Project Title:	Watercress: Optimising zinc applications for controlling crook root disease and minimising zinc discharges
Project Number:	FV 55g
Project Leader:	John Walsh
Report:	Final Report September 2004
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Location of Project:	Warwick HRI Wellesbourne Warwick CV35 9EF and 12 Watercress growing sites in Dorset, Hampshire Wiltshire and Sussex
Date Project Commenced:	01 January 2004
Date Project Completed:	01 September 2004
Key Words:	watercress, crook root, zinc, survey, zinc usage, zinc discharge, duration of zinc application, water flow rates

Disclaimer

The results and conclusions in this report are based on information gathered during a single growing season. Therefore, care must be taken with the interpretation of the results.

Use of pesticides

Only officially approved pesticides may be used in the UK. Approvals are normally granted only in relation to individual products and for specified uses. It is an offence to use non-approved products or to use approved products in a manner that does not comply with the statutory conditions of use except where the crop or situation is the subject of an off-label extension of use (The UK pesticide Guide 1999).

Before using all pesticides and herbicides check the approval status and conditions of use.

Read label before use: use pesticides safely.

CONTENTS

Page Nos.

GROWER SUMMARY

Headline

- Zinc provides effective control of crook root and the benefits in terms of reduced levels of crook root achieved by applying zinc are evident

- Three sites where zinc sulphate solution was pulsed had the lowest crook root infection levels indicating that pulsing zinc may be at least as effective as applying zinc continuously. Two of these sites used less zinc per acre than some of those sites where zinc was dosed continuously.

- The two sites that had the most crook root were sites where no zinc was applied.

- Zinc emissions were quite similar for most sites where it was applied and in all cases (measurements taken at 9 sites) all were within the limits of the discharge consent (<0.075 ppm).

- Detailed replicated experiments comparing the effect of different zinc treatment regimes on crook root infection levels in similar watercress beds would be required to identify the best pulsing treatments.

Background and expected deliverables

- Crook root disease of watercress (*Rorippa nasturtium-aquaticum*) is caused by *Spongospora subterranea* f. sp. *nasturtii.* The disease is the most important one currently affecting UK watercress production and occurs in other parts of the world (Walsh & Phelps 1991).

- During the winter months when the effects of crook root on watercress are most severe, growers treat the water flowing through the watercress beds with zinc, mostly in the form of zinc solutions. This practice, which has been adopted since the 1950's has been shown to give good control of crook root.

- A high concentration of zinc is toxic to freshwater shrimps (*Gammarus pulex*) (Martin & Holdich 1986) and zinc emissions from watercress beds have been implicated in the reduction of numbers of these shrimps in rivers and streams downstream of watercress beds (Roddie, Kedwards & Crane 1992). Formerly crook root was controlled by the application of zinc to the spring water supplying watercress beds to give a concentration of 0.1 ppm in water flowing through the crop (Tomlinson 1960). Currently UK watercress producers are allowed to discharge zinc at only 0.075 ppm (0.075 mg/l).

- This project surveyed 12 watercress growing sites and sampled plants, which were scored for crook root disease, from all sites, in the hope of identifying the most effective zinc treatments and thereby optimising zinc applications for controlling crook root disease and minimising zinc discharges.

The causal organism of crook root (*Spongospora subterranea* f. sp. *nasturtii*) infects watercress (*Rorippa nasturtium-aquaticum*) roots, where it proliferates and causes the roots to become swollen and brittle and frequently curved in the shape of a crook (Tomlinson 1958). Roots are often stunted and tend to rot causing, in extreme cases, the plants to become dislodged. This is accompanied by a loss of vigour and a consequent reduction in yield. The disease is present in watercress roots all year round, but is particularly debilitating in winter when plants are growing slowly.

The crook root organism has the added importance of acting as the vector of watercress yellow spot virus (WYSV) which is another important disease affecting watercress production in the UK (Walsh, Clay & Miller 1989). The virus is also known to occur in France (Spire 1962). Like crook root, the virus is present in watercress roots all year round. At certain times of year (sometimes in winter, but mostly in spring) unknown factors induce the virus to move up into the leaves where it causes the characteristic yellow spot symptoms. Plants with such symptoms are commercially unmarketable.

Different watercress growers use different modes of applying zinc and currently little is known about the relative efficacy of the different approaches. The Environment Agency survey of operational practices on watercress farms stated that only the two intensive growers used zinc. One intensive grower used zinc sulphate solutions whereas the other used zinc chloride solutions. Application practices were different, although they were relatively uniform within each business. Both pulsed and continuous application regimes were used. Average application rates were very similar if the pulsed nature and maximum flow rates were taken into account.

The objectives of this project were:

- to survey current zinc application methods and materials and to determine the efficacy of these in controlling crook root disease and the resulting zinc emissions
- to investigate variations in zinc application regimes in order to identify optimum regimes in terms of improved crook root control and reduced zinc emissions
- to quantify crook root infection levels in February 2004 at the outlet of watercress beds, and compare infection levels with zinc application regimes.

Summary of the project and main conclusions

- The benefits of zinc treatments in controlling crook root are confirmed
- Information is presented on crook root levels at sites where different zinc application rates and regimes were used
- The survey has shown that pulsed zinc treatments can control crook root at least as well as some continuous applications
- By pulsing zinc, growers may be able to reduce zinc inputs, thereby reducing perceived environmental impact and costs
- Irrespective of the method of zinc application, all watercress farms surveyed operated within the EA discharge consent of 0.075ppm.
- Differences between sites and the different practices at each site make comparisons of crook root levels at each site very difficult
- The major benefits from this work will be environmental in terms of minimising zinc emissions into the pure chalk streams that the watercress farms discharge into and also commercial in terms of reducing crook root and minimising yield losses caused by crook root

Financial benefits

- Growers may be able to reduce zinc inputs by pulsing and thereby reduce costs whilst still controlling crook root and maintaining yields
- Differences in crook root levels at different sites indicate that there is potential to increase yields and hence profitability by improving crook root control at some sites

Action points for growers

- The benefit of zinc treatments for controlling crook root is confirmed
- Pulsing zinc could reduce zinc emissions without compromising crook root control
- Levels of crook root at different sites suggest improvements in zinc treatments and cultural practices will have benefits in terms of reducing losses from crook root

SCIENCE SECTION

SUMMARY OF RESULTS

1. The severity of crook root at each of 12 watercress growing sites has been determined. There were significant differences between some beds at particular sites and also between sites.

2. Where available information on zinc usage (kg/acre/season), zinc type, application method, target application rate, target discharge level, actual discharge, summer background zinc levels, duration of zinc application, flow rates (gal/hr/yd bed width), water source, bed substrate, physical location of beds (sheltered or not), when crop planted, number of cuts, number of frosts and any other relevant information was collected and recorded.

3. The only zinc compound used was zinc sulphate. There were 4 regimes, no zinc applied, zinc solution applied continuously, zinc solution pulsed (one "squirt" every 90 sec, or 1 hr on, 2 hr off) and zinc pellets applied by hand.

4. The three sites that had the lowest level of crook root were sites where zinc solutions were pulsed. The two sites that had the most crook root were sites where no zinc was applied.

5. There was no clear correlation between the amount of zinc used each season and the amount of crook root found at each site.

6. Variation in crook root levels within and between sites suggests there is considerable scope for improving crook root control.

7. All sites were unique, often utilising quite different growing methods. Such differences made comparisons between sites very difficult.

8. Zinc emissions were quite similar for most sites where it was applied and all were within the limits of the discharge consent (<0.075 ppm).

9. Statistical analyses showed that there were no clear associations between crook root infection levels and zinc usage, method of zinc application, summer zinc levels, duration of zinc treatment and number of cuts (harvests) across all sites.

Introduction

Crook root disease of watercress (*Rorippa nasturtium-aquaticum*) is caused by *Spongospora subterranea* f. sp. *nasturtii.* The disease is the most important one currently affecting UK watercress production and occurs in other parts of the world (Walsh & Phelps 1991). The causal organism infects watercress roots, where it proliferates and causes the roots to become swollen, brittle and frequently curved in the shape of a crook (Tomlinson 1958). Roots are often stunted and tend to rot causing, in extreme cases, the plants to become dislodged. This is accompanied by a loss of vigour and a consequent reduction in yield. The disease is present in watercress roots all year round, but is particularly debilitating in winter when plants are growing slowly.

The crook root organism has the added importance of acting as the vector of watercress yellow spot virus (WYSV) which is another important disease affecting watercress production in the UK (Walsh, Clay & Miller 1989). The virus is also known to occur in France (Spire 1962). Like crook root, the virus is present in watercress roots all year round. At certain times of year (sometimes in winter, but mostly in spring) unknown factors induce the virus to move up into the leaves, where it causes the characteristic yellow spot symptoms. Plants with such symptoms are commercially unmarketable.

During the winter months when the effects of crook root on watercress are most severe, some growers treat the water flowing through their watercress beds with zinc, mostly in the form of zinc solutions. This practice, which has been adopted since the 1950's has been shown to give good control of crook root. Recent research at Wellesbourne has shown that due to the vector relationship of crook root to WYSV, such treatments also give some control of WYSV. Formerly crook root was controlled by the application of zinc to the spring water supplying watercress beds to give a concentration of 0.1 ppm in water flowing through the crop (Tomlinson 1960). It has been claimed that zinc is toxic to freshwater shrimps (*Gammarus pulex*) (Martin & Holdich 1986) and zinc emissions from watercress beds have been implicated in the reduction of numbers of these shrimps in rivers and streams downstream of watercress beds (Roddie, Kedwards & Crane 1992). Currently UK watercress producers are allowed to discharge zinc at only 0.075 ppm (0.075 mg/l).

Different watercress growers have widely different modes of applying different zinc solutions and currently little is known about the relative efficacy of the different approaches. The Environment Agency survey of operational practices on watercress farms revealed that only the two intensive growers used zinc. One intensive grower used zinc sulphate solutions, whereas the other used zinc chloride solutions. Application practices were different, although they were relatively uniform within each business. Both pulsed and continuous application regimes were used. Average application rates were very similar if the pulsed nature and maximum flow rates were taken into account.

Materials and Methods

In January 2004 (between 15 and 27 January), twelve watercress growing sites in Hampshire, Dorset, Wiltshire and Sussex, selected by HRI in consultation with growers and representing the spectrum of environments in which watercress is grown and the different regimes used to apply zinc to watercress beds for crook root control, were surveyed by Michael Payne (Horticultural Consultant). The sites included four sites where zinc was thought not to be applied (A, F, E and M). Although site A was selected as a site where no zinc is applied, the survey revealed that zinc is used at this site as a trace element and usage was in excess of most of the sites where pulsed zinc treatments were used. Other sites chosen were: one site where the beds are left fallow in summer (C), a site (D) where zinc is applied as pellets, sites (G, H and J) where zinc is pulsed and sites where zinc is applied continuously (B, L and K). Factors such as the nature of the zinc compound used (chloride or sulphate), use of seedlings or stubble in propagation, variables such as flow rate and bed substrate were also considered when choosing sites.

Farm managers were interviewed during the first visit to each site and data sets collected (on methods and materials used for applying zinc plus rates of application). The data has been collated and associations between zinc solution types, methods of application, zinc input measurements and zinc emission levels plus crook root infection levels investigated. This has identified which zinc treatment regimes are giving the best crook root control. The information obtained on zinc discharges was not considered to be sufficiently variable to draw any robust conclusions on relationships between this and crook root levels (discharge rates for many sites appeared to be quite similar). Figures on zinc usage as kilos/acre/season have been derived.

The sites were visited between 16th - 18th and 23rd - 25th February 2004 by Judith Bambridge of Warwick HRI, further cultural and environmental information was gathered and watercress plants sampled. Ten plants were collected, at even spacing across the beds, 2m from the bottom of those beds selected. Each plant was put into a separate polythene bag and brought back to Warwick HRI for visual inspection and scoring for crook root presence and severity on a scale of 0 to 5. The scale was as follows: 0 - no visible crook root, 1 – a small trace, 2 - low levels, 3 – intermediate, 4 – severe and 5 – very severe crook root. Sampling strategies within beds were agreed in consultation with growers and statisticians and results analysed for statistical significance.

An analysis of variance (statistical analysis) was carried out on the crook root severity data in order to determine whether any differences in crook root severities between sites and within sites, were statistically significant. Scatter plots were made to compare mean crook root infection levels and zinc usage, method of zinc application, summer zinc levels, duration of zinc treatment and number of cuts (harvests) across all sites. Additionally a principal component analysis was carried out to investigate such correlations more closely.

Results and Discussion

The 12 sites visited and sampled were as follows:
Chalke Valley Watercress, Broadchalke, Salisbury, Wilts
Hairspring Watercress, Hambrook, Sussex
Holwell Watercress, Cranborne, Dorset
Holwell Watercress, Ludwell, Wilts
John Hurd, Stonewold Watercress Farm, Hill Deverill, Warminster, Wilts
John Hurd's site at Sydling St Nicholas, Dorset
Vitacress Salads Ltd, Doddings, Dorset
Vitacress Salads Ltd, Abbots Anne, Hants
Vitacress Salads Ltd, St Mary Bourne, Hants

The Watercress Company, Waddock, Dorchester, Dorset
The Watercress Company, Bishops Sutton, Hants
The Watercress Company, Manor Farm, Old Alresford, Hants

Comparisons between sites

Mean crook root scores for all sites are given below in Table 1 along with zinc usage, zinc application method, background zinc levels and flow rates where know.

Table 1

Site	Rank for least crook root	Mean crook root disease score	Zinc sulphate usage kg/acre /season	Application method	Summer background zinc level mg/l	Duration of zinc application (days)	Flow rate gal/hr/yd width (Av. for site)
G	1	1.23[n]	61	Pulsed [1]	0.0104	211 [3]	No record
C	2	1.53[p]	162.5	Pulsed [2]	0.005	181 – 212 [3]	No record
J	3	1.58[pq]	61	Pulsed [1]	0.005	211 [3]	No record
K	4	1.71[q]	37.5	Continuous	N T [5]	91 [3]	No record
D	5	2.33[r]	75	By hand [6]	0.0018	91 [3]	No record
A	6	2.83[s]	111	Continuous	0.005–0.0078	92	400
M	7	2.96[s]	0	N/A [4]	0.005	N/A	No record
B	8	3.05[t]	130	Continuous	0.005–0.0072	92	400
L	9	3.19[t]	60	Continuous	0.0126	181 [3]	No record
H	10	3.7[u]	61	Pulsed [1]	0.005	211 [3]	No record
F	11	4.06[v]	0	N/A	0.005	N/A	310
E	12	4.4[w]	0	N/A	0.005	N/A	330
		Lsd 0.18 [7]					

[1] - Pulsed one "squirt" every 90 sec
[2] - Pulsed 1 hr on 2 hr off
[3] - From middle of start month to middle of end month
[4] - Not applicable, no zinc applied
[5] - Not tested
[6] - Zinc sulphate pellets applied by hand
[7] - Least significant difference between mean crook root disease scores
[n] - This site had significantly less crook root than all other sites
[p] - This site had significantly less crook root than [q - w]
[q] - This site had significantly less crook root than [r - w]
[r] - This site had significantly less crook root than [s – w]
[s] - This site had significantly less crook root than [t – w]
[t] - This site had significantly less crook root than [u – w]
[u] - This site had significantly less crook root than [v & w]
[v] - This site had significantly less crook root than [w]
[w] - This site had significantly more crook root than all other sites.

Comparisons between the sites (Table 1) showed that sites E and F, where no zinc is applied, had the highest mean crook root disease score (4.4 & 4.06). They had significantly more crook root than all other sites. Site M (where no zinc is applied) was ranked 7th out of the 12 sites sampled with a mean disease score of 2.96, which was significantly less than some sites where zinc was applied, but also significantly more than other sites where zinc is applied. This could have been because this site had only just been brought back into use after several years out of watercress production.

Not all sites where zinc is pulsed (C, G, H & J) use similar methods or amounts of zinc/acre/season, but of the three with the same zinc regime (sites G, H & J) there were significantly different amounts of crook root ranging from mean disease scores of 1.23 to 3.7. The 2 sites (C & G) where lowest levels of crook root were found (significantly less crook root than all other sites) were sites where zinc was pulsed.

Sites where zinc is applied continuously (A, B, K & L) also had significantly different crook root disease scores (between 1.71 and 3.19). Although the continuous zinc treated sites had significantly more crook root than the best sites where zinc was pulsed, they had significantly less than most sites where no zinc was applied. The site where zinc sulphate pellets were applied by hand (D) was ranked 5th best for crook root, out of the twelve sites sampled. The two sites that had the most crook root were sites where no zinc was applied.

The scatter diagrams showed that there were no clear associations between crook root infection levels and zinc usage, method of zinc application, summer zinc levels, duration of zinc treatment and number of cuts (harvests) across all sites. The principal component analysis showed a relationship between 3 sites (E, F and M) and zinc. These sites had high levels of crook root with no zinc applied.

Comparisons within sites

Comparisons between watercress beds within sites are shown in Appendices 1 – 3. Appendix 1 gives information on water supply, flow rate, growers' perceptions of quantity and source along with bed substrate, the reason the beds were selected and the perceived status of crook root in those beds. Appendix 2 shows the data obtained on zinc at each site and Appendix 3 shows additional information gathered about each site.

Statistical analyses showed that there were no clear associations between crook root infection levels and zinc usage, method of zinc application, summer zinc levels, duration of zinc treatment and number of cuts (harvests) within sites.

Zinc emissions were quite similar for most sites where it was applied and all were within the limits of the discharge consent (<0.075 ppm).

Conclusions

All sites were unique, often utilising quite different growing methods and with different water supply/distribution systems. There were many differences between sites and also between beds at each site. Additionally, information on certain factors e.g. water flow rates were not available for many sites or there were few / small differences between sites e.g. zinc discharge rates. This meant that comparisons between mean crook root levels for each site and other factors was difficult and firm conclusions difficult to make because there were so many variables.

Growers' perceptions of the amount of crook root they had in particular beds were generally quite accurate, but not always so.

The only zinc compound used was zinc sulphate. There were 4 regimes, no zinc applied, zinc solution applied continuously, zinc solution pulsed and zinc pellets applied by hand.

The three sites that had the lowest level of crook root were sites where zinc solutions were pulsed. The two sites that had the most crook root were sites where no zinc was applied. This confirms that applying zinc can give good crook root control. It also demonstrates that pulsing zinc can give at least as good control of crook root as continuous applications do.

There was no clear correlation between the amount of zinc used each season and the amount of crook root found at each site. This suggests that other factors probably cultural practices or the efficacy of zinc applications can have a major effect on the amount of crook root infection in watercress beds.

The variation in crook root levels within different beds at some sites and between sites suggests there is still considerable scope for improving crook root control.

There were no clear associations between crook root infection levels and zinc usage, method of zinc application, summer zinc levels, duration of zinc treatment and number of cuts (harvests) across all sites.

Acknowledgements

We would like to thank Steve Rothwell and Charles Barter for guidelines on which sites to sample and factors to be assessed and Steve for being the Grower co-ordinator. We also thank Mike Payne for the first part of the survey, all the growers who participated in the survey, Rod Bambridge for giving up his time to help with the project and Rodney Edmondson for statistical advice.

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Appendix 1 Water supply to beds, substrates, reasons for selection and crook root information

	Bed no.	Water supply	Flow rate gal/hr/yd width	Water quantity	Water source	Bed substrate	Reason for selection	Crook root status	Crook root disease score [1]
Site A	1		400	Adequate	Spring	Natural	No zinc	Not given	3.3
	2		″	″	Primary	gravel,	Treated with zinc	Low	4.0
	3		″	″	″	Mendip	″	Medium	3.6
	4	Boreholes,	″	″	″	scalpings	″	Med/bad, WYSV at edges	3.4
	5	pumped	″	″	″	and	″	Medium	3.0
	6	and	″	″	″	⅜ gravel	″	Low	2.1
	7	springs	″	″	″	topping	″	Low	1.9
	8		″	″	″	on the	″	Low	1.4
	9		″	″	″	whole	″	Not given	1.5
	10		″	″		site	Not much zinc	Bad	4.1
Site B	1		400	Adequate	Primary	Natural	Most beds had crook root	All beds sampled at this site	3.2
	2		″	″	″	gravel,	″	had crook root - medium	3.0
	3		″	″	″	Mendip	″		2.1
	4	Boreholes,	″	″	″	scalpings	″	WYSV worst here	2.5
	5	pumped	″	″	″	and	″		3.3
	6	and	″	″	″	⅜ gravel	″		2.9
	7	springs	″	″	″	topping	″		4.1
	8		″	″	Secondary	on the	″		4.1
	9		″	″	Primary	whole	″		2.7
	10		″	″	Secondary	site	″		2.6
Site C	1		Not measured	Adequate	Primary	Gravel	Cross section of beds	Low	0.8
	2		″	but	″	″	″	Low	0.8
	3	Artesian,	″	sometimes	″	″	Springs present	Bad	2.2
	4	boreholes,	″	not	″	″	Cross section of beds	Low	1.1
	5	pumped	″	enough	Secondary	″	Springs present	Bad	2.0
	6	and	″	″	″	″	″	Low	2.2
	7	springs	″	″	″	″	″	Low	2.0
	8		″	″	Primary	″	Cross section of beds	Low	1.3
	9		″	″	″	″	″	Low	1.0
	10		″	″	″	″	″	Low	1.9

	Bed no.	Water supply	Flow rate gal/hr/yd width	Water quantity	Water source	Bed substrate	Reason for selection	Crook root status	Crook root disease score [1]
Site D	1		Not given	Not given	Primary	Gravel	Only beds on site in	All beds on site	2.4
	2		″	″	″	″	which watercress	had crook root	1.8
	3		″	″	″	″	was growing		2.2
	4	Artesian	″	″	Primary - well	″			2.8
	5	and	″	″	Primary & Secondary	″			2.1
	6	boreholes	″	″	″	″			3.3
	7		″	″	″	″			3.4
	8		″	″	Primary	″			1.3
	9		″	″	″	″			1.9
	10		″	″	″	″			2.1
Site E	1		400	Adequate	Primary	Gravel	Springs	Not given	5.0
	2		300	″	″	and	Stubble return, machine harv.	″	4.6
	3		300	″	″	chalk cap	″	″	4.3
	4	Boreholes,	300	″	″	over	″	″	4.8
	5	pumped	400	″	″	peat base	Very late stubble, susceptible	″	2.8
	6	and	300	″	″	for the	New seedlings, strong	″	4.9
	7	springs	400	″	″	whole	Stubble return, strong	″	4.6
	8		300	″	″	site	New seedlings	″	4.8
	9		300	″	″		″	″	4.6
	10		300	″	″		Stubble return, weak	″	3.6
Site F	1		400	Adequate	Primary	Natural	Springs	Not given	3.9
	2		300	″	″	with	Seedlings	″	3.9
	3		300	″	″	crushed	Stubble	″	4.0
	4	Boreholes,	200	″	″	10mm	Seedlings	″	2.8
	5	pumped	400	″	″	gravel	Multi-crop stubble	″	3.8
	6	and	400	″	″	on top	High water use seedlings	″	4.8
	7	springs	300	″	″	for the	Machine cut stubble	″	2.6
	8		200	″	″	whole	Replants from old crop	″	4.9
	9		300	″	″	site	Strong seedlings	″	5.0
	10		300	″	″		Short bed good flow	″	4.9

	Bed no.	Water supply	Flow rate gal/hr/yd width	Water quantity	Water source	Bed substrate	Reason for selection	Crook root status	Crook root disease score [1]
Site G	1		¾ million gall/day	Adequate	Primary	Gravel	Near water source	"Normal" for the site	1.3
	2		〃	〃	〃	〃	〃		1.1
	3		〃	〃	〃	〃	〃		1.1
	4		〃	〃	〃	〃	〃		0.8
	5	Artesian	〃	〃	〃	〃	〃		1.7
	6		½ million gall/day	〃	Tertiary	〃	Near discharge		2.2
	7		〃	〃	〃	〃	〃		1.1
	8		〃	〃	〃	〃	〃		1.0
	9		〃	〃	〃	〃	〃		1.0
	10		〃	〃	〃	〃	〃		1.0
Site H	1		Not given	Not enough	Primary	Gravel	Cross section of the site	Not given	2.1
	2		〃	〃	〃	〃		〃	2.4
	3		〃	〃	〃	〃		〃	2.7
	4		〃	〃	〃	〃		〃	4.9
	5	Boreholes	〃	〃	〃	〃		〃	4.5
	6		〃	〃	〃	〃		〃	4.8
	7		〃	〃	〃	〃		〃	4.8
	8		〃	〃	〃	〃		〃	3.8
	9		〃	〃	〃	〃		〃	3.6
	10		〃	〃	〃	〃		〃	3.4
Site J	1		Not given	Adequate	Primary	Gravel	Primary water	"Don't know"	1.3
	2		〃	〃	〃	〃	〃	〃	1.1
	3		〃	〃	〃	〃	〃	〃	1.0
	4	Boreholes	〃	〃	〃	〃	〃	〃	1.0
	5	and	〃	〃	〃	〃	〃	〃	1.1
	6	pumped	〃	〃	Tertiary	〃	Tertiary water	〃	3.0
	7		〃	〃	〃	〃	〃	〃	2.3
	8		〃	〃	〃	〃	〃	〃	2.5
	9		〃	〃	〃	〃	〃	〃	1.4
	10		〃	〃	〃	〃	〃	〃	1.1

	Bed no.	Water supply	Flow rate gal/hr/yd width	Water quantity	Water source	Bed substrate	Reason for selection	Crook root status	Crook root disease score [1]
Site K	1	Artesian, boreholes and springs	Not measured	Adequate but sometimes not enough	Primary	Gravel	Top near water source	No high incidence on the site	1.0
	2		″		″	″	″		3.3
	3		″		″	″	″		1.1
	4		″		Secondary	″	Middle		2.8
	5		″		″	″	″		1.6
	6		″	″	Quaternary	″	″		1.7
	7		″	″	6th bed	″	″		0.9
	8		″	″	3rd bed	″	″		2.2
	9		″	″	Tertiary	″	Furthest from source		1.2
	10		″	″	Prim & Sec	″	″		1.3
Site L	1	Springs	Not measured	Adequate	Primary	Gravel	Cross-section of the site	Crook root always present on the site	3.0
	2		″	″	″	″			3.8
	3		″	″	″	″			3.7
	4		″	″	″	″			2.1
	5		″	″	″	″			2.6
	6		″	″	″	″			2.6
	7		″	″	″	″			3.8
	8		″	″	″	″			3.6
	9		″	″	″	″			3.5
	10		″	″	″	″			3.2
Site M	1	Springs	Not measured	Adequate	Secondary	Gravel with lots of silt on top for the whole site	Only beds on site in which watercress was growing	Crook root always present on the site	3.5
	2		″	″	″				2.9
	3		″	″	″				3.1
	4		″	″	″				2.8
	5		″	″	″				2.2
	6		″	″	Tertiary				2.4
	7		″	″	″				2.4
	8		″	″	″				3.4
	9		″	″	″				3.2
	10		″	″	″				3.7

[1] – Mean crook root disease score, lsd for comparisons between crook root score for individual beds = 0.57

Appendix 2 Zinc information compared with crook root disease score for individual beds at sites

	Bed no.	Crook root disease score [1]	Zinc usage	Type of zinc	Zinc application method	How zinc is dissolved	Target zinc application rate mg/l	Target zinc discharge rate mg/l	Actual zinc discharge rate mg/l	Summer background zinc level mg/l	Period of zinc application
Site A	1	3.3	500kg	Zinc	Continuous	In water	0.075	0.075	0.025	0.005 -	20 Oct
	2	4.0	on	sulphate	in all beds	with a	at bottom	for the	Jan 04	0.0078	to
	3	3.6	4.5 acres	in all		small	of beds	whole	for the	July 03	30 April
	4	3.4	=	beds		amount	for the	site	whole	EA	=
	5	3.0	111kg			of acid	whole		site	for the	192 days
	6	2.1	per			for the	site			whole	for the
	7	1.9	acre			whole				site	whole
	8	1.4				site					site
	9	1.5									
	10	4.1									
Site B	1	3.2	250 - 400kg	Zinc	Continuous	In water	0.075	0.075	0.0287 and	0.005 -	20 Oct
	2	3.0	on	sulphate	in all beds	with a	at bottom	for the	0.0277	0.0072	to
	3	2.1	2.5 acres	in all		small	of beds	whole	for the	June 03	30 April
	4	2.5	=	beds		amount	for the	site	whole	EA	=
	5	3.3	100-160kg			of acid	whole		site	for the	192 days
	6	2.9	per			for the	site			whole	for the
	7	4.1	acre			whole				site	whole
	8	4.1				site					site
	9	2.7									
	10	2.6									
Site C	1	0.8	650kg	Zinc	Pulsed	|In water	0.5 - 1	0.5 - 1	0.01 -	0.005	Sept
	2	0.8	on	sulphate	1hr on	for the	Bottom	Bottom	0.075	July 03	to
	3	2.2	4 acres	in all	2hr off	whole	to top	to top	for the	EA	March/Apr
	4	1.1	=	beds	in all	site	for the	for the	whole	for the	=
	5	2.0	162.5kg		beds		whole	whole	site	whole	181 - 212
	6	2.2	per				site	site		site	days
	7	2.0	acre								for the
	8	1.3									whole
	9	1.0									site
	10	1.9									

	Bed no.	Crook root disease score [1]	Zinc usage	Type of zinc	Zinc application method	How zinc is dissolved	Target zinc application rate mg/l	Target zinc discharge rate mg/l	Actual zinc discharge rate mg/l	Summer background zinc level mg/l	Period of zinc application
Site D	1	2.4	600kg	Zinc	Pellets	N/A [2]	<1.5 tons	Max	0.005	0.0018	November
	2	1.8	on	sulphate	spread		per ha	0.05	for the	May 03	to
	3	2.2	8 acres	in all	on beds			for the	whole	EA	February
	4	2.8	=	beds	by hand			whole	site	for the	=
	5	2.1	75kg		as a spot			site		whole	91 days
	6	3.3	per		treatment					site	for the
	7	3.4	acre		when						whole
	8	1.3			spots						site
	9	1.9			appears						
	10	2.1									
Site E	1	5.0	No zinc	N/A	N/A	N/A	N/A	N/A	N/A	0.005	N/A
	2	4.6	used on							July 03	
	3	4.3	the site							EA	
	4	4.8	since							for the	
	5	2.8	March							whole	
	6	4.9	2002							site	
	7	4.6									
	8	4.8									
	9	4.6									
	10	3.6									
Site F	1	3.9	No zinc	N/A	N/A	N/A	N/A	N/A	N/A	0.005	N/A
	2	3.9	used on							June 03	
	3	4.0	the site							EA	
	4	2.8	since							for the	
	5	3.8	March							whole	
	6	4.8	2002							site	
	7	2.6									
	8	4.9									
	9	5.0									
	10	4.9									

	Bed no.	Crook root disease score [1]	Zinc usage	Type of zinc	Zinc application method	How zinc is dissolved	Target zinc application rate mg/l	Target zinc discharge rate mg/l	Actual zinc discharge rate mg/l	Summer background zinc level mg/l	Period of zinc application
Site G	1	1.3	Average 61kg/acre	Zinc sulphate in all beds	Pulsed one squirt every 90 sec for the whole site	In acid for the whole site	0.1 at source for the whole site	0.075 for the whole site	0.065 Dec 03 for the whole site	0.0104 June 03 EA for the whole site	October to May = 211 days for the whole site
	2	1.1									
	3	1.1									
	4	0.8									
	5	1.7									
	6	2.2									
	7	1.1									
	8	1.0									
	9	1.0									
	10	1.0									
Site H	1	2.1	Average 61kg/acre	Zinc sulphate in all beds	Pulsed one squirt every 90 sec for the whole site	In acid for the whole site	0.1 at source for the whole site	0.075 for the whole site	0.05 - 0.075 for the whole site	0.005 July 03 EA for the whole site	October to May = 211 days for the whole site
	2	2.4									
	3	2.7									
	4	4.9									
	5	4.5									
	6	4.8									
	7	4.8									
	8	3.8									
	9	3.6									
	10	3.4									
Site J	1	1.3	Average 61kg/acre	Zinc sulphate in all beds	Pulsed one squirt every 90 sec for the whole site	In acid for the whole site	0.1 at source for the whole site	0.075 for the whole site	0.05 - 0.075 for the whole site	0.005 July 03 EA for the whole site	October to May = 211 days for the whole site
	2	1.1									
	3	1.0									
	4	1.0									
	5	1.1									
	6	3.0									
	7	2.3									
	8	2.5									
	9	1.4									
	10	1.1									

	Bed no.	Crook root disease score [1]	Zinc usage	Type of zinc	Zinc application method	How zinc is dissolved	Target zinc application rate mg/l	Target zinc discharge rate mg/l	Actual zinc discharge rate mg/l	Summer background zinc level mg/l	Period of zinc application
Site K	1	1.0	75kg on 2 acres = 37.5kg per acre	Zinc sulphate in all beds	Continuous in all beds	In water with a small amount of acid for the whole site	Doesn't have one for the site	Doesn't have one for the site	Site not tested	Site not tested	November to February = 91 days for the whole site
	2	3.3									
	3	1.1									
	4	2.8									
	5	1.6									
	6	1.7									
	7	0.9									
	8	2.2									
	9	1.2									
	10	1.3									
Site L	1	3.0	300kg on 5 acres = 60kg per acre	Zinc sulphate in all beds	Continuous in all beds	In acid for the whole site	Doesn't have one for the site	Doesn't have one for the site	0.008 Jan 04 for the whole site	0.0126 May 03 0.0331 Sep 03 EA for the whole site	September to March = 181 days for the whole site
	2	3.8									
	3	3.7									
	4	2.1									
	5	2.6									
	6	2.6									
	7	3.8									
	8	3.6									
	9	3.5									
	10	3.2									
Site M	1	3.5	No zinc used on the site	N/A [2]	N/A	N/A	N/A	N/A	0.005 Dec 03 for the whole site	0.005 EA for the whole site	N/A
	2	2.9									
	3	3.1									
	4	2.8									
	5	2.2									
	6	2.4									
	7	2.4									
	8	3.4									
	9	3.2									
	10	3.7									

[1] – Mean crook root disease score, lsd for comparisons between crook root score for individual beds = 0.57
[2] – Not applicable, no zinc applied

Appendix 3 Additional information

	Bed no.	Crook root disease score [1]	Sheltering	When crop planted (2003)	No. of cuts since planting	No. of frosts since 01 Jan 2004	Comments
Site A	1	3.3	Wind breaks between each 2 beds	Sept	2	No record	Zinc used as a trace element on the site
	2	4.0	″	August	2	for the	
	3	3.6	″	August	2	site	
	4	3.4	″	May (seed)	2		
	5	3.0	″	May (seed)	1		Cut 3 days ago
	6	2.1	″	May (seed)			
	7	1.9	No wind breaks	August	2		
	8	1.4	″	August	2		
	9	1.5	Wind breaks between each 2 beds	August	2		
	10	4.1	″	Sept	2		
Site B	1	3.2	Plastic windbreak between all beds	Aug/Sept	1	-4 one night	
	2	3.0	on the site	Aug/Sept	1	Quite a	
	3	2.1		Aug/Sept	1	few weeks	
	4	2.5		Aug/Sept	1	of frost	
	5	3.3		Aug/Sept	1	then warm	
	6	2.9		Aug/Sept	1	No written	
	7	4.1		Aug/Sept	1	records	
	8	4.1		Aug/Sept	1	kept for	
	9	2.7	Additional fleecing	Aug/Sept	1	the site	
	10	2.6		Aug/Sept	1		
Site C	1	0.8	Whole site naturally sheltered	August	0	-6, 29 Jan	
	2	0.8	by trees and hedges	August	0		
	3	2.2		August	1		
	4	1.1		Aug/Sept	2		Just harvested
	5	2.0		Not given	2		
	6	2.2		″	3		
	7	2.0		″	3		
	8	1.3		″	1		Ready to Harvest
	9	1.0		″	2		
	10	1.9		″	1		

	Bed no.	Crook root disease score [1]	Sheltering	When crop planted (2003)	No. of cuts since planting	No. of frosts since 01 Jan 2004	Comments
Site D	1	2.4	Site surrounded by some low hedges.	All sampled	All sampled	-4, Jan 2	
	2	1.8	No big trees	beds planted	beds have	-2, Jan 5	
	3	2.2		July or Aug	been cut	-1, Jan 15	
	4	2.8			3 times	-4, Jan 29	
	5	2.1				-5, Feb 9	
	6	3.3				-4, Feb 10	
	7	3.4					
	8	1.3					
	9	1.9					
	10	2.1					
Site E	1	5.0	Trees either side of site.	October			Seedling crop
	2	4.6	Long, narrow area	October	1		Cut late
	3	4.3	"bit of a frost trap"	October	1		Cut late
	4	4.8		October	1		Cut late
	5	2.8		October	1		Cut late
	6	4.9		October			Late planted
	7	4.6		Sept/Oct	1		Very wide bed
	8	4.8		October			
	9	4.6		October			
	10	3.6		Aug/Sept	1		Wildfowl disturbed
Site F	1	3.9	Tall hedge	Oct	1		Stubble
	2	3.9	Tall trees	Nov			New crop
	3	4.0	″	Sept	1		Stubble
	4	2.8	Not really	Nov			Pulled over Jan
	5	3.8	Trees and walls	Sept\Oct			"Stubble, 1of best "
	6	4.8	Open	Oct			Strong bed
	7	2.6	″	Sept	1		Suffers in cold
	8	4.9	″	Dec			Cuttings/old crop
	9	5.0	″	Oct			Strong seedlings
	10	4.9	″	Nov			Stubble

	Bed no.	Crook root disease score [1]	Sheltering	When crop planted (2003)	No. of cuts since planting	No. of frosts since 01 Jan 2004	Comments
Site G	1	1.3	Site sheltered by perimeter hedges.	12.05.03	6	11 frosts	
	2	1.1	No wind breaks	12.05.03	5	since	
	3	1.1		02.07.03	4	01 Jan	
	4	0.8		02.07.03	4	-6, 28 Jan	Stubble
	5	1.7		01.07.03	3	-5, 29 Jan	Stubble
	18	2.2		08.07.03	3	('3 frosts	Stubble
	19	1.1		19.08.03	3	below -2	
	20	1.0		27.06.03	4	then 4th	Stubble
	21	1.0		27.06.03	4	does the	Stubble
	22	1.0		08.07.03	3	damage)	Stubble
Site H	1	2.1	Quite open site.	23.06.03	2 or 3		
	2	2.4	No natural shelter	23.06.03	cuts for		
	3	2.7		23.06.03	all beds		
	4	4.9		24.06.03			
	5	4.5		24.06.03			
	6	4.8		25.06.03			
	7	4.8		25.06.03			
	8	3.8		25.06.03			
	9	3.6		26.06.03			
	10	3.4		25.06.03			
Site J	1	1.3	Around the edges of site only	04.07.03	3		Large plants
	2	1.1		04.07.03	3		
	3	1.0		04.07.03	3		
	4	1.0		07.07.03	3		
	5	1.1		07.07.03	3		
	6	3.0		07.07.03	3		Recently topped
	7	2.3		07.07.03	3		″
	8	2.5		03.07.03	3		″
	9	1.4		03.07.03	3		″
	10	1.1		02.07.03	3		″

	Bed no.	Crook root disease score [1]	Sheltering	When crop planted (2003)	No. of cuts since planting	No. of frosts since 01 Jan 2004	Comments
Site K	1	1.0	Naturally sheltered site.	July	3	-4, 28 Jan	Some cuttings but not many
	2	3.3	Close hedges and odd mature tree	July	3	-3, 29 Jan	New seedlings self seeded
	3	1.1		Aug	3		
	4	2.8		July	3		
	5	1.6		July	3		
	6	1.7		July	3		
	7	0.9		July	2		
	8	2.2		July	4		
	9	1.2		July	4		
	10	1.3		Sept	2		
Site L	1	3.0	Naturally sheltered site in a hollow	31.05.03	4	4 or 5	
	2	3.8	and sheltered by conifer hedges	26.06.03	4	severe	
	3	3.7		13.06.03	3	frosts	
	4	2.1		13.06.03	3	caused	
	5	2.6		07.06.03	5	damage	
	6	2.6		07.06.03	5	to tops	
	7	3.8		03.07.03	2	of plants	Suffer most form crook root
	8	3.6		27.07.03	4		Suffer most form crook root
	9	3.5		11.05.03	3		
	10	3.2		28.06.03	5		
Site M	1	3.5	Naturally sheltered site	08.08.03	2	No record	
	2	2.9		23.08.03	3	for the	
	3	3.1		20.08.03	3	site	
	4	2.8		18.06.03	3		
	5	2.2		15.05.03	2		
	6	2.4		08.08.03	3		
	7	2.4		17.04.03	4		
	8	3.4		10.06.03	3		
	9	3.2		14.01.04	0		
	10	3.7		25.11.03	0		

[1] - Mean crook root disease score, lsd for comparisons between crook root score for individual beds = 0.57