehead Tray methods for the samples used for site selection and the first assessment in July 2003, to ensure a complete picture of the plant-parasitic nematode fauna was obtained, thereafter the Whitehead Tray method only was used.

Extracted samples were examined under a binocular microscope and the number, genus and, if possible, species of plant-parasitic nematodes were recorded. All nematode counts were recorded as numbers per 200g soil. Only stubby-root and root-lesion nematodes are likely to have any effect on carrot quality, but all plant-parasitic nematode types were identified and counted in this study, as total numbers may in some cases be important for their effect on facilitating disease development.

Assessments of quality at harvest

At harvest, assessments of the numbers of carrots designated Class 1, with cavity spot (including all *Pythia* spp.) fanging or other problems (including diseases such as bacterial rots including crown rot, scab, canker, violet root rot, virus, carrot fly, cutworm and other malformed carrots) were made. In each plot the sample dig was a 0.5 metre length for the full width of the bed and there were two digs from each plot which were recorded separately. Each sample was weighed and the weights for each variable was recorded separately. Fanged carrots were assessed first, then the remainder were assessed for cavity spot and other problems, with the remaining carrots being Class 1. If soil was adhering to the dug sample it was washed before assessment. The weights were converted to percentages, which assisted in making each site comparable, as the average size of carrot at each site varied and thus also the yield

Assessment of the effect of Temik in the trial fields with the effect of no Temik in the trial plots

At harvest, an assessment of carrot quality in the trial field, that had been treated with Temik, and the trial plots that had not been treated with Temik was made. Two samples were taken at random in the field to match with the manure and no manure treatments of the four main cultivation treatments.

Assessment of the effect of various cultivation regimes on volunteer potato populations

Assessments for potato volunteers were first done in June/July 2003. Where plant numbers were low, as at NO and YK, all visible potato plants were counted in each assessment zone. At EC and ED, where volunteer potato numbers were very high, for each zone the numbers of plants in six single square metre areas were counted. These counts were then averaged to a population per square metre, and finally, factored up by the number of square metres in the zone.

The second assessment was done in October 2003 after the establishment of the Sudangrass, and just prior to the onset of autumn frosts. Populations of volunteer potatoes were low on all sites, enabling all visible plants to be counted.

During late May and early June 2004 another assessment of volunteer potatoes was done, using the counting method employed in 2003 as all sites had high numbers of volunteer potato plants.

Statistical analysis

Analysis for treatment effects was done by ANOVA in Genstat using the "Split-Split-Plot Design" option. This allowed data from all sites to be analysed together. To stabilise the variances the nematode counts were transformed to log10 (n+1). The +1 was added to each count to overcome the problem associated with zero counts (there is no log of zero). Nematode counts for July and September were analysed separately and then tested for differences between the two assessments. The difference between July and September counts was calculated as [log10 (July + 1) - log10 (September + 1)] which is equivalent to the July count divided by the September count - i.e. the ratio of the two counts. The resulting value is zero if there is no change, positive if the population decreases, and negative if the population increases (be careful to read it the right way round!). Note that this approach assumes that a reduction from 100 to 10 nematodes is equal in biological terms to a reduction from 10 to 1 nematodes.

A statistical analysis of the changes in nematode numbers between each of the sampling dates April 2004, June 2004 and January 2005 was done by paired t-tests to see if the differences between counts at two dates differed significantly from zero. These tests were performed with Genstat v7 using log (n+1) values for the nematode counts.

In the complex analysis of variance (anova) for the effects of the cultivation treatments and green manure on carrot quality, the mean of the two assessments was used as the percentage value for a sub-plot. The percentages were also subjected to angular transformation. Four contrasts (the maximum permitted) were added to the anova, to compare the control treatment with each of the four cultivation treatments. In addition, an all-pairwise Bonferroni test was conducted, but this lacks the sensitivity of the Contrasts in the anova because the decision level drops to p=0.00833.

For the incidental comparison between the quality on the trial site and that on the rest of the field, anova was performed on the angular transformed percentages, with sites as blocks and nul, yes and no (green manure) as three treatments. Contrasts were used to compare nul with yes and nul with no. The individual results were entered as though they were replicates.

Correlation coefficients were produced for comparisons between carrot quality and nematode numbers at sampling dates April 2004 (pre-drilling), June 2004 (two-leaf stage) and January 2005 (harvest).

Results

The methods of cultivation used on each site were similar and fallow year cultivations were done according to plan. The cultivators employed had changeable points which varied in width from 40mm to 60mm. These were fixed to ridged tines spaced at between 25 and 30cm. The target depth for these cultivations of 15 to 20cm was achieved at all sites with only the top 8-10cm of soil being semi inverted where it was thrown off the leading edge of the tines. Very few clods were evident in the tilth on these generally loamy sands.

Due to the continued dry weather, establishment of the Sudangrass was poor on all sites and varied. The poor crop cover finally succumbed to early autumn frosts that resulted in total defoliation of the Sudangrass. The York site did have an almost universal cover of seedling oilseed rape volunteers that prompted a decision to use this as a test substitute green manure crop (this crop has also been used in biofumigation studies). The continual growth of the oilseed rape would have also rendered it very different from the other sites in any case. On those YK plots not due to receive green manure the oilseed rape was treated with herbicide in October and the oilseed rape on manure plots was incorporated in February 2004, prior to herbicide being applied in March and discing in April. No special measures were taken during the incorporation procedure, such as attention to the length of plant fragments or the speed of incorporation, factors considered to be of prime importance in using these crops as biofumigants. Such actions are often difficult to achieve in practice and it was decided to assess the results of minimal additional work.

Nematode species and genera recorded

Nematode genera and species identified in 2003 and 2004 were also recorded at harvest in January 2005. Two new genera, *Neodolichorhynchus* sp. (stunt nematodes) and *Paratylenchus* sp. (pin nematodes) were found in 2005 (Table 3). During the July assessment in 2003 *Heterodera* cysts were examined to determine if *Heterodera carotae* (the carrot cyst nematode) was present. This species was not found.

Table 3. Nematode genera and species recorded during the investigation 2003-2005, with species identified on each site (√).

GENUS/SPECIES (common name)	**SITES FOUND**			
	YK	**EC**	**ED**	**NO**
Amplimerlinius icarus (stunt nematode)			√	
Bitylenchus dubius (stunt nematode)	√	√	√	√
Criconemoides sp. (ring nematode)	√			
Cyst nematode juveniles	√	√	√	√
Globodera sp. (round cyst nematodes)	√	√	√	√
Hemicycliophora sp. (sheath nematode)	√			
Heterodera sp. (lemon cyst nematodes)	√	√	√	√
Longidorus sp.(needle nematodes)		√	√	
Longidorus attenuatus		√	√	
Longidorus elongatus		√	√	
Longidorus leptocephalus			√	
Longidorus profundorum				√
Merlinius sp. (stunt nematodes)	√	√	√	√
Merlinius microdorus	√	√	√	√
Neodolichorhynchus sp. (stunt nematode)			√	
Neodolichorhynchus judithae (stunt nematode)		√		
Paratrichodorus sp. (stubby-root nematodes)	√	√	√	√
Paratrichodorus pachydermus		√	√	√

GENUS/SPECIES (common name)	SITES FOUND			
	YK	EC	ED	NO
Paratylenchus sp. (pin nematodes)	√			
Pratylenchus sp.	√	√	√	√
Pratylenchus neglectus (root-lesion nematode)	√	√	√	√
Pratylenchus thornei (root-lesion nematode)				√
Trichodorus sp.	√	√	√	√
Trichodorus cylindricus (stubby-root nematode)	√	√	√	
Trichodorus primitivus (stubby-root nematode)	√	√		√
Trophurus sp. (stunt-nematode)	√			

Nematode types and numbers at harvest January 2005, for each cultivation regime and green manure treatment

At harvest, there was no significant difference between numbers of nematodes overall from each of the fallow year cultivation treatments (p=0.527). However, those plots which had green manure crops produced a significant increase in nematode numbers overall (p=0.004) (Fig. 2; Appendix 1), but the YK site, where the oilseed rape was incorporated, was the only site to reflect this effect with a significant, but marginal increase in nematode numbers overall (p=0.027) (Fig. 3; Appendix 1).

Fig. 2. Mean number of all plant-parasitic nematodes at harvest at all sites January 2005

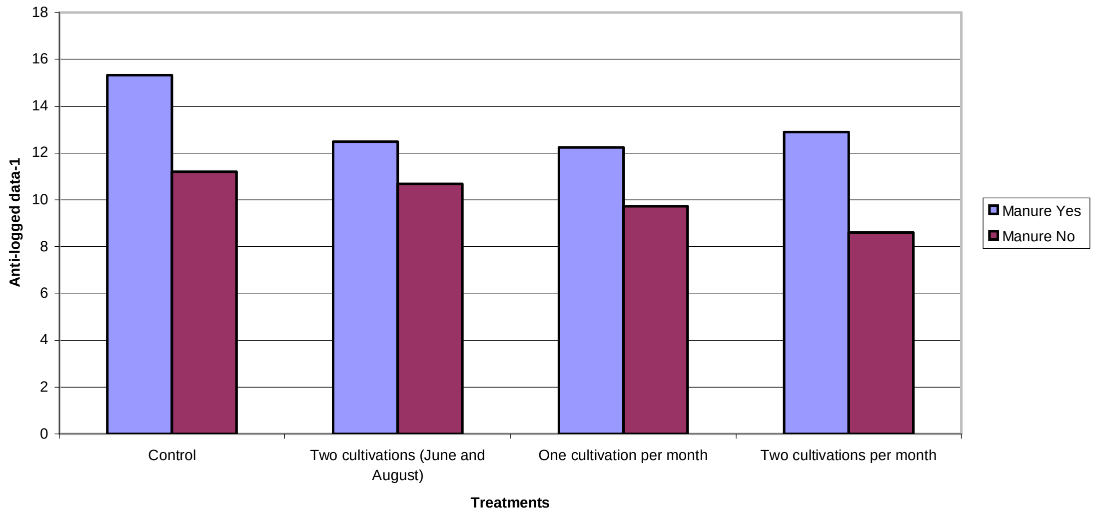
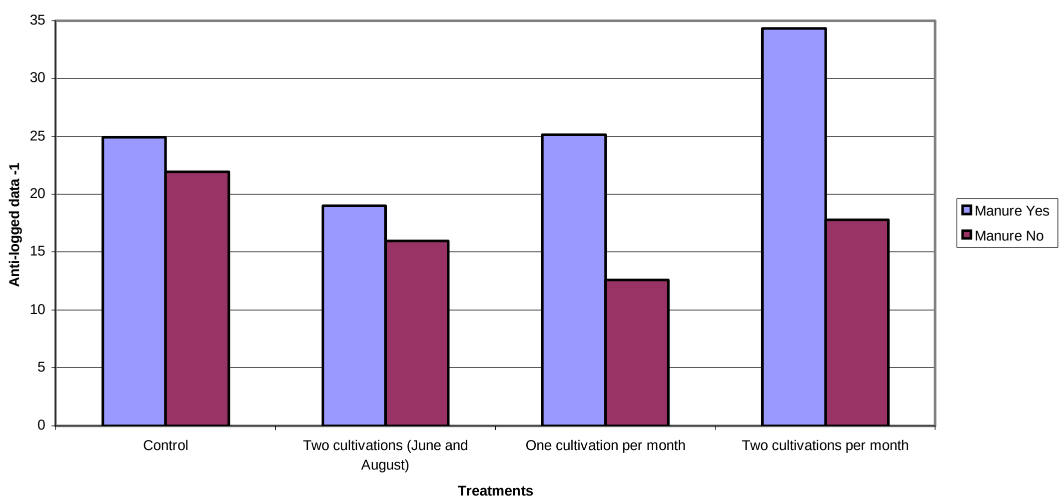
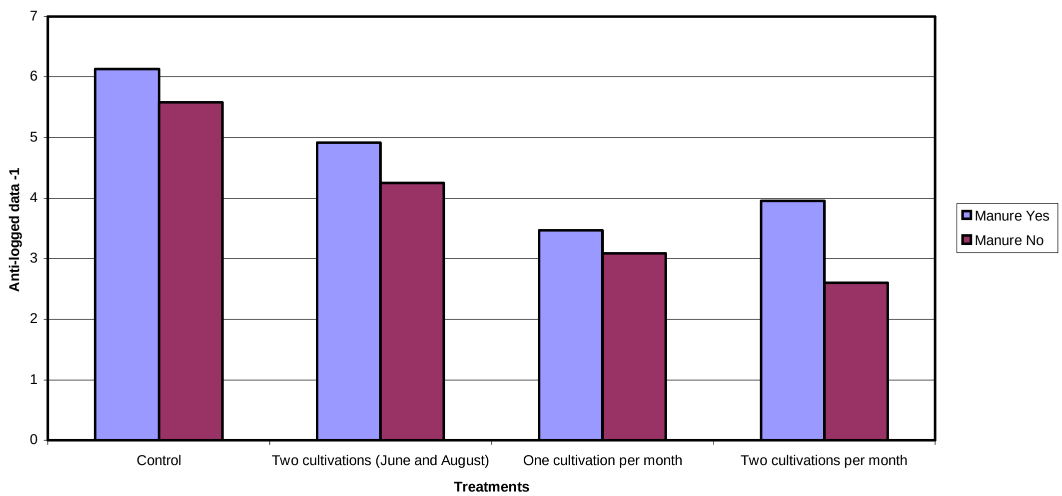


Fig. 3. Mean numbers of all plant-parasitic nematodes at harvest January 2005 at the YK site



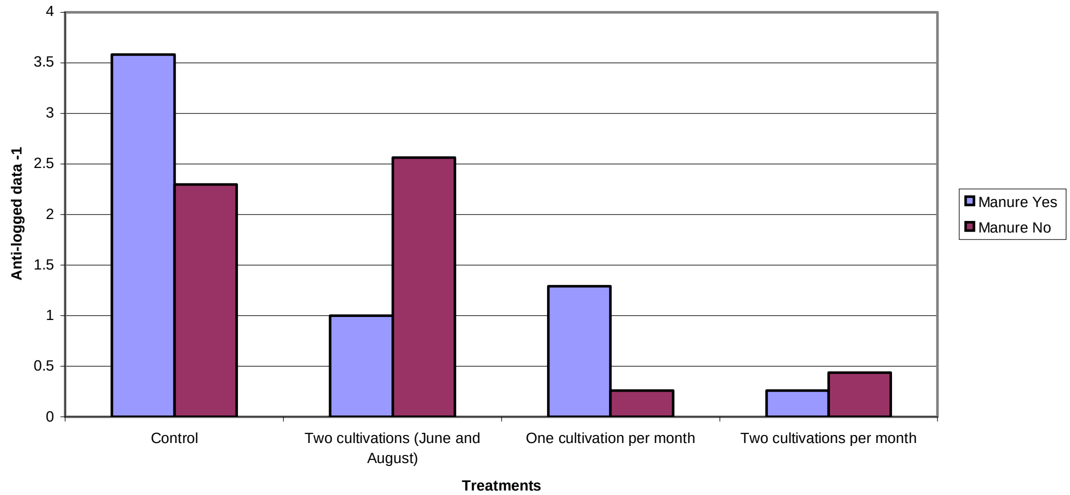
When individual groups of plant-parasitic nematodes were examined, however, there was a significant beneficial effect of fallow year cultivation treatments on numbers of root-lesion nematodes overall at harvest (p=0.007 for treatments; p=0.002 for treatments compared with the control), but no effect of green manure (Fig. 4; Appendix 1).

Fig. 4. Mean numbers of all root-lesion nematodes at harvest at all sites January 2005



However, ED was the only site to record a significant reduction in root-lesion nematodes by the fallow year cultivations (p=0.022)(Fig. 5; Appendix 1). Green manure had no effect on numbers of root-lesion nematodes at any site.

Fig. 5. Mean numbers of root-lesion nematodes at harvest January 2005 at the ED site



There was no overall effect of fallow year cultivation treatments on numbers of stubby-root nematodes overall at harvest (Fig. 6; Appendix 1), although there was a marginal effect of treatments on decreasing numbers of these nematodes at the YK site (p=0.02) (Fig. 7; Appendix 1) and the NO site (p=0.024)(Fig. 8; Appendix 1).

Overall numbers of stubby-root nematodes were significantly greater in plots with green manure than those without green manure (p=0.003)(Fig 6; Appendix 1). The YK site (Fig 7) and the ED site (Fig. 9) also had marginally significantly and significantly respectively more stubby-root nematodes in green manure plots than in plots with no manure (p=0.028 and p=0.007 respectively).

Fig. 6. Mean numbers of all stubby-root nematodes at harvest at all sites January 2005

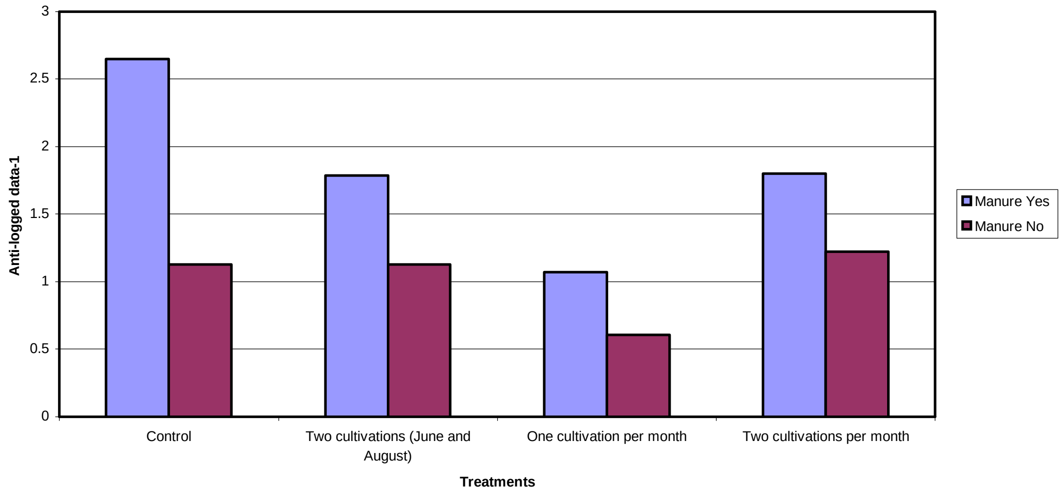


Fig. 7. Mean numbers of stubby-root nematodes at harvest January 2005-YK site

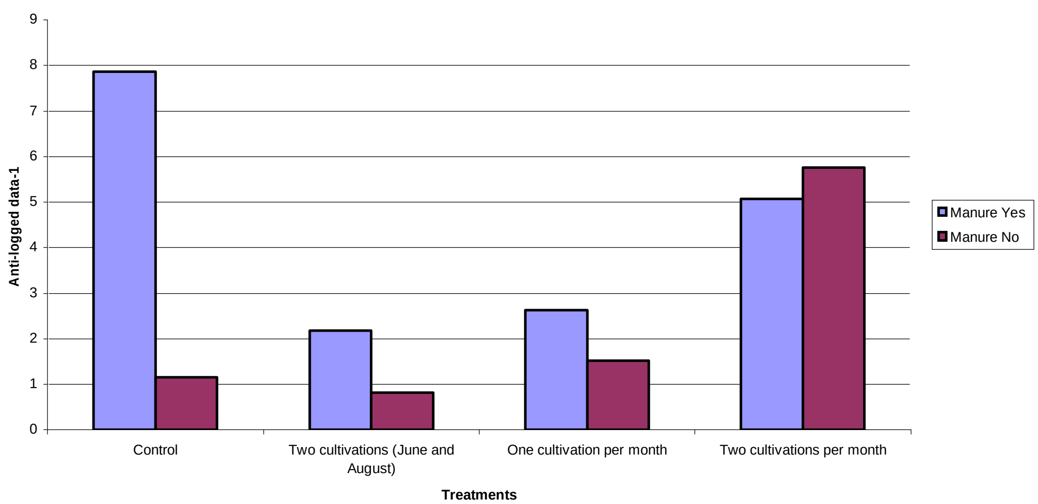


Fig. 8. Mean numbers of stubby root nematodes at harvest Jan 2005 - NO site

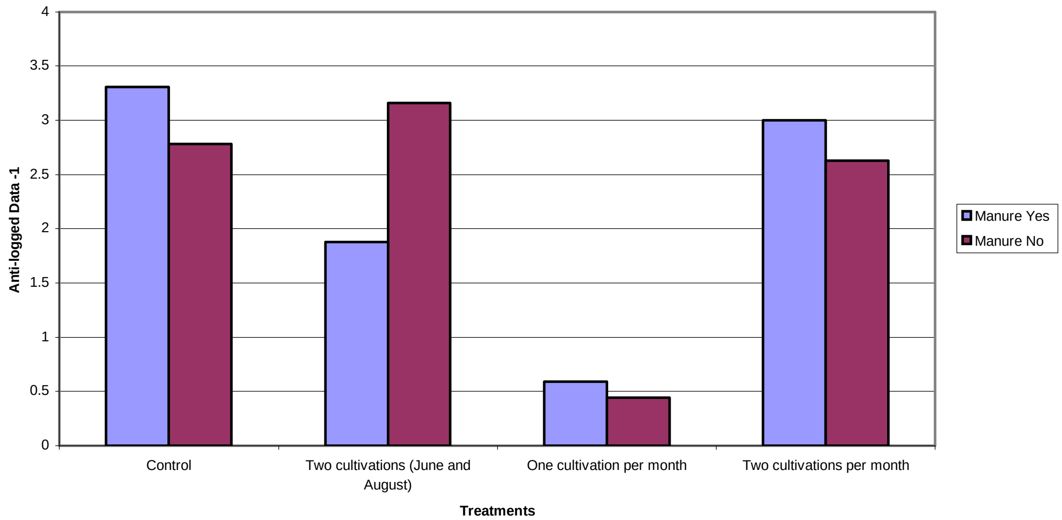
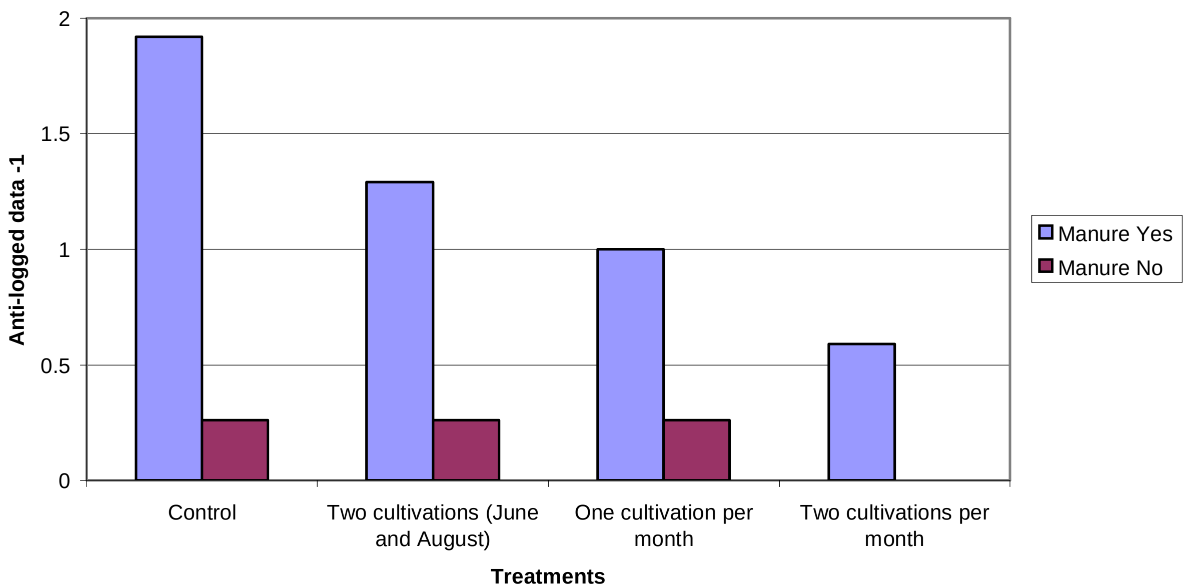


Fig. 9. Mean numbers of stubby root nematodes at harvest Jan 2005-ED site



Nematode numbers at each sampling time during the investigation, for each cultivation regime and green manure treatment

Overall, nematode numbers continued to decrease significantly between April 2004 (pre-drilling) and June 2004 (two-leaf stage) and January 2005 (harvest) (Fig. 10). This trend was repeated for the two main nematode groups of concern, namely root-lesion nematodes and stubby-root nematodes (Figs. 11 and 12).

Fig. 10. Mean numbers of all plant-parasitic nematodes at all sites from July 2003 to January 2005

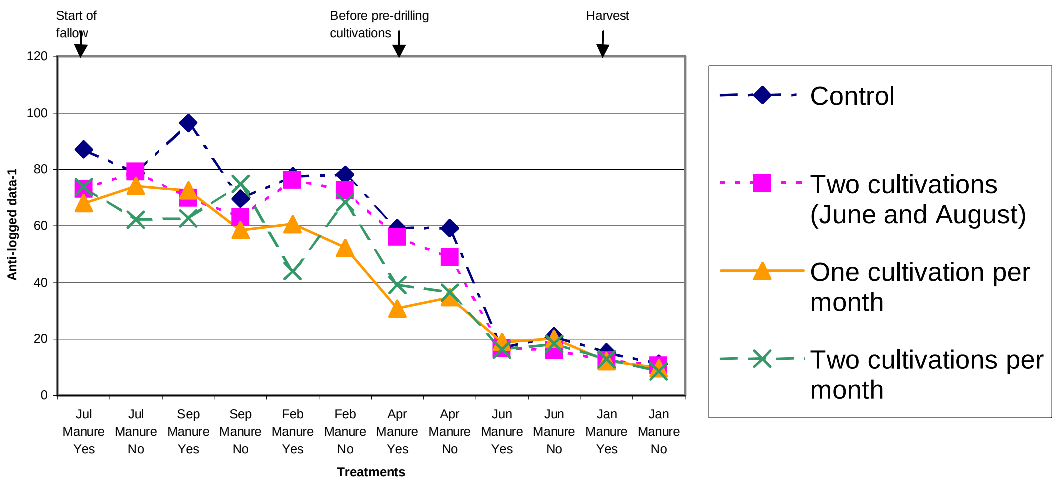


Fig. 11. Numbers of root-lesion nematodes at all sites from July 2003 to January 2005

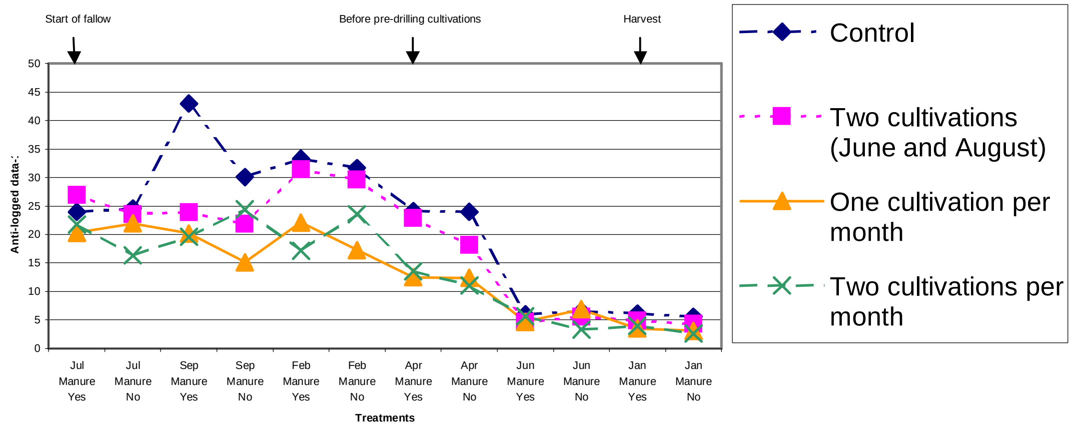
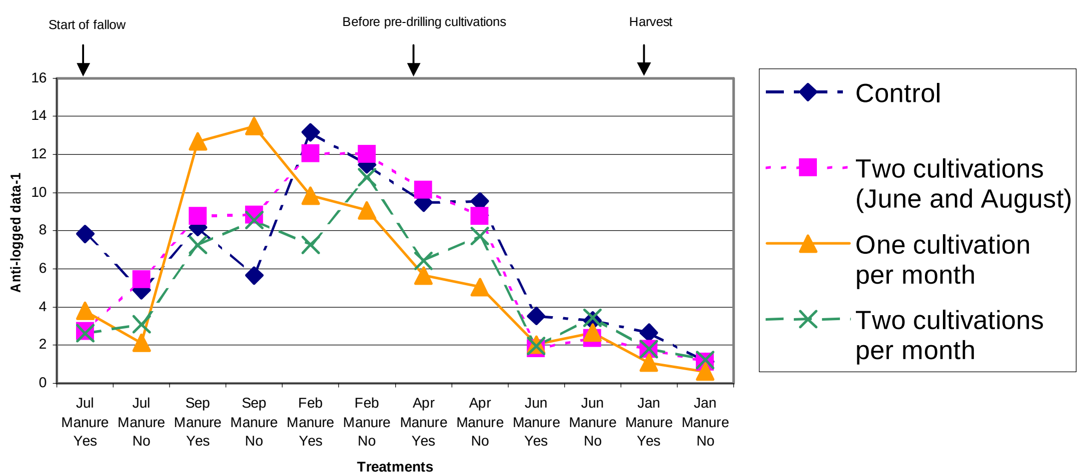


Fig. 12. Mean numbers of stubby-root nematodes at all sites from July 2003 to January 2005



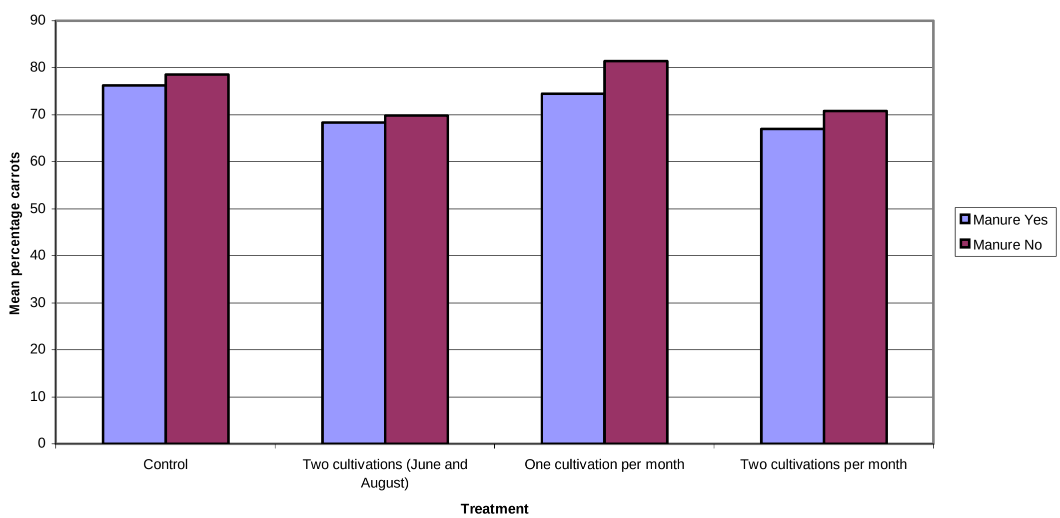
Statistical analysis showed that in all cases except for a group of stunt nematodes at the ED site, there was a significant decrease in all nematode numbers between April 2004 (pre-drilling) and June 2004 (two-leaf growth stage) (p=<0.001 to p=0.282) (Appendix 2). Between June 2004 and January 2005 (harvest) nematode populations overall continued to decrease significantly (p=0.001 to p=0.975). Specific types of nematodes did not show this trend on specific sites; at York the number of stunt nematodes showed no decrease, at EC neither lesions nor stubby-root nematode populations significantly changed, and at the NO site the root-lesion nematode numbers increased significantly whilst the stubby-root and stunt nematodes showed no significant change in numbers.

Effect of fallow year cultivations and green manure on carrot quality

There were no significantly promising effects of fallow year cultivations and/or green manure treatments on the overall quality of the carrots at harvest as had been anticipated. Summaries of the means and anovas with angular transformations of the percentages are set out in Appendix 4.

The effect of fallow year cultivation treatments on Class 1 overall was just significant (p=0.04), whereas the effect of the green manures was not significant (p=0.137) (Fig. 13; Appendix 4). The use of two cultivations and two cultivations per month had a marginal, beneficial, effect on carrot quality.

Fig.13. Mean percentage of carrots recorded as class 1 for all sites



At the YK site, where the incorporation of oilseed rape appeared to have increased nematode numbers, including stubby-root nematodes, overall, the mean percentage of carrots recorded as Class 1 was less in these plots than in plots where no manure had been incorporated, but the difference was marginal (p=0.031) (Fig 14; Appendix 4).

There was also a marginal effect of cultivation treatments on Class 1 at NO (p=0.027) (Fig. 15), but no effect of green manure.

Fig.14. Mean percentage of carrots recorded as class 1 for YK site

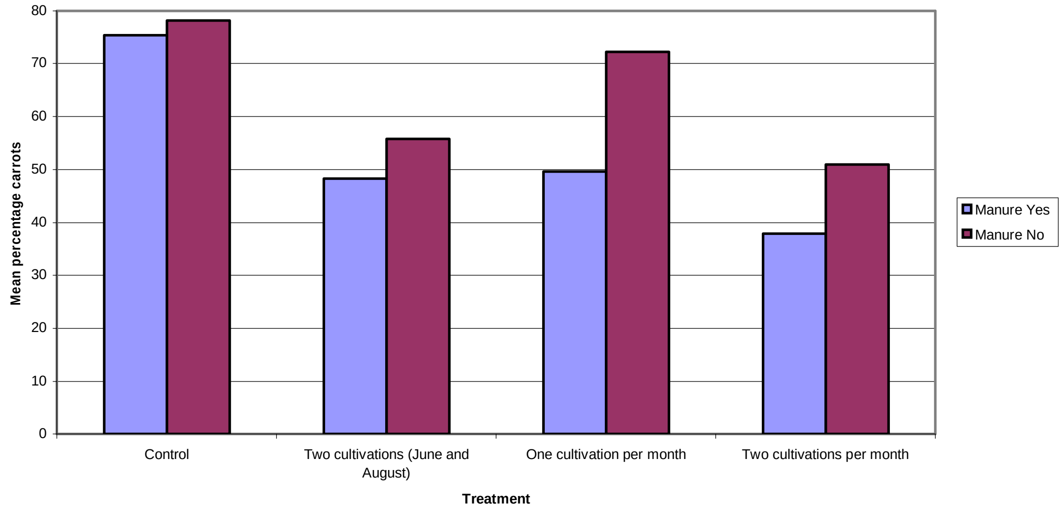
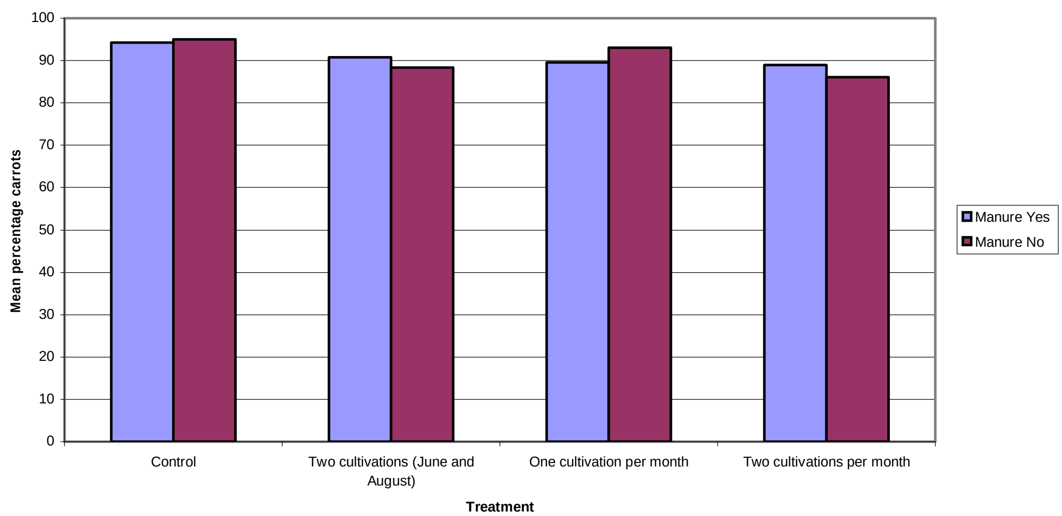
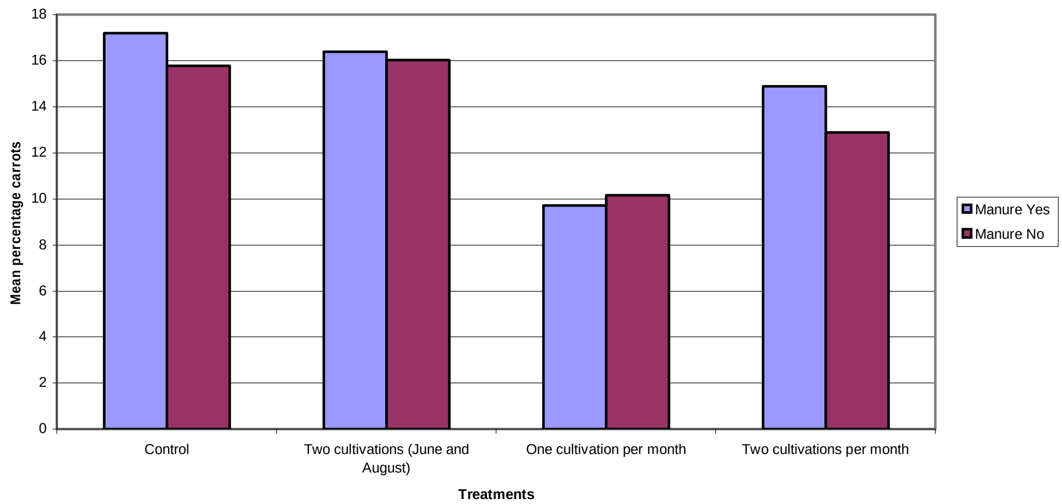


Fig.15. Mean percentage of carrots recorded as class 1 for NO site



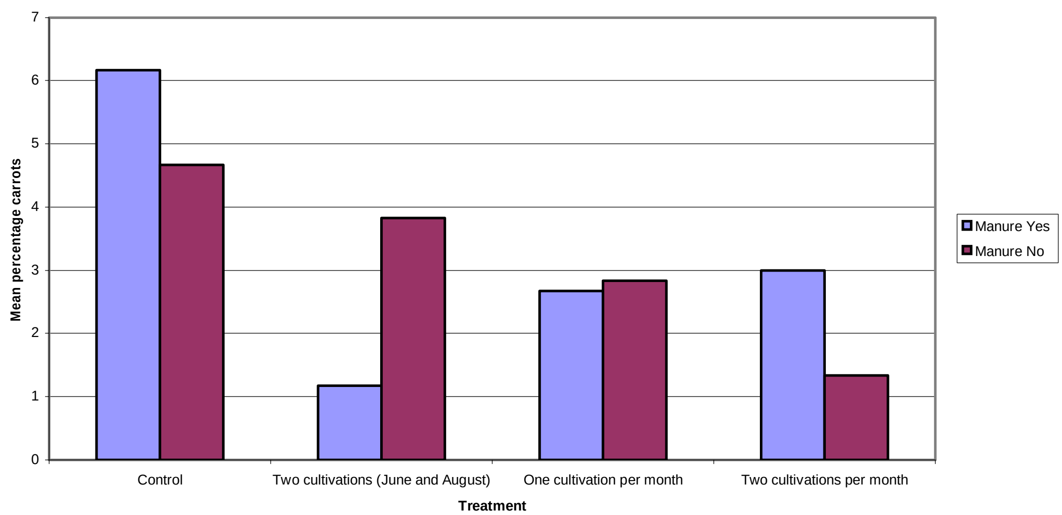
No fallow year cultivation treatment or the addition of green manure showed a significant overall effect on fanging (Fig 16). The one cultivation per month plots had the lowest number of fanged carrots, but the significance of this was marginal because of the varying results recorded.

Fig.16. Mean percentage of carrots with fanging for all sites



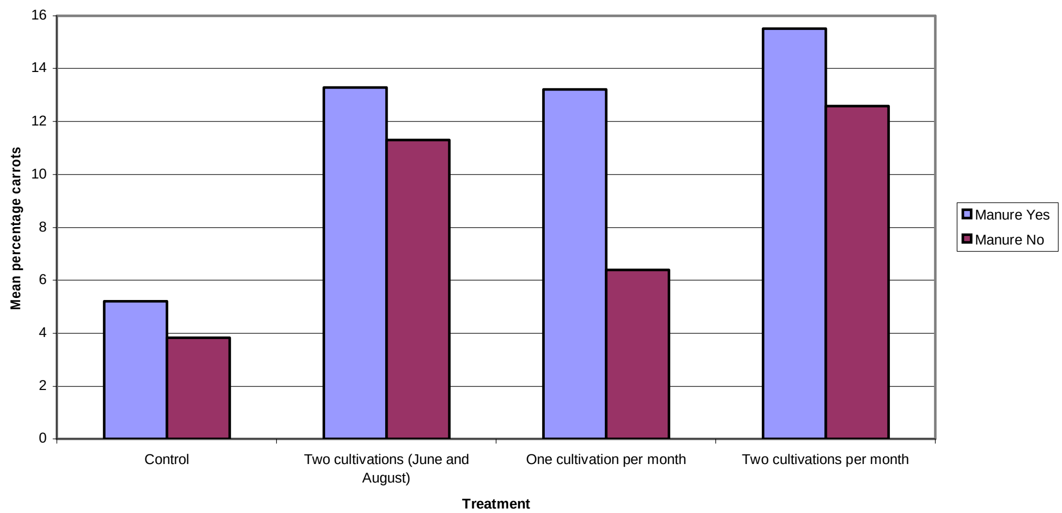
The YK site produced the only significant site effect of the cultivation treatments on fanging (p=0.043) (the incorporation of the green manure had no effect, even though it tended to increase numbers of nematodes, including stubby-root nematodes) (Fig. 17; Appendix 4).

Fig.17. Mean percentage of carrots with fanging for YK site



Cavity spot incidence overall was significantly raised by fallow year cultivation treatments (p=0.022) and green manure (p=0.033) (Fig 18; Appendix 4).

Fig.18. Mean percentage of carrots with cavity spot for all sites



At individual sites, significant effects on cavity spot were registered at ED, where there was no cavity spot in green manure plots (p=0.031)(Fig. 19), and at YK, where the fallow year cultivation treatments resulted in a significant increase in cavity spot (p=0.034) (Fig. 20).

Fig. 19. Mean percentage of carrots with cavity spot for the ED site

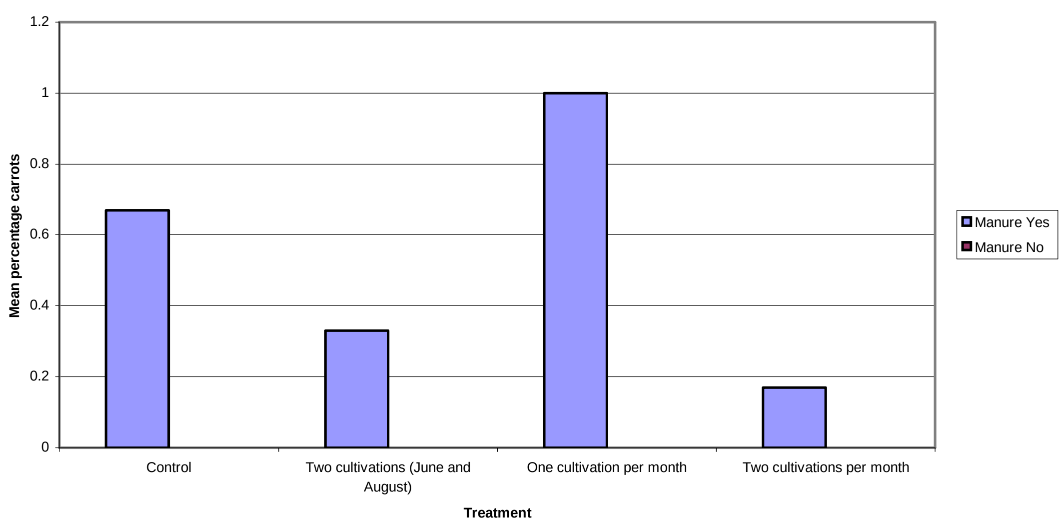
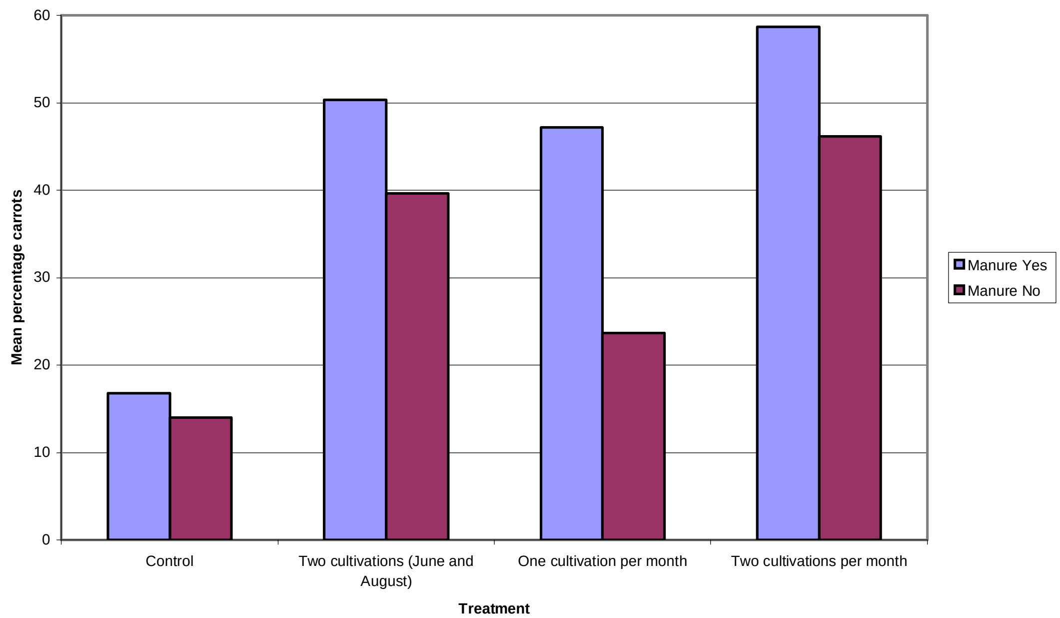
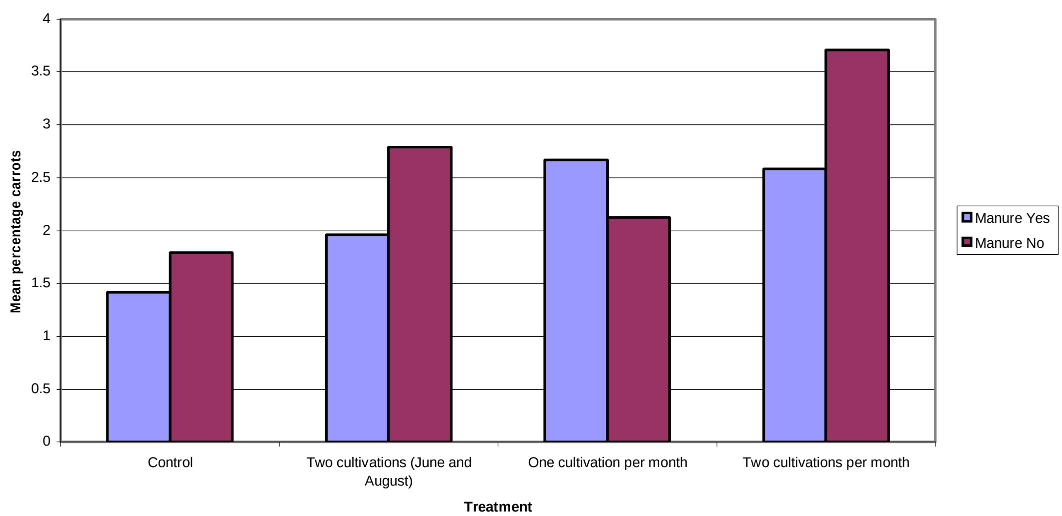


Fig. 20. Mean percentage of carrots with cavity spot for the YK site



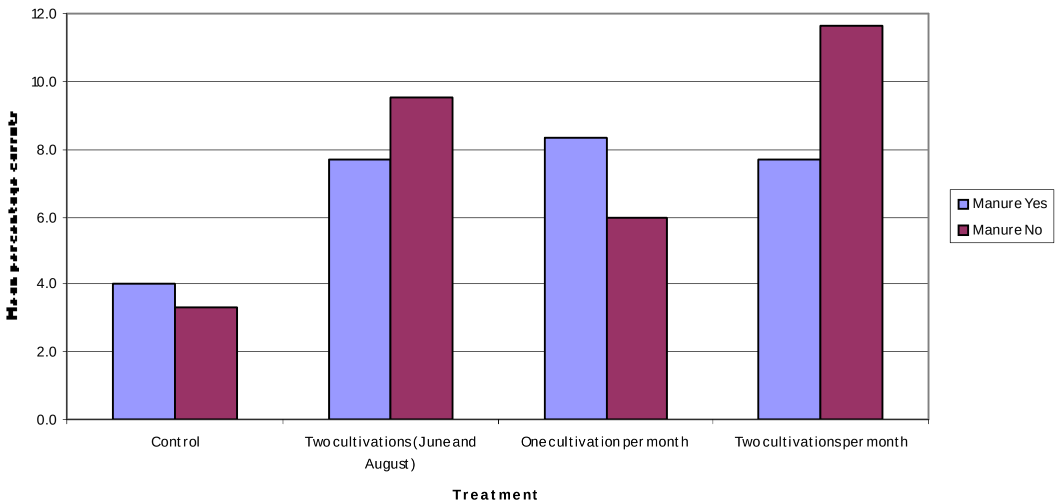
There was no significant effect of the fallow year cultivation treatments overall on Other Problems (Fig 21). The effect of the green manures overall was marginal (p=0.048) (Appendix 4) and not always consistent (Fig. 22).

Fig. 21. Mean percentage of carrots with other problems for all sites



The exception to the trend for other problems was at NO, where a significant adverse effect of fallow year cultivation treatments on other problems was recorded (p=0.008) (Fig 22; Appendix 4).

Fig. 22. Mean percentage of carrots with other problems for NO site



Comparison between nematode numbers at pre-drilling, post-drilling and harvest and carrot quality

There were no strong correlations overall between nematode numbers at specific times and carrot quality (Appendix 5). There were some significant correlations between stubby-root nematodes and fanging (a), but also some statistically significant weak correlations for root-lesion nematodes and cavity spot, that, when investigated further, were found not to be significant on individual sites (b). Examples of these effects are described below.

(a) link between stubby-root nematodes in April and June 2004 and fanging recorded at harvest

Significant correlations were achieved between numbers of stubby-root nematodes and the percentage of fanged carrots from each plot in April 2004 and June 2004, for ED and

EC sites respectively. Such correlations were more significant in April than June (see Figs. 23 and 24; Appendix 5).

Fig. 23. Relationship between stubby-root nematodes and fanging at ED April 2004

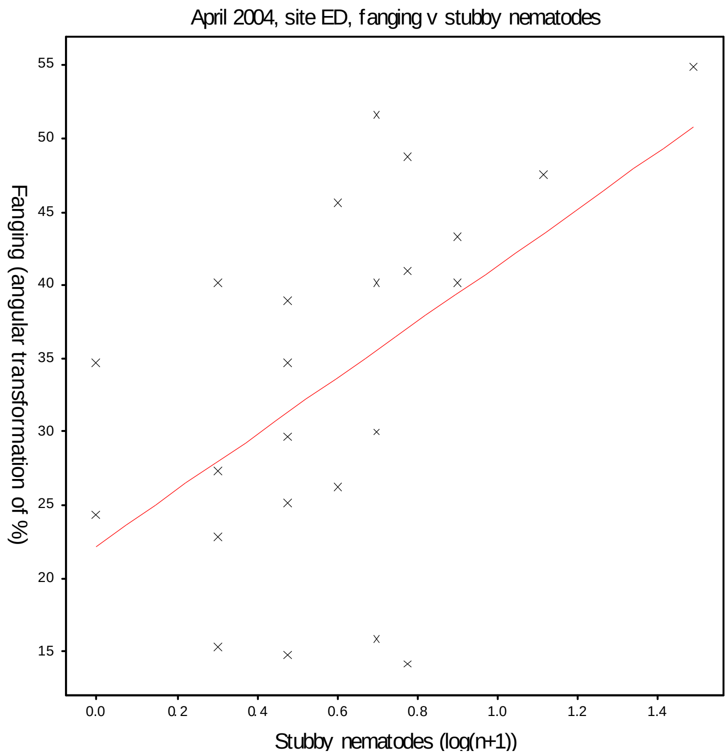
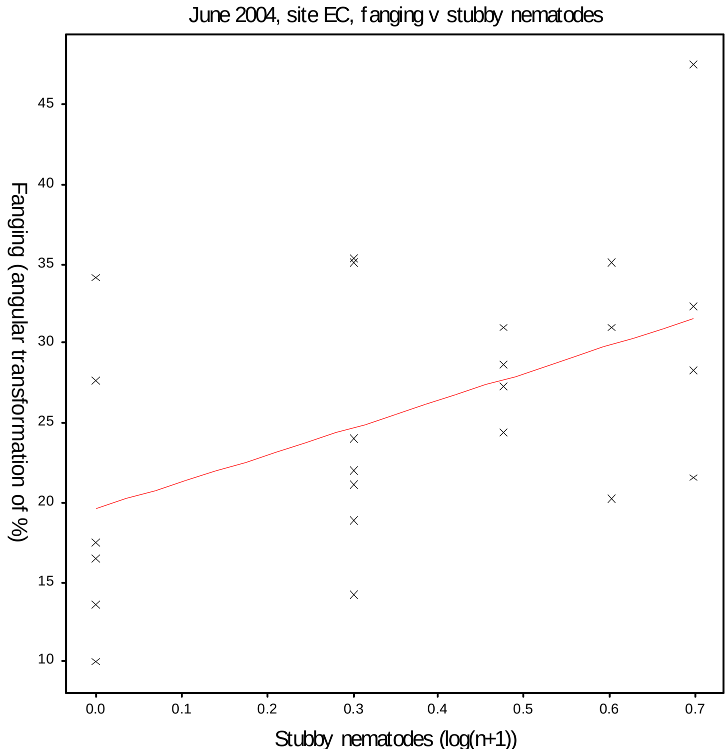


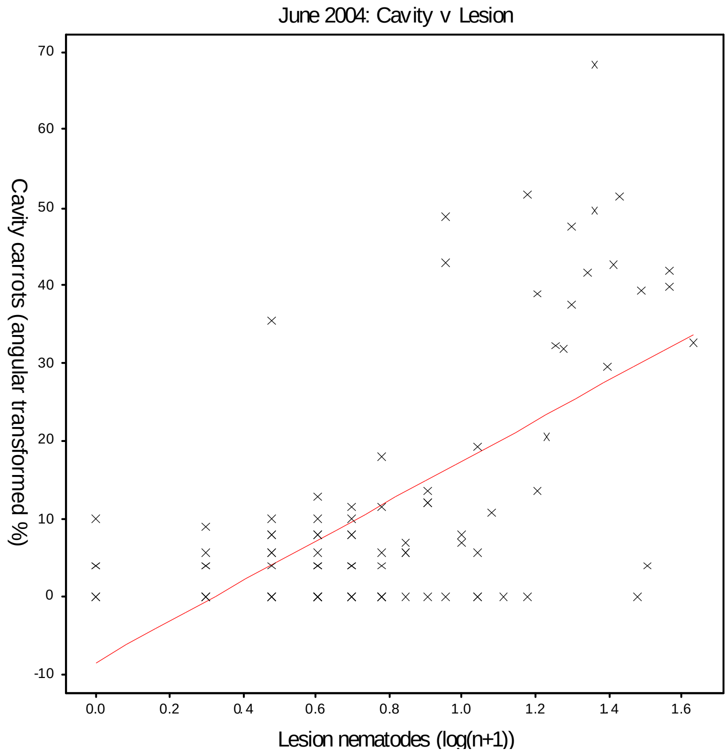
Fig. 24. Relationship between stubby-root nematodes and fanging at EC, June 2004



(b) link between root-lesion nematodes and cavity spot when June 2004 nematode data compared with harvest assessment

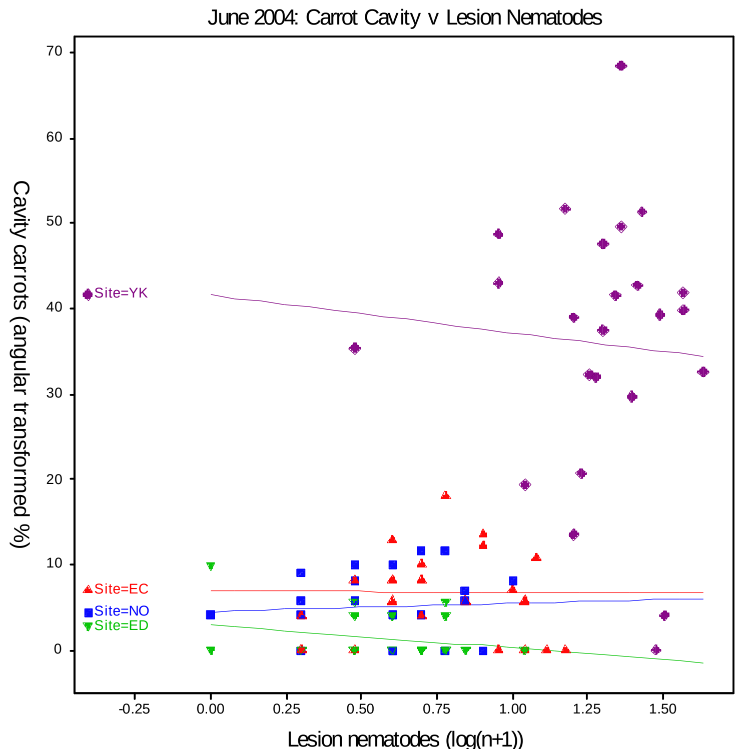
There was a significant regression for the combined data from all sites when comparing root-lesion nematode numbers in June 2004 and incidence of cavity spot recorded at harvest (Fig 25; Appendix 5).

Fig. 25. Relationship between root-lesion nematodes and cavity spot overall June 2004



However, for individual sites there was little or no correlation between cavity spot and lesion nematodes in June 2004. Lines all slope down to right or are level or nearly so, indicating little or no correlation (Fig. 26).

Fig. 26. Relationship between root-lesion nematodes and cavity spot at individual sites, June 2004.



Thus the correlation between cavity spot and root-lesion nematodes recorded overall needs to be treated with caution.

Comparison between carrot quality in trial plots (no Temik but pre-cropping cultivation treatments and green manure) and in the trial field (Temik applied)

Both the trial area and the associated field areas which had been treated with Temik had the industry standard of pre-drilling cultivations as described earlier. Observations were made on the remainder of the trial fields in 2004 that were not involved in the investigation and had all been treated with Temik (aldicarb). This chemical is known to stimulate plant growth so that crops look in good condition, but in at least one case, at York, the crop on the trial plots which had received fallow year cultivations were thought to look better; this may be due to the cultivations resulting in better soil condition. There was no significant difference between the percentage of Class 1, the incidence of fanging or other problems from the Temik area and the trial area. There was a significant effect on cavity spot – it was actually worse in fields where Temik had been used (Figs. 27-30; Appendix 6).

Fig. 27. Mean percentage of carrots recorded as class 1 for overall trial samples compared with field (Temik) samples

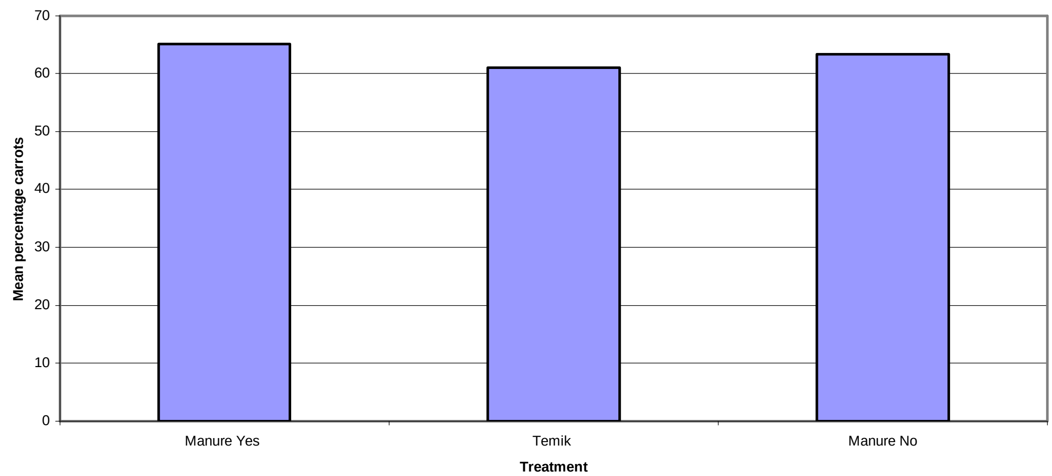


Fig. 28. Mean percentage of carrots with fanging for overall trial samples compared with overall field (Temik) samples

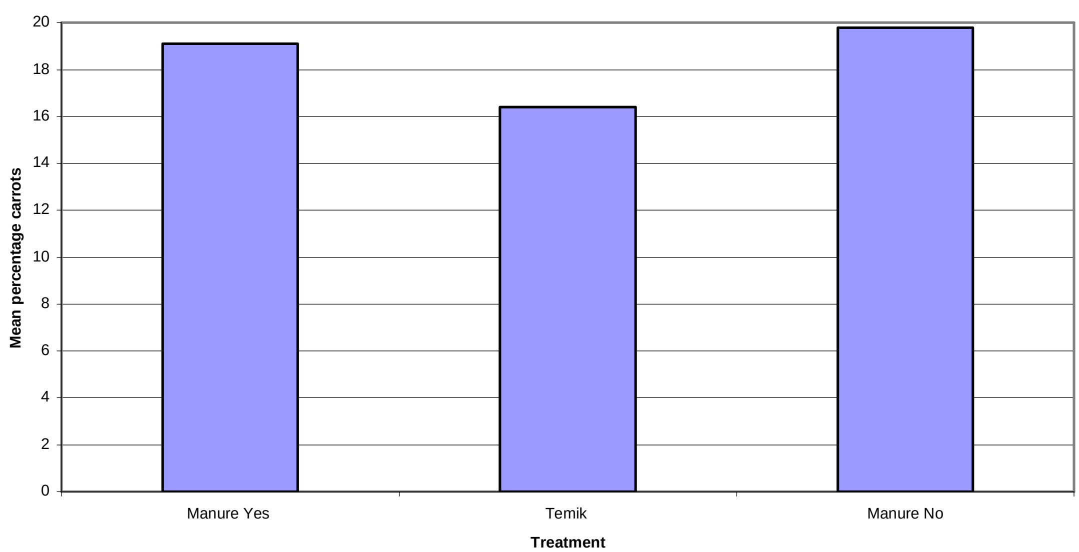


Fig. 29. Mean percentage of carrots with cavity spot for overall trial samples compared with field (Temik) samples

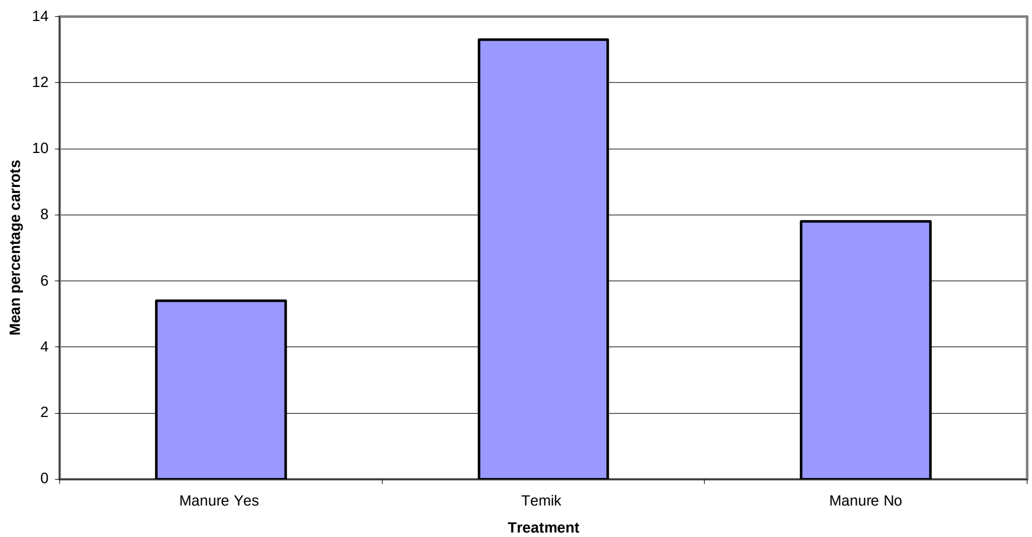
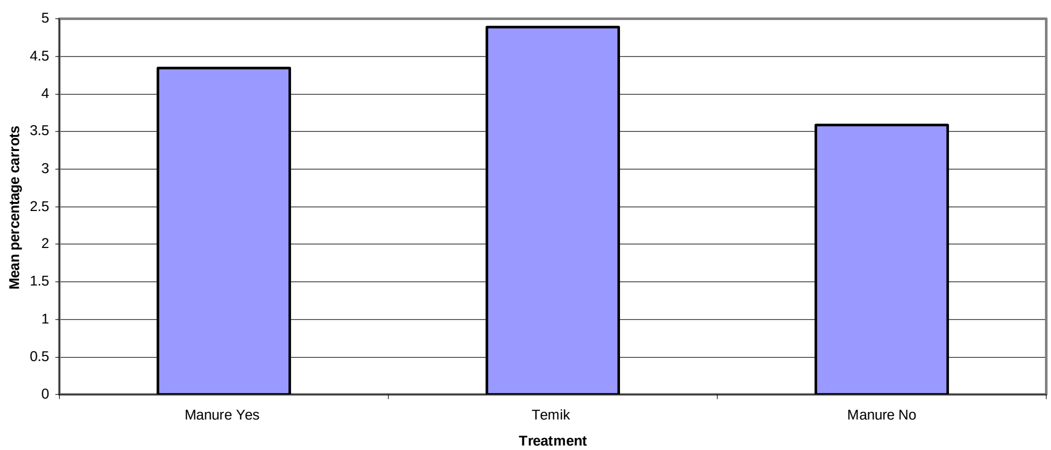


Fig. 30. Mean percentage of carrots with other quality related problems for overall trial samples compared with field (Temik) samples



Comparison of data from individual sites

In several of the statistical analyses the aspects of quality examined were not explained by reference to nematode numbers or treatments alone. This prompted a comparison of the quality assessments for each plot at each site, which therefore gave a visual comparison of the overall differences between each site (Figs. 31-34). For each quality aspect there appeared to be a difference between sites.

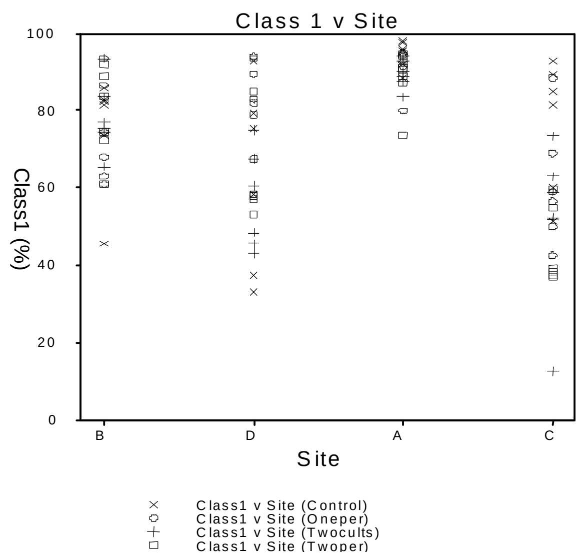


Fig. 31 (above). Mean percentage Class 1 carrots from each site

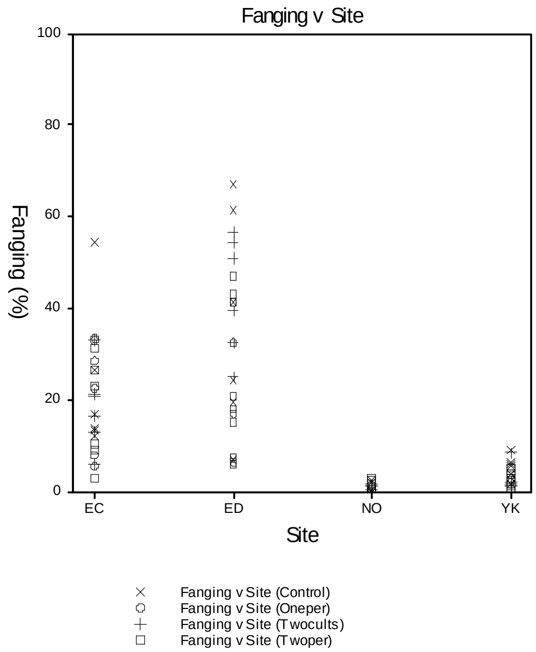


Fig. 32 (above). Mean percentage fanged carrots from each site

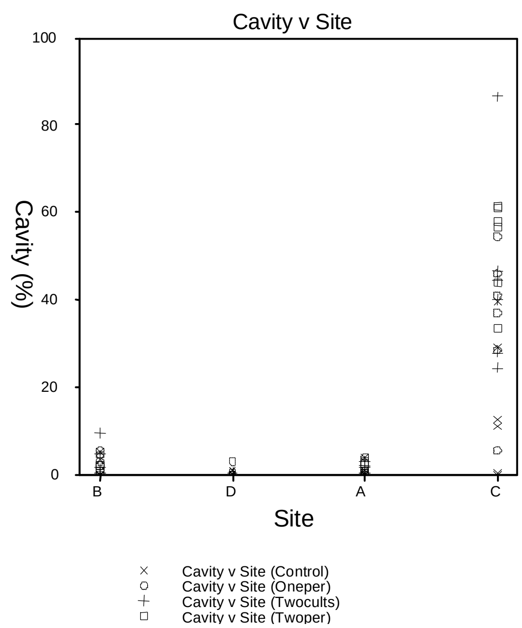


Fig. 33 (above). Mean percentage carrots with Cavity Spot from each site

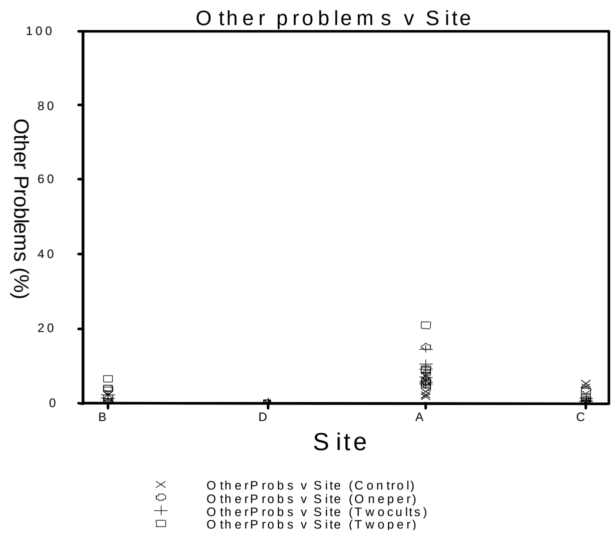
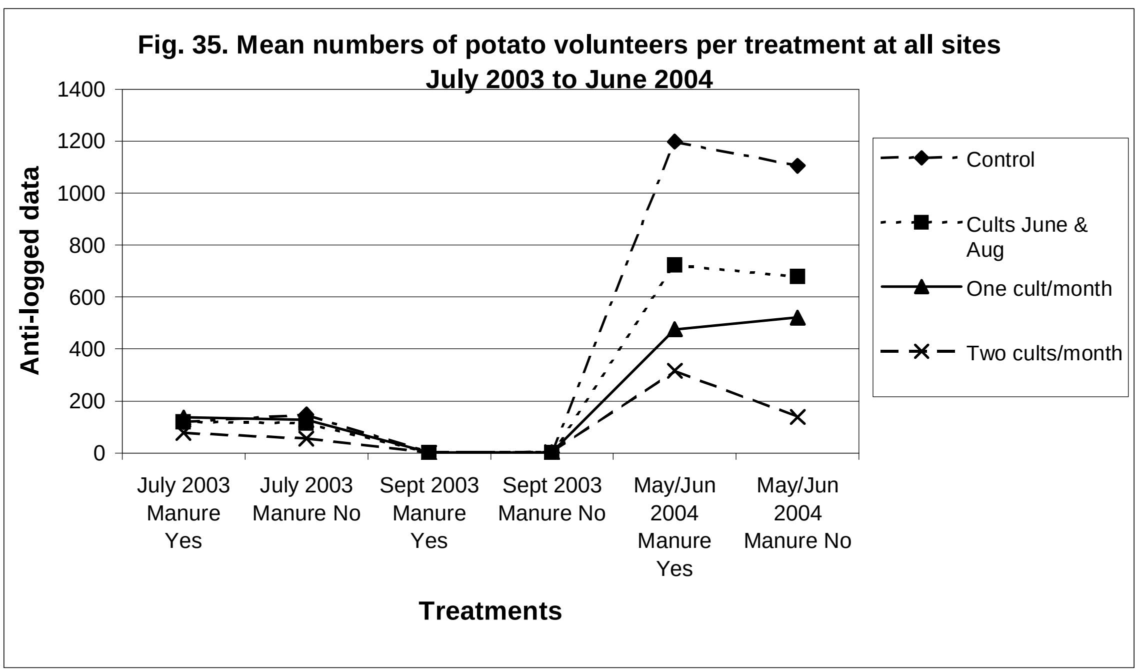


Fig. 34 (above). Mean percentage carrots with Other Problems from each site

Assessment of the effect of various cultivation regimes on volunteer potato populations

The results of the assessments are set out in Fig. 35 and the statistical analysis in Appendix 7.



Data from the York site was not included in the statistical analysis because there were so few plants present.

Fig. 35 illustrates that increasing cultivation intensity significantly reduced numbers of potato volunteers in the cropping year compared with doing nothing at all (p=<0.001); there was also a corresponding significant difference between the cultivation treatments on potato volunteers (Appendix 7). These results were mainly influenced by the results at ED and NO, where there was a significant and very significant effect of cultivations on potato volunteers respectively (p=0.003 and p=<0.001 respectively).

There was no difference between the plots due to receive green manure and those not.

By mid August, when cultivation treatments had been completed, the high levels of volunteer potatoes in the controls at EC and ED, with their potential blight infection risk, and the very high levels of volunteer rape in the control zones at YK necessitated that all sites were ploughed across the treatment strips to facilitate the drilling of the Sudangrass. Volunteer counts that were done in October were very low and were not statistically analysed. Detailed statistical data is filed in Appendix 7.

Discussion

Most nematode genera recorded at harvest had been found on previous sampling occasions. The two new genera found, *Neodolichorhynchus* sp. (stunt nematodes) and *Paratylenchus* sp. (pin nematodes) are not considered of significance in this investigation. The needle nematodes (*Longidorus* species) and sheath nematodes (*Hemicycliophora* species) became less numerous, but this is a common feature of these species when recorded under continuous cultivation.

The root-lesion nematodes (*Pratylenchus* species) found during this investigation have been implicated in damage to carrots in Europe. The most common species found here and in the UK, *P. neglectus*, is attracted to root tips, and apparently prefers feeder roots to the coarser lateral and main roots, and so may not be important in damaging the tap root of carrots once they have started to develop. They are often associated with facilitating the entry of disease into root systems, so may important in some situations. The other root-lesion nematode found, *P. thornei*, has been known to damage a range of crops, but does not seem to be important in carrot production. *P. crenatus*, associated with 'carrot sickness', has not been found in the trial sites to date. Thus there seems little need to control the root-lesion nematodes found here on the grounds of causing direct damage.

Stubby-root nematodes (*Paratrichodorus* and *Trichodorus* spp.) were found on all sites and are typically associated with sandy soils. *Paratrichodorus pachydermus* was found at three sites, and is fairly common in the UK. It has a wide host range, and, in common with other stubby-root nematode species, their activity is particularly dependent on adequate soil moisture, and they can be found at depths varying from 15 to 70cm. It is associated with damage to crops, particularly onions. *Trichodorus cylindricus* was also found on three sites. It tends to be most common in soils from pastures and from grasses along roadsides, but whilst it has been found in the rhizosphere of potatoes, lettuce and sugar beet, amongst others, it does not seem to have been recorded as pest of carrot. *Trichodorus primitivus* is widely distributed in the UK, and was found on three sites in this study. It has a wide range of hosts, occurs at a wide range of depths and is known to cause direct damage to most plant roots. All these species are potential pathogens of carrot and are the prime suspects for any symptoms of fanging not caused by other factors such as disease, pesticide damage, soil structure or waterlogging.

Needle nematodes (*Longidorus* species) have often been cited as pests of carrot, but usually are only found in low numbers. In this study they were mostly found in the Suffolk sites, but one species was found in Nottinghamshire. This species, *Longidorus profundorum*, is not considered a major pathogen. In Suffolk, *L. attenuatus, L. elongatus* and *L. leptocephalus* were all found in low numbers. They are potentially important pathogens, and *L. attenuatus* in particular has been associated with fanging on sugar beet, but less so on carrots.

Of the remaining nematode species, some such as *Bitylenchus dubius, Criconemoides* spp. and *Hemicycliophora* spp., are often implicated in damage to crops, but none were thought to be present in sufficiently high numbers on trial sites to be a cause for concern. The total effect of feeding by groups of these species thought to be of secondary importance, or in combination with more pathogenic species, may be more important.

The monitoring of nematode species during the fallow year period suggested that any time during this period would be suitable for pre-crop sampling, although the months immediately prior to drilling would perhaps give the most representative results, depending on the prevailing soil temperature and moisture levels. The dramatic decrease in nematode numbers recorded at for all sites in June 2004 coincided with the pre-drilling cultivations, but cannot be attributed to it because the untreated plots were included in the cultivations. It could equally be due to another event, or to sampling error. However, this dramatic decrease was a repeat of findings reported in the first annual report for HDC Project FV 232 (May 2001), when the decline after pre-drilling was observed on all sites, whether Temik (aldicarb) had been used or not. The evidence here suggests that this decline will happen anyway, due either to the current standard method of cultivation at drilling, drying out of the soil surface or perhaps to the fact that the principal plant-parasitic nematodes are drawn to the close proximity of the carrots themselves, an area that would be difficult to sample without removing the crop itself and would require analysing many more samples of small amounts of soil taken with seedlings.

In general, numbers of plant-parasitic nematodes appeared to continue to decrease whilst the carrot crop was present, according to the two sampling dates of June 2004 and January 2005. More frequent sampling would have confirmed this steady decline, but if levels did remain below the recognised treatment guidelines then this would help to explain why it has proved difficult to link nematode numbers with any damage to the subsequent crop quality. Conversely, the population declines in the absence of a nematistat (a product that stuns rather than kills nematodes) or nematicide on the experimental plots provides support for calls to review the use of nematistats and nematicides on carrots.

In 2004, the effect of fallow year cultivations had been inconsistent and at harvest, there was no significant effect of these treatments on nematode numbers overall, leading to the conclusion that any effects are short-lived. Numbers of root-lesion nematodes were significantly reduced and thus may be particularly susceptible to this type of treatment; the relatively marginal decrease in numbers of stubby-root nematodes, perhaps the main target of treatments, was disappointing, but perhaps suggested that populations of these nematodes can quickly recover.

The effects of fallow year cultivation on stubby-root nematodes has been difficult to determine. This may be due sampling errors that are inevitable with the vertical migratory habits of this group; they are rarely numerous in the surface layers except after periods of prolonged rainfall. They appear susceptible to desiccation but are able to avoid such stress by migrating vertically for considerable distances for example to deeper, moister soil layers in summer; in autumn they move up through the soil to recolonise the upper soil layers, and this might explain the higher than expected numbers recorded in September 2003 (Rössner, 1972; Decraemer, 1980). For these reasons, the effects of cultivations on stubby-root nematodes may be difficult to assess. However, there is evidence that they are susceptible to mechanical disturbance (Bor & Kuiper, 1966) and are usually found below the depth of cultivation (Cooke, 1973). This susceptibility is much lower in water-logged soils (Bor & Kuiper, 1966).

In the USA the Environmental Protection Agency is funding work that is examining nematodes as indicators of physical and chemical disturbance of agricultural soil, with a view to defining soil quality. There is accumulating evidence that some genera are more sensitive to the effects of tillage or cultivation than others, though unfortunately plant-parasitic genera have not been studied (Fiscus & Neher, 2002). In this investigation, numbers of root-lesion nematodes were reduced to a much greater degree than stubby-root nematodes. This provides even stronger support for the recommendation for farmers to know the types and numbers of plant-parasitic nematodes present in fields to be cropped before devising control programmes.

As a result of the dry conditions, establishment of the Sudangrass in 2003 was poor on all sites and varied. Owing to the continuing dry weather, growth was slow resulting in poor crop cover with maximum heights of only 10/12cm by October when all sites suffered frosts, which totally defoliated the Sudangrass. The drought conditions also affected other crops, such as cereals, drilled at the same time. On the York site, an almost universal cover of oilseed rape prompted a decision to use this as a test substitute green manure crop. This was done on the grounds that continual growth of the oilseed rape would have rendered it very different from the other sites in any case. On those plots not due to receive green manure the oilseed rape seedlings were treated with herbicide.

Overall, at harvest, there were more nematodes in the green manure plots than in plots that had not had green manure. It may be postulated that this effect was influenced by the results at YK, where the volunteer crop of oilseed rape was incorporated as an alternative biocidal crop. However, the results at ED, where the ill-fated Sudangrass seemed to have little influence, showed a more significant increase in these plots, indicating some unknown cause was having an effect. Perhaps green manure crops, even if grown for only a short while, actually provide some soil enhancement factor that facilitates plant growth and hence provides a better environment for some nematode species to reproduce. The most recent research in the USA suggests cereal cover crops produce the largest amount of biomass and are best used to build soil organic matter, rather than influence nematode numbers directly, whilst brassica cover crops seem more effective in suppressing plant-parasitic nematodes. Indeed, brassica-cereal mixtures seem to show most promise for a wide range of needs (Snapp *et al*., 2005).

The findings here suggest that some biofumigant crops might actually result in a significant increase in numbers of nematodes such as stubby-root nematodes. Conversely, numbers of root-lesion nematodes were not affected in the green manure plots, either overall, or at YK, reflecting the potential selective effect of green manure crops on nematodes. These apparently variable effects reflect recent findings in the USA (Crow *et al.*, 2001). Such differences would increase the importance of pre-crop sampling for nematodes in order to assess the types of nematodes present. Clearly, the effects of green manure crops need to examined further.

The insignificant effect of the fallow year cultivations on nematode numbers was reflected in the general lack of beneficial effects of these treatments on crop quality. The relatively low numbers of nematodes recorded at the two-leaf stage (June 2004) and harvest (January 2005) might explain why it was difficult to link nematodes with an adverse effect on quality. Any effect of fallow year cultivations on nematode numbers is therefore concluded to be short-lived, but there were locally significant effects that resulted in a complex picture of results.

The final assessments at harvest generally supported the view that it was statistically difficult to justify more than the simplest relationship between nematode numbers and fallow year cultivations. This might be partly explained by the significant variations in quality assessments found at individual sites. Nematode levels remained below treatment guidelines but fanging did occur, emphasising the arbitrary nature of thresholds or treatment guidelines.

Fanging damage is often assumed to be the result of feeding by nematodes, especially stubby-root nematodes. In this investigation the fallow year cultivations had relatively little impact on nematode numbers and there was no significant effect of these cultivations on fanging, even on those sites where green manure plots had higher levels of stubby-root nematodes. Where fanging did occur, a significant correlation between stubby-root nematodes and this type of distortion was shown on two sites, ED and EC in April 2004 (pre-drilling) and June 2004 (two-leaf stage) respectively, which supported the general conclusion that these nematodes are contributory factors in fanging even below recognised treatment guidelines. Whilst the results for June 2004 are considered more relevant because the crop was in the ground at this time, the stronger correlation of fanging with the April 2004 data suggests that sampling at this time for these nematodes might provide the basis for an early warning system of subsequent damage. However, even if treatment levels were lowered, this project provides some evidence that growers might not find the increased chances of treatment beneficial, as the individual site results show how the incidence of fanging can vary; YK had perhaps the highest number of stubby-root nematodes, but one of the lowest incidences of fanging.

As stated previously, fanging can also be the result of an array of other factors, such as disease, stony soil, herbicide use, water-logged or compacted soils; on one site in this investigation with a high incidence of fanging it was concluded that compacted soil rather than nematodes was to blame, hence a prediction system would have to incorporate a decision tree for treatment guidelines based on a number of possible factors. If a review of the current treatment guidelines as set out in the Decision Tree (Appendix 3) is prompted, more data from more sites and growers' experiences is required.

The apparent correlation between cavity spot at harvest and numbers of root-lesion nematodes in June 2004 was not repeated when the data for individual sites was examined. This relationship was repeated for all the quality assessments and illustrates the benefits of investigating innovative treatments at several sites to realise the complex interaction between sites, incidence of pathogens and effect of treatments. It must be concluded that there are other underlying factors on farm sites that will influence how they may or may not benefit from a particular change in cultivation. The illustration of the differences between sites in all aspects of carrot quality hinted at the difficulty in drawing too many conclusions from experimental work but reinforced the crucial importance of individual site factors.

This investigation included an additional assessment of the differences between the crop in the main field that had been treated with Temik and that from the trial area to provide some feedback to the site managers. Whilst it was not part of the replicated trial the number of samples taken at harvest did provide data that was statistically acceptable. The overall benefit from using Temik, either as a nematode control product or, consequently, as an enhancer of quality at harvest, was not proven. This latter result was surprising given that growers have commented on the enhanced vigour of plants treated with Temik. However, since the numbers of nematodes present during the life of the crop were below recognised guidelines for treatment, this result is not surprising. However, the numbers of nematodes that were present prior to the pre-drilling operations, when sampling results would have recommended treatment, was above the guidelines for nematode groups such as stubby-root nematodes. These results not only call into question the justification for the use of Temik, but also the role of pre-crop sampling. If the dramatic fall in numbers of nematodes after drilling does occur as a result of the industrial standard method of cultivation, then growers should not be concerned about the proposed withdrawal of Temik in 2007. However, if pre-drilling operations should change, or for other horticultural crops not subject to such drilling operations, the risk of damage due to nematodes may still exist and sampling should thus be seen as a management tool for sustainable production, establishing knowledge about the population dynamics of plant-parasitic nematodes. It should also be retained to allow informed decisions about the selection of biocidal plants, if these are to be incorporated for sustainable pathogen control or soil enhancers.

The losses that did occur through fanging, disease, low quality and other factors need to be put into context against other losses that occur during harvesting, for example; up to 15% losses might be expected during harvesting, through mechanical damage in field and factory operations. Nationally, approximately 7.5% of the carrot crop is affected by fanging, but the proportion that is as a result of nematode feeding is unknown.

Standard pre-drilling cultivation practices were resumed by farmers on all sites in 2004, after the fallow year cultivations. The crop was drilled relatively late, in May, for harvesting in January 2005 and was thus strawed in the autumn of 2004. Earlier drillings, in March for summer harvest, may have exposed the crop to more damage as nematodes sought nourishment as temperatures rose. Later drillings may expose the seedlings to less damage as the carrot plants are able to overcome the effects of feeding much more quickly. However, later drilling may have increased the incidence of cavity spot, as the crop was taken to the following year under straw. Clearly, methods of mulching (soil cover, straw mulch, etc.) may also influence the incidence and effect of a variety of pathogens, especially in a mild winter.

The relatively low numbers of nematodes at each site during cropping, combined with the occurrence of related damage, albeit deemed insignificant, prompted a review of the maximum number of stubby-root and root-lesion nematodes found in relation to recognised treatment guidelines for economic damage. The Decision Tree that was produced in the HDC Project FV 232 is considered the basis by which decisions on chemical control should now be made (Appendix 3). As can be seen from Figs. 36 and 37, the numbers of nematodes present in the ground during the time the crop was grown are way below these treatment guidelines (200 per litre or 40 per 200g for stubby-root nematodes; 2500 per litre or 500 per 200g for root-lesion nematodes). This result also prompts a debate about the relevance of sampling prior to drilling, if, as has been suggested, the current standard cultivations at drilling are responsible for a significant decrease in nematode numbers. However, as has been mentioned in relation to the choice of biocidal plants, it is important to be aware of the population dynamics of plant-parasitic nematodes so that informed decisions can be made about the particular pathogenic species present and the most appropriate pest management practices.

Fig. 36. Maximum Number of Stubby-Root Nematodes found on each Site at each Sampling Date

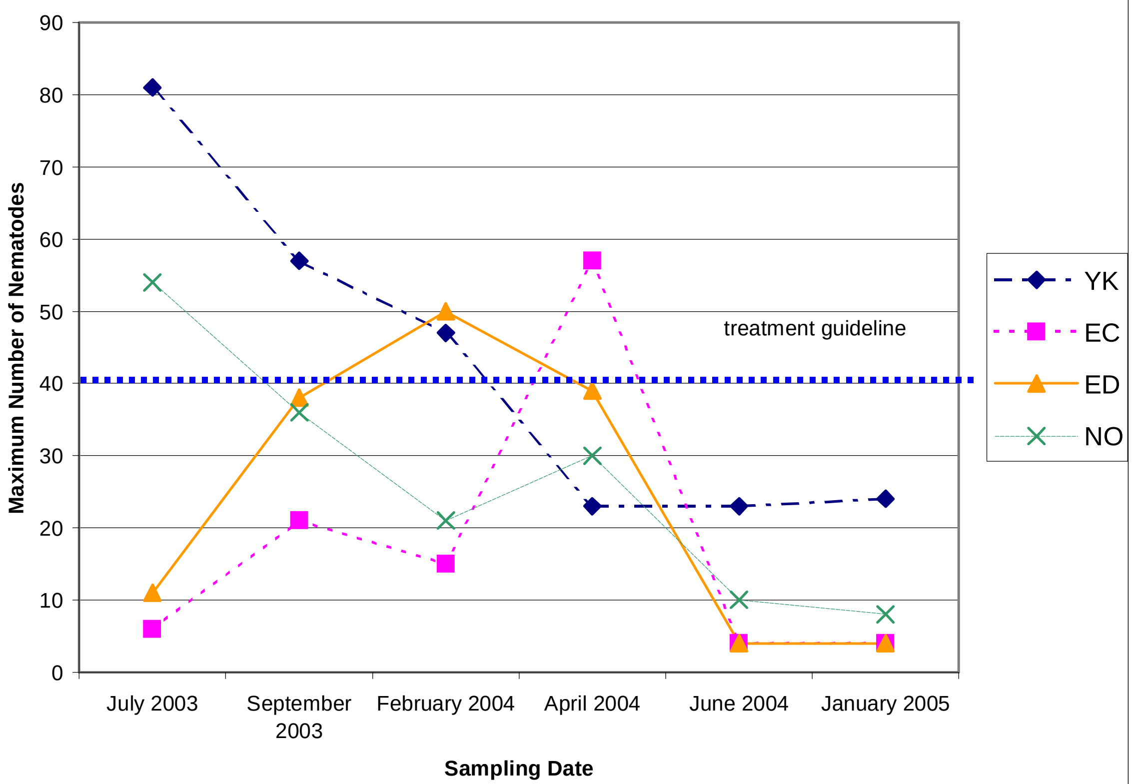
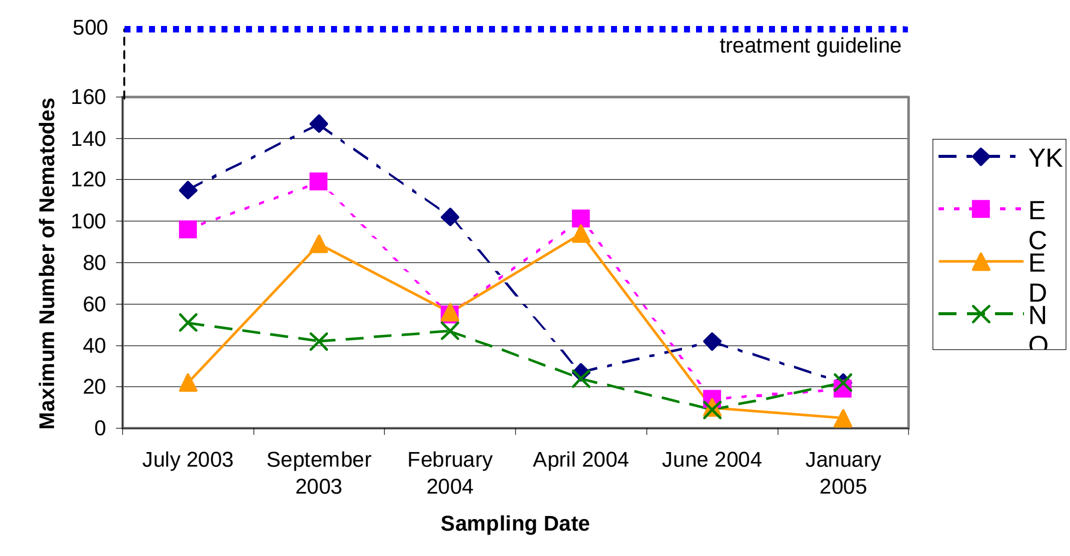


Fig. 37. Maximum Number of Root-Lesion Nematodes at Each Sampling Date



The fallow year cultivations had a significant effect on numbers of potato volunteers, but only on those sites where numbers of plants had reached a significant level. However, numbers of plants will not be reduced in the same way as presently done with herbicide. Despite the geographical spread of the four sites, the mild winter and associated lack of frosts meant that nature, once a useful eradicant of volunteer potatoes in the winter months, had no effect. Pre-drilling cultivations would have had little detrimental effect on the number of volunteer potatoes (Knight, personal communication); the de-stoner would have sieved the soil but left the potatoes intact, whilst the bed-maker may have cut some tubers thus increasing the potential for more volunteer plants. It is evident that, unless all volunteer potatoes are eradicated during the fallow year, the explosion of plants in the following year (2004) is unacceptable.

Conclusions

- There was a correlation between numbers of stubby-root nematodes and fanging at pre-drilling and at the two-leaf stage on two sites. However, by observations and growers' comments it was concluded that fanging may also be caused by herbicide damage, compaction or waterlogged soils.

- Root-lesion nematodes should be regarded as potential pathogens, but no species of economic importance were found during this investigation, and an association with the incidence of cavity spot was not proven.
- Carrot cyst nematodes, root-knot nematodes and longidorid nematodes (needle and dagger nematodes), were not found or were uncommon in this study, reinforcing previous findings that these species tend to be localised problems, and should not be a cause for concern nationally.
- Effect of fallow year cultivations seems to be short-lived on nematodes overall, but was good for reducing the weed bank. There were no obvious effects on carrot quality.
- Root-lesion nematode numbers overall were reduced by fallow year cultivations, but stubby-root nematodes were not affected.
- Increasing the intensity of the fallow year cultivations led to increasingly significant reductions in numbers of potato volunteers where these were in high numbers, but the overall reduction was not acceptable commercially.
- The green manure crop Sudangrass is not frost tolerant. If it is to be tested and used growers will need to use it in another way (under covers or at a different drilling date).
- Oilseed rape did produce some significant but variable effects that need to be investigated further.
- The incorporation of the volunteer oilseed rape appeared to stimulate numbers of some nematodes such as stubby-root nematodes, but not others such as root-lesion nematodes.
- The benefits of green manure cannot be guaranteed and need to be investigated further.
- Fallow year cultivations do not seem to affect carrot quality.
- Treatment guidelines for plant-parasitic nematodes need to be reviewed, especially in light of the current industry practice of a range of pre-drilling

operations. Whilst numbers of plant-parasitic nematodes remained below treatment guidelines damage still occurred but set against usual industry losses the damage attributed to nematodes was deemed insignificant.

- Site-related factors appear to be more significant and perhaps more influential in crop quality than nematodes alone.
- Benefits from using Temik for the control of plant-parasitic nematodes and improvement in quality were not proven in this study.
- The dramatic reduction in nematode numbers overall recorded in June 2004 after pre-drilling cultivations (at the two-leaf stage) was consistent with previously observed effects of Temik.
- Growers need to consider the findings of this report for their own particular sites and compare final crop quality, rather than vigour, from sites with and without Temik.

Technology Transfer

An article for HDC News to be produced, based on the findings of this report. An application to present a poster for the 2005 Carrot Conference has been made.

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