HORTICULTURAL RESEARCH & DEVELOPMENT CORPORATION

The Research Arm of the Australian Horticultural Industries

Integrated management of clubroot crucifers - survey and pilot studies

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Know-how for Horticulture™

VG306

Dr I Porter
Agriculture Victoria

FINAL REPORT

VG306

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Report Contents

Part I

Report on the threat of clubroot to the Manjimup export crucifer industry

Ian Porter

April 1994

Report on a visit to the Manjimup crucifer industry by Dr Ian Porter

Contents

SUMMARY

- Clubroot poses a major threat to the future export of crucifers from the Manjimup/Pemberton district. Fortunately, however, only a small proportion of soils in the area appear to be affected at this stage.

- At present Chinese cabbage is more severely affected than other crops in the region, but the disease can equally well affect all domestic varieties of crucifers.

- Fortunately growers appear to have a reasonable level of awareness of the potential danger clubroot poses to crucifer production in the region.

- Growers, however, should immediately implement hygiene practices which prevent the spread of disease. Some of these factors include;

  (i) Controlling small outbreaks of disease immediately they occur by destroying (burning) all infected plants and fumigating the infested site and surrounding soil.

  (ii) Ensuring that transplants are free from disease.; ie. using only soilless potting mixes and sourcing seedlings from reputable nurseries.

  (iii) Making sure that seedling transplants grown on growers' properties in uninfested soil eg. quarantined sites free from domestic crops.

  (iv) Using clean bulk bins and nominating bins to specific growers.

- Discussions with the Cauliflower Export Group and the Department of Agriculture established that research is required to establish methods which control the disease on all crucifer crops grown in the district; prevent the spread of disease and minimise economic loss to disease if it occurs.

  Because research in Victoria is addressing these issues in an established research project, it was proposed that a joint project be undertaken between the Western Australian and Victorian Departments of Agriculture. The project will be supported by voluntary industry funds (Export cauliflower group, W.A., ICI, VegCo (Cooperative of East Gippsland growers in Victoria) and Victorian growers).

PURPOSE OF THE VISIT

A visit was made to the Manjimup crucifer growing region to determine the extent of the existing clubroot problem, the possibility of implementing short term strategies for reducing the spread of disease and the need for future research.

ITINERARY

Wednesday, 23 March		Meeting with the Directorate, Department of Agriculture, Perth
		Travel to Manjimup and discussions with Department staff
Thursday, 24 March		
	8.30	Meeting with crucifer growers most affected by clubroot. Development of short term strategies for disease control.
	10.30 am	Inspections of affected properties
	4.00 pm	Seminar/information session presented by Dr I. Porter to approximately 70 grower industry representatives and Departmental staff. (Video being prepared)
	7-9.00 pm	Planning meeting to determine research priorities for export cauliflowers.
Friday 25th, March		
	8.15	Interview for local Manjimup newspaper
	8.30 pm	Meeting at the Manjimup Horticultural Research Centre to develop a cooperative research program between the Western Australian and Victoria Departments of Agriculture and the Cauliflower Export Growers.
	3.00 pm	Seminar presented to staff of the Department of Agriculture, Perth
	6.00 pm	Perth to Melbourne
Tuesday, 29th March		Interview for ABC Radio for SW region program

MAJOR OUTCOMES OF THE VISIT

- Clubroot has caused limited loss to the total area (but substantial losses to individual growers eg. one growers estimates $200,000/yr). The disease is spreading rapidly and if unchecked could severely threaten the viability of exporting crucifers from the Manjimup region.

- Growers require management strategies to;

    i) prevent the spread of disease into uninfested properties,

    ii) provide clean up of small spot infections,

    iii) provide long term sustainable control measures for soils that are presently heavily infested.

  The first two issues can be addressed immediately, but the third requires urgent research into appropriate methods of control.

- In the interim, the crucifer industry in Manjimup should implement strict hygiene practices to prevent the spread of clubroot. This includes; i) restricting the movement of bulk bins from property to property. Several packing sheds have already allocated growers their own bins. Care, however must be taken at central packing sheds to make sure that bulk bins are not contaminated with infested soil brought in from another property that has the disease.

- A high priority for future research is to develop a method which guarantees that bulb bins can be sterilised routinely to prevent spread of disease.

- It was also decided that Dr I. Porter would develop a preliminary proposal for conducting a nationally coordinated approach to controlling clubroot. The Western Australian Industry would utilise results from existing research in Victoria together with results from on site field trials conducted by Angie Galati and backup support from Mr Robert Floyd, Extension horticulturalist, Department of Agriculture, Perth.

CLUBROOT IN MANJIMUP

Evidence suggests that clubroot has been in the Manjimup/Pemberton district for about 4 years and has to date only been detected on a small number of properties. The origin of infection is unknown, but is likely to have been imported into the area on either infested transplants or soil from another infested area, eg. soil on bulk bins or equipment coming from the Perth metropolitan region. Growers considered seed may have been a source of infection and this needs to be verified. Seed is not normally a carrier of the clubroot fungus.

If unchecked and because of the rapid spread of this organism, the disease has potential to completely devastate crucifer growing in the district.

PRESENT CONTROL OF CLUBROOT IN W.A.

Discussions with Departmental staff suggest that metham sodium is fairly successful at controlling clubroot in the Perth Metropolitan area. The success in Perth compared to other regions may be due to the sandy soils which are prevalent throughout this area. Metham sodium applied to heavier soils in Victoria has been less effective. Attempts to use metham in Manjimup have also been unreliable and further research is required improving application methods for this product.

Please note: Chemigation of metham (through irrigation lines) is widely practiced in Western Australia. This practice has been banned in Victoria due to the environmental hazards associated with spray drift. It is worth checking the current registration status of this product. Chemigation appeared to be giving unreliable results on soils in the Manjimup region.

WHAT CAN GROWERS DO IMMEDIATELY?

The Manjimup growers have a major opportunity to prevent the spread and impact of clubroot. Several factors can immediately be implemented to reduce the rate of further build up of disease.

1. Always obtain clean seedlings, ie. grown in soilless mixes under strict hygiene conditions or produced in soil **known** to be free of clubroot. Individual growers who have seen no sign of disease on their property can still produce their own seedlings in seedbeds but there is a risk that if these seedbeds become infested that they can rapidly infest their paddocks.

Nurserymen who grow transplants should be aware of the areas where clubroot may cause problems in the production of transplants and modify existing hygiene if necessary. ie. Soilless mixes should not be dumped outdoors exposed to high level of dust from infested paddocks. Machinery loaned to growers to plant seedlings should be thoroughly cleaned down after each use (on the growers property) and preferably not used by growers having the disease. The machine should not be washed down and stored anywhere near transplant growing areas.

At present it was agreed that a 2% solution of sodium hypochlorite may be effective for washing machinery , but more research is required to determine that it is totally effective.

2. Clean up spot infections as soon as they occur. Small patches on growers properties may be able to be cleaned up by carefully pulling out infected plants and soil adhering to roots, and burning thoroughly in an isolated area away from any dams or natural runoff areas. Healthy plants from around affected areas should be cleaned out for at least 3 m from the edge of an infected zone and burnt likewise. The infested soil should then be treated with either methyl bromide at 750 L/ha or Basamid (dazomet) at the same rate. Both of these must be covered with plastic tarps. Methyl bromide should be applied under tarps. Any equipment used in the infected area should not proceed out of that area until it has been thoroughly sterilised. The infested area should then be quarantined indefinitely, ie. fenced off and grassed.

Note: Any soil in the infested area could be carrying the disease and any small quantity dropped into another area could infect that area. Care must be taken to completely prevent soil from leaving the affected area!!

Clubroot can be easily carried on soil and in water. It is only likely to be spread through the air in large particles of dust, however, no one has tested how far it can travel.

FUTURE RESEARCH

Issues that need to be addressed in future research are:

i) A survey of the West Australian Industry to determine areas infected.

ii) Typing of the isolates in Western Australia to identify likelihood of new resistant varieties being suitable for use in the Western Australia. (Already under way in Victoria). Typing may also help identify the source of infection.

iii) Development of methods which sterilise equipment or bulk bins that may carry the disease causing organism.

iv) Testing the effectiveness of spot treatments for completely eradicating the disease.

Continuation of trials in Victoria to identify appropriate treatments for the W.A. industry. These trials have for the first time in Australia shown treatments which offer growers potential for disease control besides the use of soil fumigation.

Specifically treatments and methods of applying treatments are needed for;

(i) direct seeded crops, particularly Chinese Cabbage,
(ii) transplanted crops, particularly cauliflower.

Time frame for preparing a research proposal:

23 April, 1994	- Preparation of the preliminary proposal.
7 May, 1994	- Review and comments by the Cauliflower Export Growers Group and Department of Agriculture, Western Australia.
7 June, 1994	- Submission of the final proposal to HRDC
30 July, 1994	- Approval from HRDC for project to commence.
Sep., 1994 - July, 1997	- Project to develop long term options for disease control in Victorian and West Australian Crucifer Industries.

(The submission of the final proposal is dependent on obtaining the necessary funds from the Victorian and Western Australian Crucifer Industries, ICI Chemicals. A commitment has already been made by the latter two groups.)

FUTURE FUNDING AND DEVELOPMENT OF A COOPERATIVE PROJECT.

Control of clubroot is seen as vital to the survival of the crucifer export industry and research was given high priority by growers. The cauliflower export growers agreed that it was important to fund a large coordinated project which makes use of existing technology and resources already available in Victoria. For this reason it is anticipated that the future project will be partly funded by the Cauliflower Trust Fund (W.A.), ICI (Victoria and W.A.) and the Victorian Crucifer Industry (Vegco, VGA and growers).

Considerable support is available in the Western Australian and Victorian Department of Agriculture including staff and facilities at Perth, Manjimup and at the Institute for Horticultural Development at Knoxfield in Victoria.

Estimated staff involvements:

Western Australia

Ms Angie Galati	40%
Mr Rob Floyd	25%
Mr Dennis Phillips	5%

Victoria

Ms Sue Cross	100%
Dr I. Porter	30%

THE NEED FOR FURTHER RESEARCH

It is anticipated that treatments which have shown success in trials in Victoria will be trialled on infested sites at growers properties in Manjimup. Research in Victoria will be aimed at finding effective treatments for both direct seeded and transplanted crops, and will rely on modifying treatments which have recently been extremely successful. Most Victorian results should be immediately applicable to the Manjimup area or require minor refinements in trials under local conditions.

Trials in Victoria have provided preliminary data that fluazinam and Terraclor provide excellent control of clubroot and metham sodium and lime moderate control.
Fluazinam is a new fungicide being registered by ICI mid 1995, however, the registration will only apply to a transplant drench that occasionally is proving phytotoxic to certain crucifer crops and under certain environmental conditions. The registration will only cover application of this product as a high volume drench (200 ml per plant), which may not be suitable for most crucifer growers growing broad acres of crucifers. The existing registration will not be suitable for direct seeded crops and further research is required.

Terraclor is registered as a soil treatment but results have been too unreliable. Better results are being obtained when it is applied as a root dip at transplanting or as a soil drench over the transplants at the time of transplanting. New methods of applying Terraclor are required.

Clubroot control using metham sodium in Victoria has been very variable and recent efforts to use the product in Manjimup similarly disappointing. Application methods to maximise the effect of metham sodium are urgently required, especially as national regulations ban the use of this product for chemigation.

Trials need to be conducted in Manjimup soils to confirm that similar affects are occurring under the different climatic conditions and soil types to Victoria.

Several other treatments need to be assessed in Manjimup soils; eg. different types of lime, nitrophoska fertilizers, organic matter, etc. Most of these latter treatments are being evaluated in Victoria trials.

Part II

Integrated managment of clubroot for crucifers: survey and pilot studies

I Porter, S Cross, N Asirifi and W Morgan

June 1994

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1 Industry and Technical Summary

Surveys during this 12 month study established the need for further research on clubroot in Australia. The economic loss in production in Victoria is estimated at well over $1 million and the disease is threatening the survival of a $12 million crucifer export industry in Western Australia. Nearly all growers surveyed were supportive of Agriculture, Victoria conducting a major 3 year research project on clubroot. Voluntary funds have now been obtained from both the Victorian and Western Australian Industries, to conduct a major 3 year research project on control and prevention of spread of clubroot.

In the current study the surveys, together with the pilot studies, identified over 80% of Victorian properties were affected by clubroot with average crop losses between 2 and 4 acres per property. Only 26% of growers were achieving 'adequate' control of clubroot and none of the existing control practices (lime, metham sodium and Terraclor) was considered totally effective. The annual cost of clubroot control was estimated to be in excess of AU$500/ha by 28% of growers on clubroot affected properties.

In a field trial on a naturally infested site, several organic (chicken manure, stable manure, rice hulls and lucerne hay) and chemical treatments were evaluated for control of clubroot in broccoli. The fungicides Terraclor (PCNB) and Shirlan (fluazinam - registration pending) significantly reduced the severity of infection, and dramatically increased marketable yield from 0.3 t/ha to 4.2 and 6.2 t/ha, respectively. Organic treatments were ineffective in reducing disease severity, and had no effect on yield (0.04-0.6 t/ha). Lime and metham sodium treatments improved marketable yield (1.8 and 2.5 t/ha, respectively) but there was no significant reduction in disease severity.

The organic soil amendments applied in field trials increased the population densities of bacteria and fungi 10-fold, and actinomycetes 3-fold, compared to the untreated and chemically treated plots. The increase in microbial populations gave no short term advantage in control of clubroot and stressed the need for longer term studies to more accurately assess the biological effect.

A report from the Clubroot Workshop at the 6th International Plant Pathology Conference in Montreal, 1993 was circulated to all members of the International Clubroot Working Group. New methods presented on control chemicals (e.g. surfactants) and soil identification of clubroot (e.g. Elisa) are being incorporated into our future research project. The workshop convenor, Professor Geoff Dixon from Scotland, presented results from our research at a major clubroot meeting in Portugal in November, 1994.

Variation in *Plasmodiophora brassicae* populations throughout the brassica growing regions in Australia formed part of this study and will be further studied in the major project. Preliminary screenings indicate that the South East Australian isolates are genetically similar, although further typing and molecular studies are planned. This information will be essential to the adoption of varieties with resistance to clubroot into Australia.

2 Introduction

Clubroot is the most important soil borne disease of cruciferous vegetables in Australia. The disease is caused by the soil borne fungus *Plasmodiophora brassicae* which infects the root system of susceptible plants, causing the roots to swell. Infection reduces yield, as the efficiency of the swollen roots for water uptake and transportation is diminished (Kunkel , 1918; Larson, 1934), and the proliferating fungus diverts nutrients away from the plant. The disease is most severe in warm, moist and acidic soils (Monteith, 1924), because these conditions favour germination of the pathogen's resting spores. However, where spore density is high, the disease will often develop under unfavourable soil conditions (Colhoun, 1953). The fungus is obligate, and multiplies prolifically inside host tissue, but lays dormant in the soil when no host is available (Colhoun, 1958). The dormant resting spores are able to survive for long periods even under adverse conditions, and therefore eradication of the fungus from infested soils is extremely difficult to achieve.

The disease, clubroot has been present in Australia since at least 1890 (McAlpine, 1901). Clubroot control has traditionally been achieved by minimising the build up of the pathogen (long crop rotations), and by preventing the spores present from infecting the roots (liming and fungicide treatments). The current global resurgence of the disease can be largely attributed to the proliferation of the pathogen under more intensive crucifer production. These conditions favour the rapid increase in soil populations of *P. brassicae* and thus control methods tend to be less effective.

2.1 Project Objectives

Funds were made available through the Horticultural Research and Development Corporation (HRDC) to support a twelve month research project on clubroot. The major aim of this work was to evaluate the effectiveness of existing and potential new control measures for clubroot, and to demonstrate to the vegetable industry the need for future research on prevention of spread and control of the disease.

The following specific objectives were outlined at the onset of the project;

i) to survey all Victorian crucifer growers to obtain information about the effectiveness of their present methods for controlling clubroot,

ii) to conduct pilot studies on the environmental impact of some of the existing control methods and to determine which treatments are most beneficial to the soil ecosystem,

iii) to coordinate the crucifer growers and determine their level of support for future research on clubroot and other crucifer diseases,

iv) to attend the International Clubroot Working Group meeting held in conjunction with the International Plant Pathology Congress in Montreal, 1993.

Two additional objectives were incorporated during the course of the project;

v) to conduct a field trial evaluating existing practices and new products for the control of clubroot,

vi) to identify *P. brassicae* ("clubroot") pathotypes present in Australia using the European Clubroot Differential set (ECD).

3 Materials and Methods

3.1 Grower Survey

A survey consisting of 29 questions was developed at the Institute for Horticultural Development, and sent out to growers via the Vegetable Growers Association Newsletter in August 1993. Further surveys were distributed to growers attending information evenings conducted by Dr Ian Porter and Dr Wendy Morgan in Cranbourne, Werribee and Bairnsdale during 1993. Responses were summarised by the scientist appointed to the project (Ms. Sue Cross) for the sixty five completed questionnaires returned to IHD by November, 1993.

3.2 Evaluation of Clubroot Control Methods

A field trial was designed to evaluate existing and several new clubroot control methods with potential for use in cruciferous vegetable crops. The treatments evaluated were selected from those reported by growers to have some effectiveness against clubroot in the survey questionnaire (Table 1), and included soil fumigants, organic amendments, lime and a single registered fungicide. In addition a promising new fungicide, Shirlan (50% fluazinam, ICI) was included for evaluation.

A randomised trial with six replicates of eleven treatments was established on a commercial property in a market garden region, at Werribee, south west of Melbourne. The selected site had a long history of broccoli production and was frequently affected by clubroot. The site was prepared by the grower as for normal commercial production, with raised beds ("lands") formed two weeks prior to transplanting.

Treatments were applied to preformed beds as detailed in Table 1. Beds were reformed after treatment applications where necessary. Irrigation and general maintenance of the site was conducted by the grower.

Destructive sampling of plants was carried out at 14 day intervals, commencing four weeks after transplanting. The individual fresh weight and clubroot severity of the sampled plants was recorded. Clubroot severity was recorded on scale of 0-3 corresponding with 0%, $<10\%$, 10-50% and $>50\%$ of the root system showing visual symptoms of clubbing.

Mature plants were harvested from the central 5 m of each plot. Three separate cuts were taken over an eight day period. Heads were trimmed and average marketable head weight was recorded in field.

Soil samples were also collected from all plots at 14 day intervals during the trial period, commencing four weeks after transplanting. Ten soil cores (0-10cm depth) were taken at random positions within each plot, and pooled to provide a single composite soil sample for each plot at each collection. The composite samples were thoroughly mixed and subsamples were oven dried (48 hours at 40°C) before forwarding to the State Chemistry Laboratory for pH (water and 0.01M $CaCl_2$) analyses.

Table 1 Application details of treatments evaluated for clubroot control, Werribee 1993

Treatment	Product Application Rate (per ha)	Application Timing[1]	Application Details
A Untreated	-	-	-
B Chicken manure	30.7 t	9 DBT	Surface broadcast & incorporated
C Stable manure	30.7 t	9 DBT	Surface broadcast & incorporated
D Lucerne hay	12.3 t	9 DBT	Surface broadcast & incorporated
E Rice Hulls	12.3 t	9 DBT	Surface broadcast & incorporated
F Lime (GBA)	2.0 t	9 DBT	Surface broadcast & incorporated
G Nitrophoska (12:5:14) & $CaNO_3$	370 kg 120 kg	0 DBT 3 WAT	Banded on soil surface in two rows alongside transplants
H Terraclor (75% PCNB)	20 kg	0 DBT	seedling dip (5 ml @ 0.5% ai) & plant drench (30ml @ 0.75%ai)
I Shirlan (50% Fluazinam)	3 L	0 DBT	plant drench (200 ml/plant @ 0.0125 % ai solution)
J Metham (42.3% M sodium)	500 L	9 DBT	Sprayed at depth (blade mounted) across width of lands & rolled
K Basamid (98% Dazomet)	200 kg	9 DBT	Banded in two 5 cm deep trenches and back filled

[1] DBT = days before transplanting; WAT = weeks after transplanting; 0 DBT = at transplanting

3.3 Soil Ecosystem Studies

Studies were undertaken to investigate the influence of soil fumigation, fungicides and soil organic amendments on the number of saprophytic microorganisms in soils naturally infested with *P. brassicae*. Soil samples were collected from the triai site as detailed in 2.2. A 10g subsample of soil from each plot was dried, and the soil moisture content was calculated. A second 10g subsample of soil was homogenised with 90 ml of sterile distilled water in a mechanical blender for 2 minutes. Soil suspensions were then serially diluted in 0.075% sterile water agar. 0.1 ml samples of suspension were spread onto selective media plates which were then incubated at 25°C, to allow development of the microbial colonies. Three types of selective media were used: Difco tryptic soy agar (TSA); starch casein agar (CSA) and rose bengal agar (RBA) supplemented with 10 μg/ml chloramphenicol and 75 μg/ml streptomycin, to select bacteria, actinomycetes and fungi, respectively. Colonies were counted on TSA and RBA plates on days 3 and 4 after incubation, and on CSA plates on day seven after incubation. Populations were expressed as colony forming units (cfu) per gram dry soil.

3.4 Pathotype Identification Studies

Studies were undertaken to identify the pathotypes or races of *P. brassicae* populations collected from different crucifer growing regions within Australia, and from different host crops. Races were identified on the basis of the disease development reaction of 15 differential hosts (European Clubroot Differential set) (Table 2) to each collection of *P. brassicae*. Fifteen seedlings of each host were raised in individual pots for approximately 2 weeks prior to inoculation. Inoculum was prepared by homogenising the root galls from infected plants in distilled water in a mechanical blender. The suspension was filtered through muslin cloth and the spore concentration in the filtrate was adjusted to approximately 10^8 spores/ml. Each seedling was inoculated with 2ml of spore suspension, pipetted into the soil, close to the stem. Following inoculation, plants were maintained in a glasshouse at 15-30°C for a further six weeks and then the roots of each plant were rated for clubroot severity on a scale of 0-3 as described in 3.2.

Table 2 European Clubroot Differential Set (ECD) host details

Differential Number	Host Name	Binary Value	Denary Value
	20 Chromosome Group *(Brassica campestris)* :		
01	ssp. *rapifera* line aaBBCC	2^0	1
02	ssp. *rapifera* line AAbbCC	2^1	2
03	ssp. *rapifera* line AABBcc	2^2	4
04	ssp. *rapifera* line AABBCC	2^3	8
05	ssp. *pekinensis* cv. Granaat	2^4	16
	38 Chromosome Group *(Brassica napus)* :		
06	var. *napus* line Dc101	2^0	1
07	var. *napus* line Dc119	2^1	2
08	var. *napus* line Dc128	2^2	4
09	var. *napus* line Dc129	2^3	8
10	var. *napus* line Dc130	2^4	16
	18 Chromosome Group *(Brassica oleracea)* :		
11	var. *capitata* cv. Badger Shipper	2^0	1
12	var. *capitata* cv. Bindsachsener	2^1	2
13	var. *capitata* cv. Jersey Queen	2^2	4
14	var. *capitata* cv. Septa	2^3	8
15	var. *fimbriata* cv. Verheul	2^4	16

The disease index for each host was calculated as follows:

$$\text{Disease Index} = \frac{[(N_0 \times 0) + (N_1 \times 1) + (N_2 \times 2) + (N_3 \times 3)]}{(N_0 + N_1 + N_2 + N_3)} \times \frac{100}{3}$$

where N_0 is the number of plants rating 0, N_1 is the number of plants rating 1 etc.

Hosts achieving a disease index of zero were termed resistant, those achieving a disease index of > 33 were termed susceptible and hosts with a disease index of greater than zero but less than 33 were termed uncertain after Dobson et al 1983

For example, if differential host number 5 produced five plants with moderate galling (5 x "2") and ten plants with severe galling (10 x "3") from fifteen inoculated plants, the following disease index would result:

$$DI=\frac{(0\times0)+(0\times1)+(5\times2)+(10\times3)}{15}\times\frac{100}{3}$$

$$\frac{10+30}{15}\times33.3=88.8$$

For the same *P. brassicae* collection, if susceptible reactions (DI > 33) were also achieved for hosts 6, 7, 8, 13, 14, and 15, and resistant reactions (DI = 0) were achieved for hosts 1, 2, 3, 4, 9, 10, 11, and 12, the population number 16/7/28 would be assigned to the collection by summing the denary values associated with each susceptible host within the three species groups (Table 2).

4 Results

4.1 Survey Results

A copy of the detailed survey responses is included in Appendix I. It should be noted that data are expressed as provided by survey respondents, on a per acre basis.

4.1.1 Demographics

Sixty four completed questionnaires were returned to the Institute for Horticultural Development. Fifty seven respondents (89%) had grown crucifers in the three years since January 1990.

The majority of crucifer growing respondents came from the Bairnsdale (31%) and Werribee (28 %) with the remaining 41% of growers coming from Maffra, Cranbourne, Orbost, Boneo, Dandenong, Cheltenham, Warragul, Daylesford and Kerang.

4.1.2 Crucifer production in Victoria

Only forty eight growers provided details of the total land area to be cropped with crucifers in 1993. However from the details supplied, it is estimated that a total of approximately 35% of the Victoria's total crucifer growing area (12500 acres; Australian Bureau of Statistics 1992/93 Agricultural Census) was represented by the respondents.

Broccoli was produced on sixty one percent of the crucifer-growing land represented in the survey, while cauliflower and cabbage were each grown on 19%. Chinese cabbage, Brussels sprouts, red cabbage and mustard were grown on the remaining one percent of crucifer-growing land.

The majority of growers (69%) included at least one non-cruciferous crop in their production cycles, although 14% grew continuous crucifers.

Almost half the crucifer growers (42%) produced either some or all of their own crucifer seedlings. Although the majority of these growers used soilless mixes or fumigated soil for seedling production, twenty one percent used non-fumigated soil.

Most crucifer growers (88%) applied lime, with Ground Burnt Agricultural Lime (hot lime) the most common (62%) lime form applied.

Thirty nine percent of crucifer growers applied organic material to their soils, with poultry manure the most common form (71%). Other organic material used included rice hulls, Dynamic Lifter and cereal stubble.

4.1.3 Clubroot history

Seventy one percent of all crucifer growers had been affected by clubroot on their property at some stage. Clubroot had affected a greater proportion of broccoli and cauliflower growing properties than cabbage growing properties (Figure 1). Only one grower had ceased growing crucifers because of the disease. Of the crucifer growing properties with a history of clubroot, 93% were affected by the disease between June 1992 and May 1993 and 74% were affected by the disease every year. Clubroot was observed throughout the year, but was most frequently reported between November and May (Figure 2)

Crop failure due to clubroot between June 1992 and May 1993 averaged between two and four acres per property for each of the three main crucifer crops, although individual crop losses of up to twenty acres were recorded.

Total lost yield was extrapolated from the average crop losses (acres) indicated in the survey and the State average production figures (t/ha) (Australian Bureau of Statistics Agricultural Census 1992-1993). The extrapolated lost marketable yield of broccoli, cauliflower and cabbage for survey respondants alone (i.e. approximately 35% of crucifer production area) was 200t, 270t and 450t, respectively, and with average estimated returns of $1, $0.5 and $0.3/kg for the three crops, lost revenue for the survey respondents was calculated at $470,000. These losses were based on complete crop failure due to clubroot, and do not consider reduced yields under less severe infection conditions.

Figure 1 Incidence of clubroot on properties surveyed

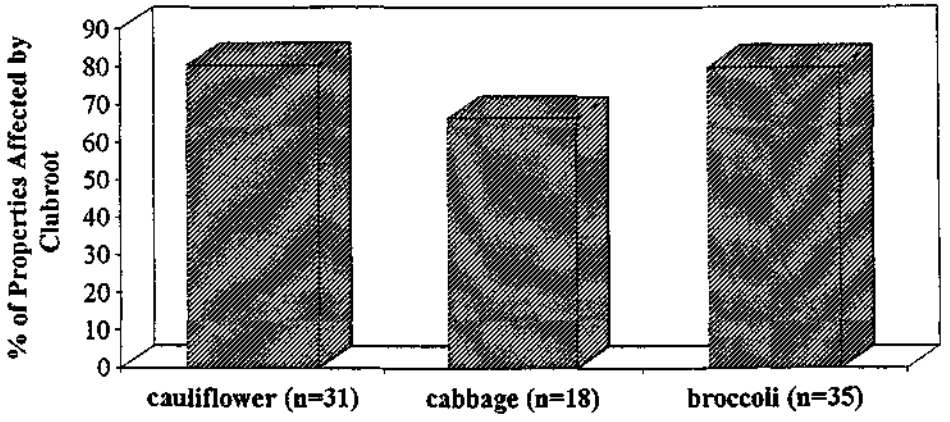
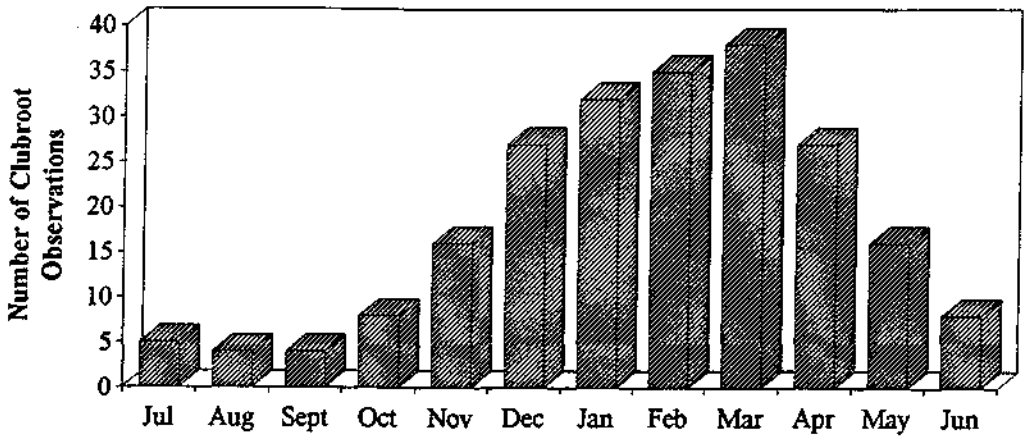


Figure 2 Annual distribution of clubroot observations on clubroot affected properties



4.1.4 Current control methods

Only 27% of crucifer growers felt they had an effective method for controlling clubroot. The most widely used control method was lime, followed by crop rotation, fumigation, fresh soil and fungicide application (Figure 3). Individual growers also cited bed height, organic matter, graded land and hygiene as methods for controlling clubroot. Metham sodium was the only fumigant used for clubroot control, at application rates of between 200 and 300 l/ac. Metham sodium was applied primarily by soil injection, although overhead sprinklers and rotary hoes were also used. Sixty percent of those applying fungicides for clubroot control used Terraclor (75% PCNB), 10% used Stand (nitrogen 19.5%; calcium 10.4%) and 30% used a combination of both products. The majority of growers cultivated treated land before sowing the next crucifer crop.

Respondents reported most methods gave only moderate control of clubroot (Figure 4), and failure of control methods was primarily (49%) associated with the weather.

The annual cost of clubroot control for crucifer growers ranged between zero and one thousand dollars per acre. Most growers estimated that their annual expenditure on clubroot control was between one hundred and five hundred dollars per acre (Figure 5).

Figure 3 Current clubroot control methods used by survey respondents

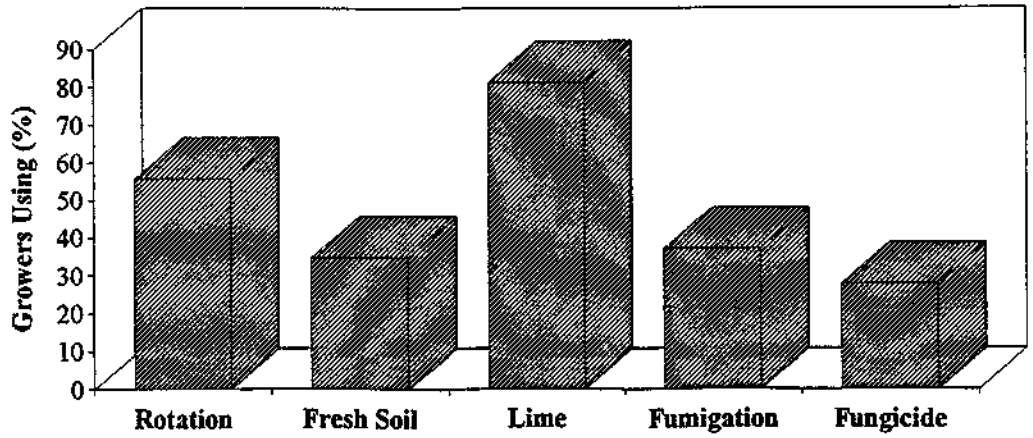


Figure 4 Grower satisfaction with current clubroot control methods used

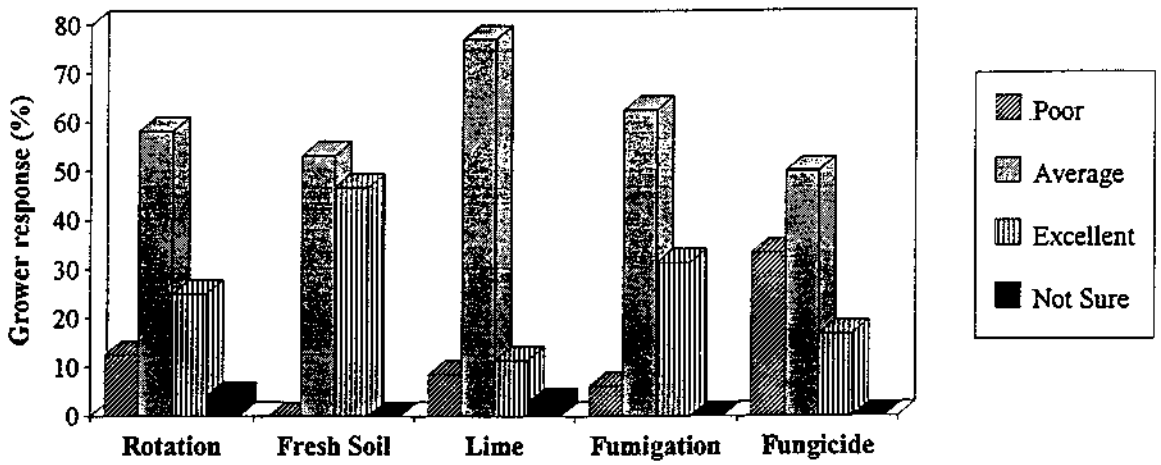
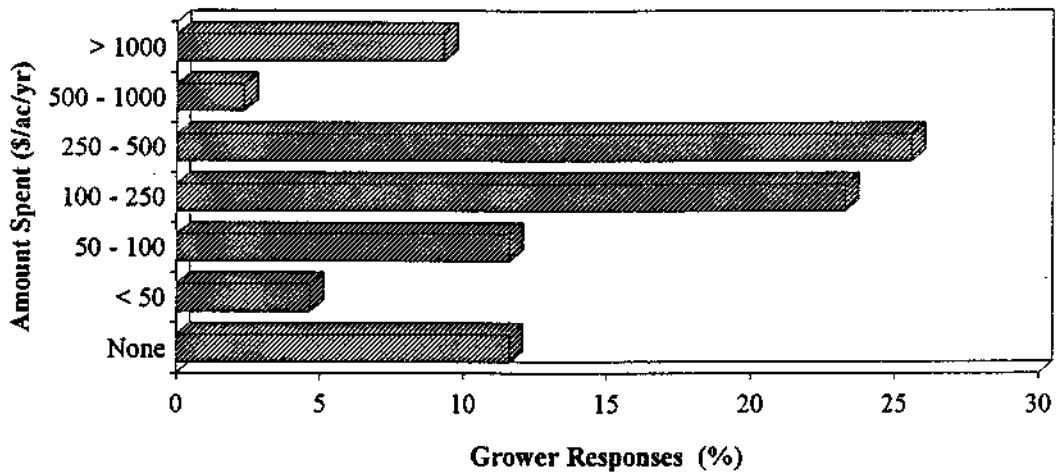


Figure 5 Annual individual expenditure on clubroot control

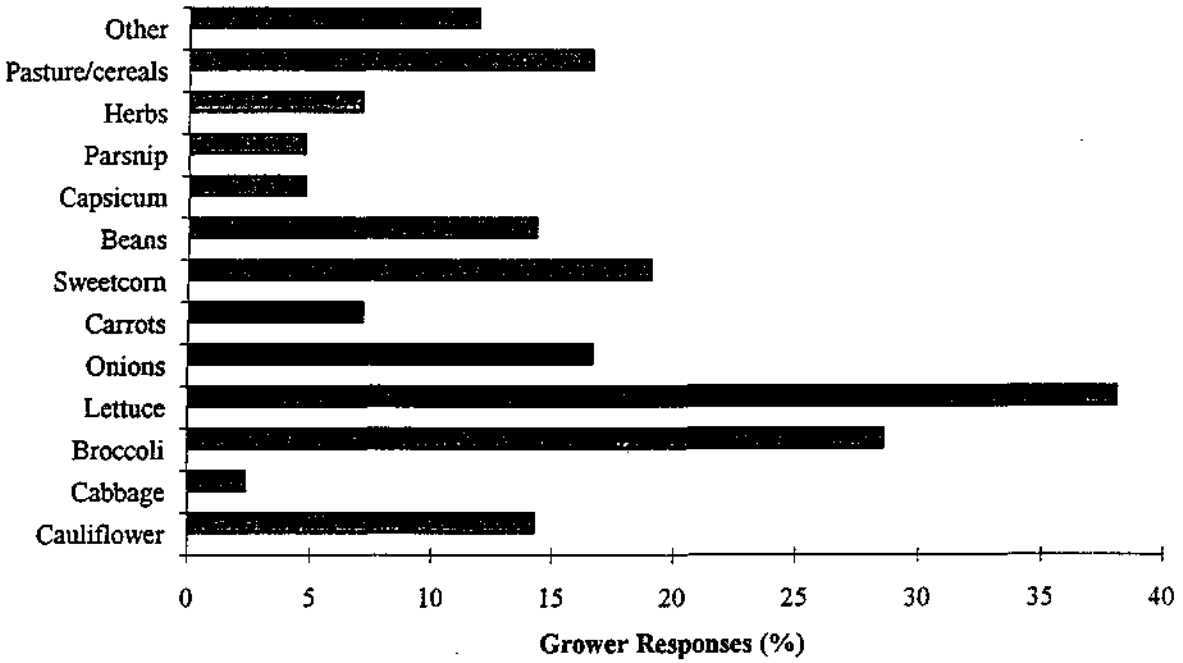


4.1.5 Post-harvest procedures following a clubroot infection

Cruciferous crops accounted for 24% of the follow-on crop species planted in areas from which a clubroot infected crop was harvested (Figure 6). Most growers (84%) who replanted affected areas with cruciferous crops did so within six weeks of harvesting the infected crop. Approximately half the growers (56%) re-planted affected areas with the same variety as was originally infected within six months of harvesting an infected crop.

The most common practices after harvesting a clubroot infected crop were to cultivate (57%) and/or deep rip (50%) and/or lime (36%) the affected area. Approximately one third of growers indicated that they would leave the area fallow for a few months before cultivation, but less than 10% would leave the area fallow for more than six months.

Figure 6 Popular follow on crops after harvesting a clubroot infected cruciferous crop



4.1.6 Other Pest and Disease Problems

Growers rated ringspot and downy mildew as the most important diseases affecting crucifers, other than clubroot (Figure 7). The least important of the diseases listed was anthracnose. Cabbage white butterfly was rated as the most important insect pest of crucifers (Figure 8).

Figure 7 Relative importance of other diseases affecting crucifer crops

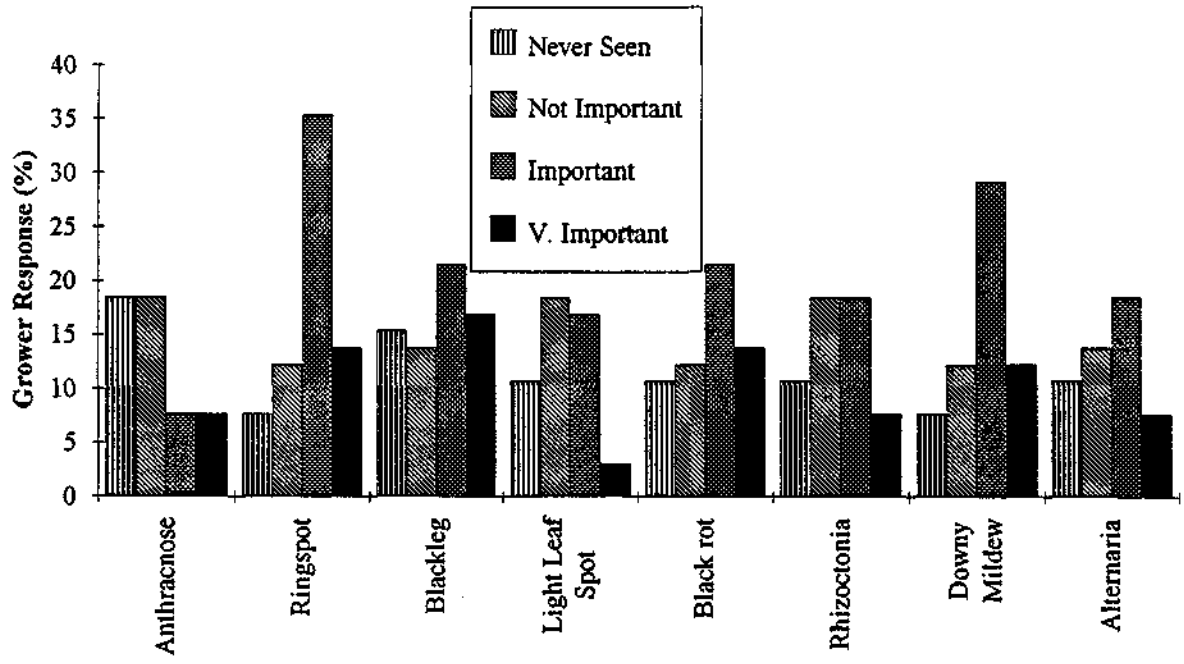
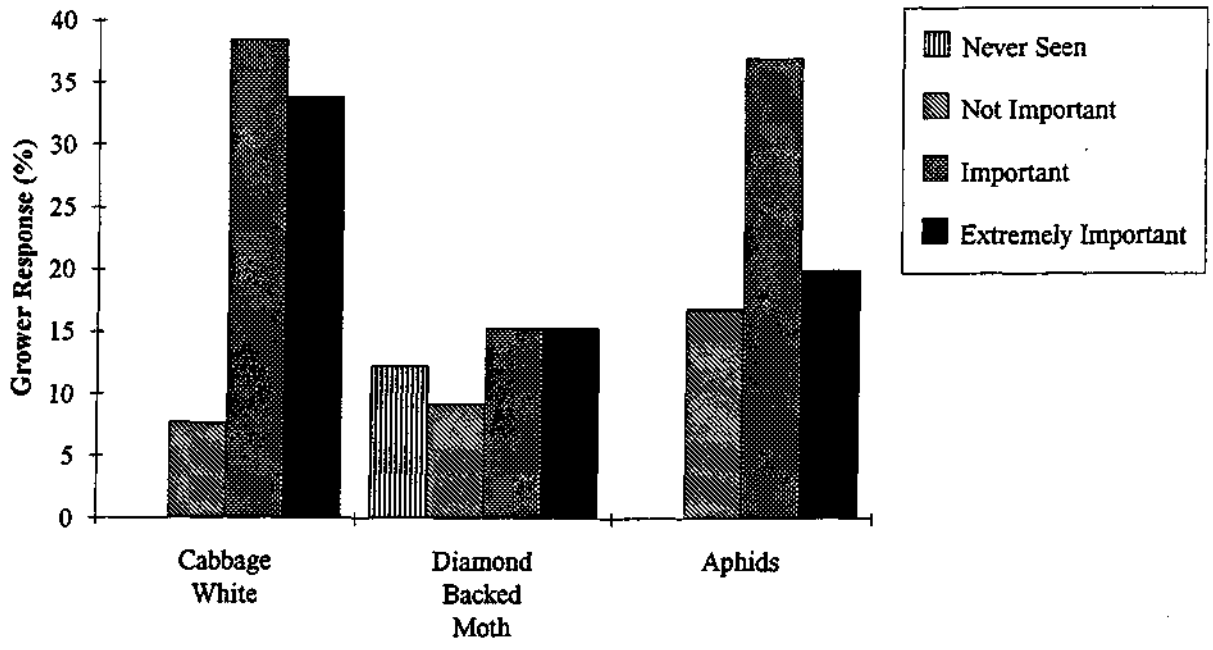


Figure 8 Relative importance of pests affecting crucifer crops



4.1.7 Grower Interest in Research and IPM Development

Most respondents (86%) were supportive of the Department of Agriculture conducting research on clubroot. Thirty eight percent of those interested in research were prepared to provide land for trials and twenty eight percent were prepared to contribute financially. A large proportion of growers were unsure about committing resources to research.

Less than 20% of all respondents indicated that they had heard of IPM. Only 12% of respondents were able to fully explain the term IPM, while a further 11% stated only that IPM meant Integrated Pest Management. However, 63% of growers were interested in developing an integrated pest management program for crucifers.

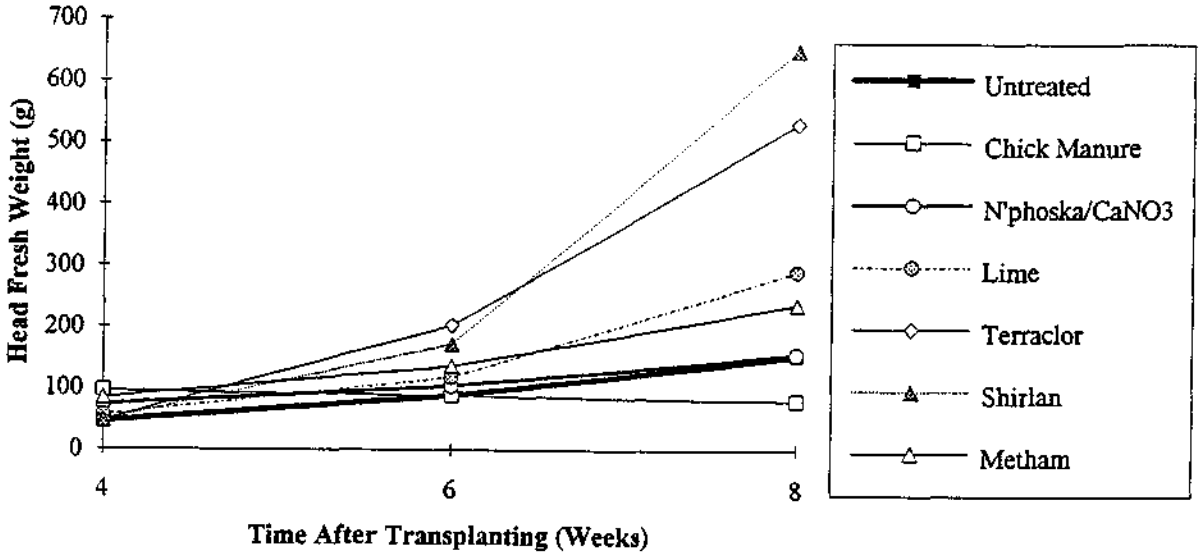
4.2 Evaluation of Clubroot Control Methods at Werribee

4.2.1 Effect of treatments on plant growth

Early plant growth was significantly enhanced by treatment with poultry manure, nitrophoska fertiliser (12:5:14; N:P:K) plus calcium nitrate and Metham, compared with untreated plots (Figure 9). Seedlings treated with Shirlan drench were observed to be visually set back, compared with other treatments, during the first few weeks after application. However, there was no significant phytotoxicity at the first assessment, made four weeks after transplanting. From six weeks after transplanting onwards, significant benefits to plant growth were observed with Shirlan and Terraclor treatments. None of the remaining treatments were significantly different to the untreated control, although a trend towards increased plant growth was evident following lime and Metham treatments.

Dry weights are not presented, as there were no additional differences between treatments and the untreated control that were not already evident from the fresh weight data.

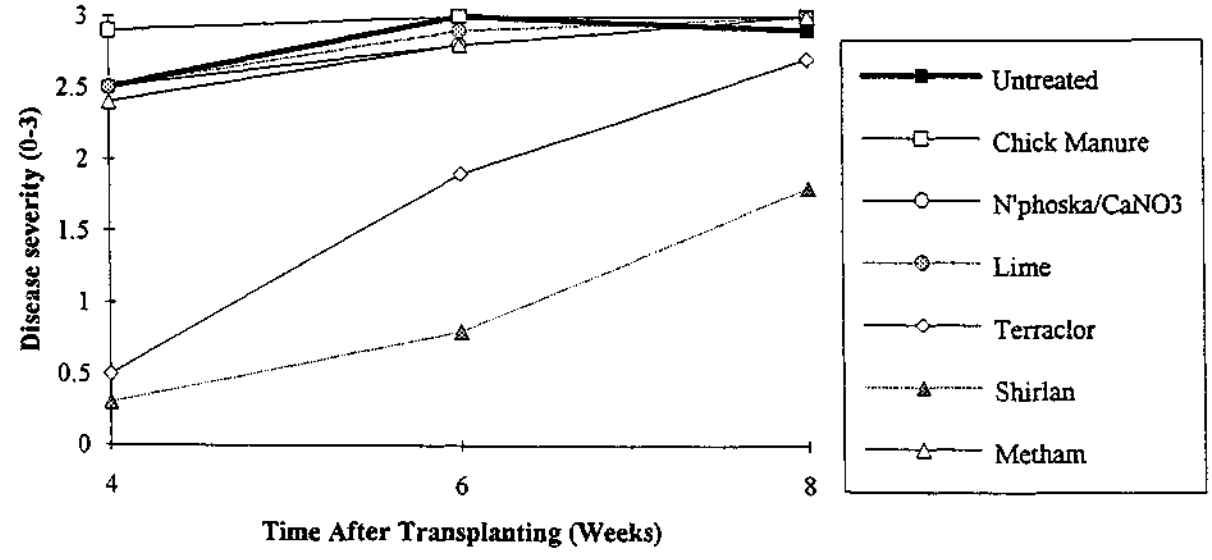
Figure 9 Effect of clubroot control treatments on plant growth from four to eight weeks after transplanting



4.2.2 Effect of treatments on disease severity

Clubroot symptoms were already well advanced at the first assessment made four weeks after transplanting. Severe clubroot had developed in all treatments with the exception of Terraclor and Shirlan (Figure 10). Disease severity increased more rapidly over time in Terraclor treated plants than in Shirlan treated plants, to the point where at eight weeks after transplanting severity in Terraclor treated plants was not significantly different from the remaining treatments. Severity in Shirlan treated plants did increase steadily over time but remained significantly lower than all other treatments throughout the growth period.

Figure 10 Effect of clubroot control treatments on disease severity



4.2.3 Effect of treatments on marketable yield and financial returns

A significantly greater percentage of plants produced a marketable sized head when treated with lime, Metham, Terraclor or Shirlan, than when untreated (Table 3). All remaining treatments failed to increase yields when compared to untreated plots and resulted in approximately 15% or less plants producing marketable sized heads. Failure to produce a marketable head meant that either plants had died, no head was produced, or the head produced was too small for cutting. Average head weights of the cut heads did not significantly differ (data not shown), and consequently marketable yield reflected the percentage of heads that were cut for each treatment (Table 3).

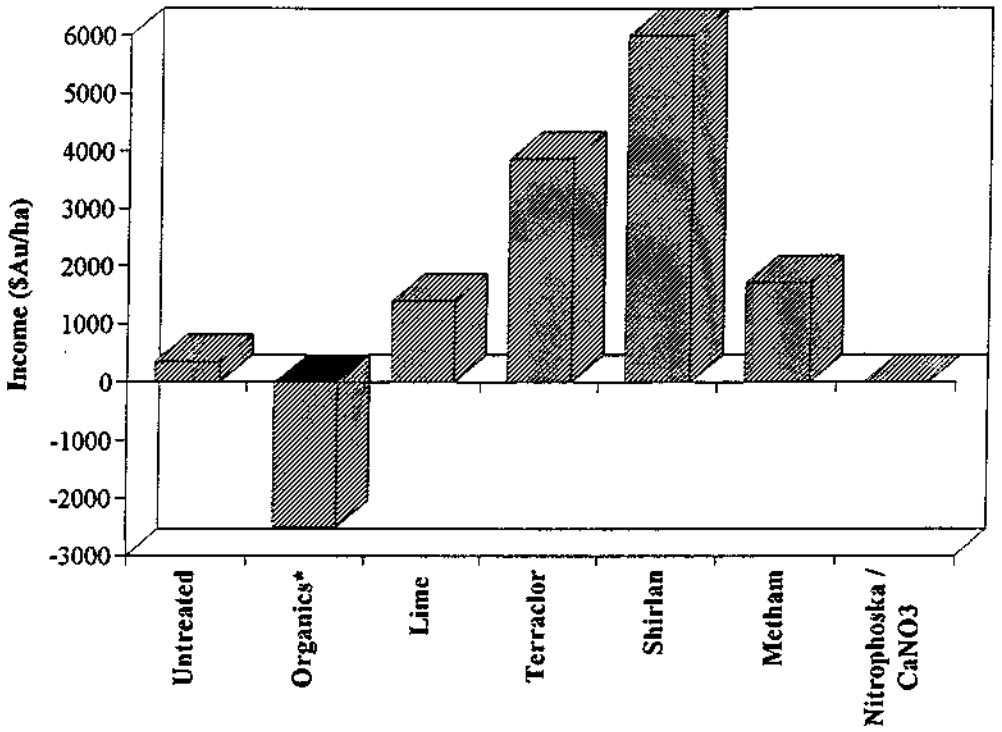
Relative gross incomes were calculated for each treatment, based on the purchase price of individual treatments and returns to the grower of $1/kg for the marketable yields achieved. The cost of the application was not estimated. Product costs were likely to be over estimated, as products were not purchased on a commercial scale. However, localised plant treatment with Shirlan was clearly the most economical clubroot control treatment, due to its low unit cost and high efficacy (Figure 11). The marketable yield obtained with the Terraclor treatment was not as high as that with Shirlan, whereas the product cost at the application rate used was more than twice that of Shirlan.

Table 3 Effect of clubroot control treatments on percentage heads cut and yield

Treatment	% Marketable Heads Cut[1]	Marketable Yield (t/ha)
Untreated	4.8	0.33
Chicken Manure	4.2	0.38
Stable Manure	5.7	0.2
Lucerne Hay	13.5	0.6
Rice Hulls	0.8	0.04
Lime (GBA)	30.8	1.76
Nitrophoska/$CaNO_3$	7.5	0.32
Terraclor	67.0	4.17
Shirlan	71.2	6.24
Metham	28.2	2.46
Basamid	6.3	0.34
S. Error	5.5	0.59
L.S.D.	15.5	1.66

1 Sum over 3 separate cuts over 8 days

Figure 11 Relative gross incomes predicted following the application of clubroot control treatments to broccoli



* average of all organic treatments

4.3 Soil Ecosystem Studies

All the organic soil amendments increased the population of bacteria, fungi and actinomycetes compared with the control and the chemical treatments (Table 4). Terraclor, Basamid, Metham and Shirlan all significantly increased the bacterial population above that of the control. No significant difference in bacterial numbers was observed between treatment with lime, nitrophoska/calcium nitrate and the control. No significant difference in fungal numbers was observed between any of the inorganic treatments and the control, with the exception of the Shirlan and lime treatments which increased fungal numbers, but to a lesser extent than the organic treatments. No significant difference in actinomycete numbers was observed between any of the inorganic treatments and the control.

In a follow up study on the effects of Metham, Terraclor and Shirlan on soil saprophytic microorganisms, Metham treated plots were found to support significantly higher bacterial and actinomycete numbers than the remaining treatments (Table 5), but exhibited no effect on the soil fungi, until the final sample date, at plant maturity, when the number of fungi was significantly lower than for the remaining treatments. Conversely, Terraclor and Shirlan treatments supported significantly higher soil fungi numbers than other treatments, but had almost no affect on the soil bacteria or actinomycete populations. The low impact of the Terraclor and Shirlan treatments on the soil microbial populations may be attributed to the localised application methods used for these treatments.

Table 4 Effect of treatments on soil microbial populations in a clubroot infested soil at Werribee, 1993

Treatment	Bacteria (x 10^6)	Fungi (x 10^4)	Actinomycetes (x 10^5)
Untreated	2.26	0.38	1.04
Chicken Manure	11.49	3.70	2.56
Stable Manure	11.54	3.36	2.33
Lucerne Hay	12.70	3.20	2.79
Rice Hulls	9.94	2.65	1.82
Lime (GBA)	2.53	1.47	0.85
Nitrophoska/$CaNO_3$	1.47	0.85	0.87
Terraclor	5.12	0.55	0.97
Shirlan	3.85	0.92	0.76
Metham	4.19	0.45	0.96
Basamid	4.27	0.49	0.90
SED (df=50)	1.562	0.527	0.29

Table 5 Effect of treatments on soil microbial populations in a clubroot infested soil at Werribee, 1994

Treatment	Bacteria (x10^5)				Fungi (x 10^3)				Actinomycetes (x 10^4)			
Weeks →	4	8	10	12	4	8	10	12	4	8	10	12
Metham	6.97	6.47	11.15	10.55	0.72	0.41	1.25	1.48	3.32	3.46	5.32	2.38
Terraclor	4.48	4.35	8.38	6.30	1.67	1.19	2.89	2.87	2.60	2.57	2.50	1.30
Shirlan	2.74	4.05	5.97	6.95	1.45	0.81	1.06	2.83	2.69	2.23	3.06	0.97
Control	3.61	3.17	6.32	6.45	0.97	0.37	1.49	2.41	2.56	2.09	2.59	1.01
SED (df=12)	1.15	0.95	1.26	1.49	0.37	0.25	0.52	0.26	0.34	0.56	0.34	0.20

4.4 Pathotype Identification Studies

Results from pathotype identification studies are inconclusive to date (Table 6), with further verification of disease reactions required on some differential hosts for most collections. It was evident however, that the reaction of the differential host set was similar for all three Victorian collections and for the New South Wales collection, regardless of the original host crop. The differential host reaction to the Western Australian collection, however, was quite different from all other collections tested, indicating genetic variation in the pathogen between the two regions.

Table 6 Reactions of the European Clubroot Differential set to inoculation with Australian *P. brassicae* isolates.

	Reaction of ECD hosts to Australian *P. brassicae* collections[1]															
ECD Host No→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Denery ID →	1	2	4	8	16	1	2	4	8	16	1	2	4	8	16	Race ID[2]
Werribee ex cauliflower	R	R	R	R	S	S	S	R	?	R	?	S	S	S	S	16/***3/30***
WA ex Chinese cabbage	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	?[3]
Werribee ex broccoli	R	R	R	R	S	?	S	R	R	R	S	S	S	S	S	16/2/31
WA ex Chinese cabbage	R	R	R	R	S	R	R	R	R	R	R	R	R	R	R	16/0/0
Bairnsdale ex Chinese cabbage	R	R	R	R	S	S	S	R	R	?	S	S	S	S	S	16/3/31
Bathhurst ex cabbage	R	R	R	R	S	?	?	R	R	?	S	S	S	S	S	16/***0***/31

1 R = resistant (DI = 0); S = susceptible (DI > 33); ? = indeterminate (DI >0, <33)

2 Components of race ID numbers in bold italics indicate uncertainty due to indeterminate host reaction within one or more of the three species groups. Indeterminate hosts require repeated testing, before being declared resistant if the disease index remains less than 33.

3 Failure to infect "universally susceptible" host 5 indicates low viability of spores in the sample, and test result was therefore declared null

5 Discussion

Clubroot first occurred in Victoria and Australia in 1890 and has spread easily to all the major crucifer growing regions in Australia by movement of infested soil and in water. Growers relied for many years on using high levels of lime to control the disease and still do today because of the lack of suitable alternatives. In the 1960's, PCNB soil treatments were recommended for control, but again they have been unreliable. Several other products (eg. Stand, Ca cyanimide, Dormex and a few 'home' remedies) have been touted by commercial companies and growers as being effective, but the disease is still a problem. More recently wide scale use of metham, and to a lesser extent banded applications of dazomet, have been more effective in controlling the disease, however, severe crop losses are still very common in fumigated soil. This study has confirmed that there is a desperate need to provide more effective treatments.

The need to develop improved controls has become even more urgent because of the large increases in both the domestic and export markets for crucifers and the high quality requirements of these markets. In addition, the widespread use of transplants throughout the crucifer industry has led to an increase in the spread of clubroot due to the ease with which infested seedlings can go undetected.

Australian crucifer growers have received little support in their battle against clubroot, due largely to the lack of research conducted on this disease in Australia. As a consequence growers rely on adhoc control methods which are at best only marginally effective. The survey showed that only 26% of growers were achieving adequate control of clubroot and that control was best achieved by moving production into fresh 'clean' soil. Several chemical treatments effective against clubroot have been withdrawn from use in recent years, and although current clubroot control treatments such as lime, metham sodium and Terraclor have been partially effective, the results have been so inconsistent that growers are seeking other alternatives.

This study identified to industry the inadequacies of present commercial treatments for control of clubroot. The detailed results of the survey have been presented to growers at information evenings in Victoria (Werribee, Bairnsdale, Myrtleford), W.A. and N.S.W. and are attached to this report (Appendix I). For this reason, they will not be further discussed here. Field trials comparing existing practices with several new treatments also identified the failure of existing practices to adequately control clubroot. Field trials did, however, identify that Terraclor applied as a root dip (a non label application) and Shirlan, a newly developed ICI fungicide, gave excellent control of clubroot and indicated that these treatments could provide substantially better control than any existing method. Profit increases of $6,000/ha were achieved in the field trial with Shirlan compared to untreated plots.

The need to improve application methods and rates for metham sodium was demonstrated not only through the inconsistent control obtained in our studies, but also through the poor control growers obtained on their own properties. The study also identified several methods that have potential for longer term more sustainable control of clubroot, such as the use of ground burnt lime with or without Nitrophoska base fertiliser and calcium nitrate and boron side dressings. These processes rely on the principal that both calcium and boron are inhibitory to germination of the clubroot resting spores.

Perhaps the most important finding from this work was the need to educate growers about how clubroot is spread and to implement into the Australian crucifer industry hygiene practices which minimise spread of the disease. In areas already infected with the disease there is a further need to find new cost effective methods of control that provide more sustainable forms of treatment than control with metham sodium fumigation. These major findings are being addressed in the new three year project which has just received voluntary support from the crucifer industries in Victoria and Western Australia and the Horticultural Research and Development Corporation.

List of Publications

"Report on the threat of clubroot to the Manjimup export crucifer industry" Dr. I. Porter, April 1994. Department of Agriculture Victoria, internal report.

"Can clubroot be controlled effectively" VGA Newsletter, May 1994 (attached)

"Can clubroot be controlled effectively" The Gippsland Farmer 1994 (attached)

"Clubroot and the Victorian brassica industry" Paper presented (by GR Dixon) at the ISHS symposium on brassicas/Ninth crucifer genetics workshop. 15-18 Nov. 1994 (abstract attached)

Cross and Porter, Oral presentation at 1994 NSW Brassica industries conference, 17 June 1994

"Improved commercial control of clubroot- A reality" Poster presentation at East Gippsland Field Days 28-30 April 1994

List of Information Evenings Conducted

Porter, Oral presentation at a meeting of Manjimup (WA) Crucifer Growers. March 24th 1994

Cross, Porter and Asirifi, Oral presentation at a meeting of Werribee Crucifer Growers. June 24th 1994

Porter, Oral presentation at a meeting of Ovens Crucifer Growers. Oct 6th 1994

Cross and Porter, Oral presentation at a meeting of Gippsland Crucifer Growers. Oct 13th 1994

Cross and Porter, Oral presentation at a meeting of Cauliflower Improvement Group, Manjimup, WA. Oct 24th 1994

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Colhoun, J. (1958) Clubroot disease of crucifers caused by *Plasmodiophora brassicae* Woron. A monograph. Commonwealth Mycological Institute Phytopathological paper No 3. 108pp

Dobson, R.L.; Robak, J. and Gabrielson, R.L. (1983) Pathotypes of *Plasmodiophora brassicae* in Washington. *Plant Diseases* **67** p 269-271

Kunkel, L.O. (1918) Tissue invasion by *Plasmodiophora brassicae. J. Agric. Res.*, **14,** p 543-572

Larson, R.H. (1934) Wound infection and tissue invasion by *Plasmodiophora brassicae. J. Agric. Res.* **49**p 607-624.

McAlpine (1901) Fungus diseases of cabbage and cauliflower in Victoria and their treatment. Dept. Agric. Vict. 38pp

Monteith, J. (1924) Relation of soil temperature and soil moisture to infection by *Plasmodiophora brassicae. Phytopathology,* **14**, p 25

APPENDIX I

Detailed Responses to the Survey Questionnaire

Q2 Size of Property (acres)

Number of responses	63
Number of missing values	2
Average farm size	139
max. farm size	740
min. farm size	10
med. farm size	100

Q3 Have you grown crucifers in the last 3 years (since Jan 1990)?

Number of responses	64
Number of missing values	1
yes	57
no	7

Q4 Have you/are you going to rent land for crucifer production this year?

All respondents:

Number of responses	56
Number of missing values	4
Number of blank cells	5
yes	13
no	43

"Yes" respondents from Q3:

Number of responses	54
Number of missing values	3
Number of blank cells	0
yes	12
no	42

Area rented (acres)

All respondents:

Number of responses	12
Number of missing values	1
Average rental area	37.5
Max rental area	90
Min rental area	3
Median rental area	29

Q5 **Total area of land to be cropped with crucifers this year (acres)**
(Current year crucifer growers):

Number of responses	48
Number of missing values	5
Ave total area	77.8
Max total area	430
Min total area	2
Median total area	100

Q6 **Major crucifer varieties grown/to be grown this year and their size**
(Current year crucifer growers):

Cauliflower

Number of responses	53
Number of missing values	0
yes	31
no	22
Ave area (acres) n=31	23.8
Max area (acres)	80
Min area (acres)	2

Cabbage

Number of responses	53
Number of missing values	0
yes	18
no	35
Ave area (acres) n=18	41.6
Max area (acres)	220
Min area (acres)	0.5

Broccoli

Number of responses	53
Number of missing values	0
yes	35
no	18
Ave area (acres) n=32	74.1
Max area (acres)	430
Min area (acres)	8.5

Other* crucifers

Number of responses	53
Number of missing values	0
yes	5
no	48
Ave area (acres) n=5	6.1
Max area (acres)	15
Min area (acres)	0.5

**Other crucifer types:*
Mustards
Red Cabbage
Chinese cabbage
Brussels sprouts

Q7 What is your most common yearly crop rotation in areas where crucifers are grown ? (All respondents)

Number of responses	54
Number of missing values	5
Number of blank cells	6
Crucifer/Crucifer/Crucifer	9
Non-crucifer/Crucifer/Non-crucifer	30
Non-crucifer/Non-crucifer/Crucifer	7
Other*	8

Rotation if "other"	Number of Responses
crucifer, crucifer, non-crucifer	*4*
crucifer once then never again	*1*
crucifer once in 5 years	*1*
crucifer once in 5 - 10 years	*1*
Carrots	*1*

Q8A Do you grow your own crucifer seedlings? (Current year crucifer growers):

Number of responses	53
Number of missing values	0
No	29
Yes, some	11
Yes, all	13

Q8B **How are they produced?**
(Those who grow some or all of own)

Number of responses	24
Number of missing values	0
untreated soil	5
fumigated soil	4
unsterile potting mix	1
sterile potting mix	13
other*	1

**direct sown*

Q9A **Do you buy crucifer seedlings?**
(Current year crucifer growers):

Number of responses	53
Number of missing values	0
No	13
Yes, some	11
Yes, all	29

Q9B **Do you buy cauliflower seedlings?**
(Those who buy crucifer seedlings)

Number of responses	40
Number of missing values	0
No	15
Yes	25

(Cauliflower growers only) -

Yes (n=31)	25

How are they produced?
(Those who buy cauliflower seedlings)

Bare rooted	1
In soil/other medium	24

Do you buy cabbage seedlings?
(Those who buy crucifer seedlings)

Number of responses	40
Number of missing values	0
No	23
Yes	17

(Cabbage growers only) -

Yes (n=18)	16

How are they produced?
(Those who buy cabbage seedlings)

Bare rooted	0
In soil/other medium	17

Do you buy broccoli seedlings?
(Those who buy crucifer seedlings)

Number of responses	40
Number of missing values	0
No	14
Yes	26

(Broccoli growers only) -	
Yes (n=35)	26

How are they produced?
(Those who buy broccoli seedlings)

Bare rooted	0
In soil/other medium	25

Do you buy other crucifer seedlings?
(Those who buy crucifer seedlings)

Number of responses	40
Number of missing values	0
No	38
Yes	2

How are they produced?
(Those who buy other crucifer seedlings)

Bare rooted (Chinese cabbage)	1
In soil/other medium (Brussels sprouts)	1

Q10 What irrigation methods do you use for crucifers?
(Current year crucifer growers):

Number of responses	53
Number of missing values	0

	Yes	No
Fixed, overhead	36	17
Furrow irrigation	0	53
Travelling irrigation	21	32
Other* types of irrigation	1	52

*(*Hand irrigation pipes*)

Q11A Do you apply lime?
(All respondents):

Number of responses	57
Number of missing values	2
Number of blank cells	6
No	7
Yes	50

(Current year crucifer growers):

Number of responses	53
Number of missing values	0
No	6
Yes	47

Q11B If you apply lime, how regularly do you apply it?
(lime users):

Number of responses	50
Number of missing values	0
Before each crucifer crop	11
3 months before each cruc. crop	0
Regularly every 6 months	0
Regularly every year	23
Regularly every second year	15
Other*	1

(When soil pH drops)

Q11C If you apply lime, what type, how much and when do you apply it?
(current year crucifer growers/lime users):

Number of responses	44
Number of missing values	3

Types		**Rates (t/ac)**				
		0.5	1.0	1.5	2.0	>2.0
GBA	28	5	15	3	5	0
CHA	5	0	3	1	1	0
Buchan	3	0	2	0	1	0
Other*	13	2	8	2	0	1

**Coopers Dolomite, Hillside lime, Nowa Nowa, Ag ground limestone, Darrimam Dry, Dried, Liquid, calcium lime*

Q11C continued - Lime Application Time

Number of responses	45
Number of missing values	5
Number of blank cells	0
prior to sowing/transplanting	18
2-4 weeks prior to sowing/transplanting	5
> 4 weeks prior to sowing/transplanting	1
Spring	5
Summer	3
Autumn	3
Winter	1
Other*	9

**whenever suitable/any time/various (n=3), late Spring to late Autumn (n=1), Every year (n=1), Every 2nd year (n=2), Mar-Oct, (n=1), 1 week to 6 months prior to planting (n=1)*

Q12A Is organic material (e.g. chicken manure) applied to soils growing crucifers?
(All respondents):

Number of responses	56
Number of missing values	3
Number of blank cells	6
No	34
Yes, before sowing crucifers	17
Yes, after sowing crucifers	4
Yes, before and after sowing crucifers	1

(current year crucifer growers):

Number of responses	51
Number of missing values	1
No	31
Yes	21

Q12B If yes, what type, how much and when is it applied?
(current year crucifer growers/organic material users):

Number of responses	20
Number of missing values	1

Types		**Rates (m^3/ac)**				
		0-5	5-10	10-15	>15	mv
Poultry manure	14	2	5	2	2	3
Rice hulls	2	1	0	1	0	0
P. manure & R. hulls	2	0	0	1	0	1
Other*	3					

**Dynamic lifter @ 0.25 t/ac, Dynamic lifter @ 1 t/ac, Cereal stubble (rate unspecified)*

Q13 Has clubroot ever occurred on your property?

(all respondents):

Number of responses	60
Number of missing values	1
Number of blank cells	4
Yes	42
No	17
Not sure	1

(cauliflower growers (n=31)):

Yes	25
No	6
Not sure	0

(cabbage growers (n=18)):

Yes	12
No	5
Not sure	1

(broccoli growers (n=35)):

Yes	28
No	6
Not sure	0

Q14 Have you stopped growing crucifers because of clubroot?

(Those who have had clubroot previously (n=42)):

Number of responses	42
Number of missing values	0
Number of blank cells	0
Yes	1
No	41

Q15A Has clubroot affected crops over the last 12 months (June 92 to May 93)?

(Those who have had clubroot previously (n=42)):

Number of responses	42
Number of missing values	0
Number of blank cells	0
Yes	37
No	5
Not sure	0

Q15B If yes, which crucifer crops and how badly were they affected?

(Cauliflower growers who have had clubroot (n=25)):

Yes	15
No	8

Area of cauliflowers LOST per property due to clubroot (Acres) (n=15)

Average	2.01
Minimum	0
Maximum	12.0
Median	0.67

(Cabbage growers who have had clubroot (n=12)):

Yes	10
No	2

Area of cabbage LOST per property due to clubroot (Acres) (n=10)

Average	3.04
Minimum	0
Maximum	20
Median	0.25

(Broccoli growers who have had clubroot (n=28)):

Yes	21
No	4

Area of broccoli LOST per property due to clubroot (Acres) (n=21)

Average	3.88
Minimum	0
Maximum	15.0

("Other*" growers who have had clubroot (n=1)):

Yes	1
No	0

** Chinese cabbage - 5 acres lost due to clubroot during the period specified*

Q16A Does the disease occur every year?

(Those who have had clubroot previously (n=42)):

Number of responses	40
Number of missing values	2
Number of blank cells	0
Yes	29
No	7
Not sure	4

Q16B Which months of the year is clubroot observed?

(Those who have had clubroot previously (n=42)):	
Number of responses	42
Number of missing values	0
July	5
Aug	4
Sept	4
Oct	8
Nov	16
Dec	27
Jan	32
Feb	35
Mar	38
Apr	27
May	16
June	8

Q17 Do you have a method which effectively controls clubroot?
(Those who have had clubroot previously (n=42)):

Number of responses	42
Number of missing values	0
Yes	11
No	23
Not sure	8

Q18A What control methods have you used for clubroot and how effective were they?
(Those who have had clubroot previously (n=42):

	Poor	Average	Excellent	?
Rotation	3	14	6	1
Fresh Soil	0	8	7	0
Lime[1]	3	27	4	1
Fumigation[2]	1	10	5	0
Fungicide[3]	4	6	2	0
Other*	0	1	0	0

**altering soil bed height, organic material and well graded land.*

1 Average application rate for lime (n=8) was 1.13 t/ac

2 Of fumigant users (n=16) 100% used metham sodium. The average application rate indicated (n=5) was 220 L/ac

3 Of fungicide users (n=12) 58% used Terraclor, 8% used Stand and 33% used a combination of both products. The sole application rate indicated (n=1) was 2 kg/ac for Terraclor.

Q18A continued
NB several growers who had never been affected by clubroot indicated the following control methods:

Average	Excellent	
Rotation	1	2
Fresh Soil	0	3
Lime	2	2
Fumigation	0	1
Good hygiene	1	0

Q18B If any of the above methods were not effective why do you think they were not?
(Those who have had clubroot previously (n=42):

Number of responses	33
Number of missing values	9
Weather	19
Application rate too low	5
Wrong application method	3
Do not know why	10
Other	2

Q18C How have fumigants been applied to control clubroot?
(Those who have had clubroot previously and fumigate (n=16):

Number of responses	16
Number of missing values	0
Overhead sprinklers	2
Injected into soils	16
Rotary hoed in	3
Other	0

Q19 How much money do you spend on clubroot control ($/ac/yr)?
(Those who have had clubroot previously (n=42):

Number of responses	38
Number of missing values	4
$0	5
< $50	2
$50-$100	5
$100-$250	10
$250-$500	11
$500-$1000	1
>$1000	4

Q20 What happens to the soil after you treat (e.g. fumigate) to kill the fungus?
(Those who have had clubroot previously and fumigate (n=16):

Number of responses	16
Number of mv	0
Cultivated immediately	1
Cultivated before sowing a crucifer	7
Cropped once and then sown to crucifers	2
Other	1
Nothing before planting	5

Q21A What is the next crop and when is it sown into the soil from where a crop infected with clubroot has been harvested?
(Those who have had clubroot previously (n=42):

Crop	No	No of weeks after crucifer harvest				
		0-2	2- 4	4 - 6	6 - 8	> 8
Cauliflower	6	0	3	3	0	0
Cabbage	1	0	0	1	0	0
Broccoli	12	0	5	4	0	2
Lettuce	16	2	7	2	1	1
Onions	7	0	3	2	0	1
Carrots	3	0	2	0	1	0
Sweetcorn	8	0	2	0	2	0
Other*	27	5	8	2	2	1

**Other crops*	*No*	*No of weeks after crucifer harvest*				
		0 - 2	*2 - 4*	*4 - 6*	*6 - 8*	*> 8*
Beans	*6*	*1*	*2*	*1*	*1*	-
Capsicum	*2*	-	*1*	-	-	-
Celery	*1*	-	*1*	-	-	-
Chervil	*1*	*1*	-	-	-	-
Coriander	*1*	*1*	-	-	-	-
Cucumber	*1*	-	-	-	-	-
Endive	*1*	-	-	-	-	-
Fennel	*1*	-	*1*	-	-	-
Parsley	*1*	-	-	-	-	-
Parsnip	*2*	-	*2*	-	-	-
Pasture/cereals	*7*	*2*	*1*	-	-	-
Pumpkin	*1*	-	-	-	*1*	-
Strawberries	*1*	-	-	-	-	*1*
Zucchini	*1*	-	-	*1*	-	-

Q21B When would the same variety of crop that had clubroot be grown in the area where it was originally infected?
(Those who have had clubroot previously (n=42):

Number of responses	41
Number of mv	1
The day after harvesting the infected crop	0
A couple of weeks later	5
1 month later	4
(1-6 months later)#	(7)
6 months later	7
A year later	9
Couple of years later	7
Never	0
Other	2

not a given option in the questionnaire

Q22 What happens to the soil after an infected crop has been harvested?
(Those who have had clubroot previously (n=42):

Number of responses	42
Number of mv	0
Immediately cultivated (to 30cm)	24
Deep ripped (to 45 cm)	21
Lime applied (at 2 t/ha)	15
Left fallow for a few months, then cultivated	14
Left fallow for more than 6 months	4
Other	5

Q23A Rate the importance of other diseases/pests which cause problems to your crucifers

	Never seen	Not important	Important	Extremely Important	Not Sure
Anthracnose	12	12	5	5	2
Ringspot	5	8	23	9	0
Blackleg	10	9	14	11	1
Light leaf spot	7	12	11	2	3
Black rot	7	8	14	9	2
Rhizoctonia	7	12	12	5	3
Downy mildew	5	8	19	8	0
Alternaria lf spot	7	9	12	5	2
Cabbage white-butterfly	0	5	25	22	0
Diamond backed-moth	8	6	10	10	2
Aphids 0	11	24	13	0	
Other*	0	1	2	1	0

**A. candida (n=1); sclerotinia (n=3)*

Q24 **Are you interested in the Department of Agriculture conducting research on clubroot?**
(All respondents (n=65):

Number of responses	63
Number of mv	2
Yes	56
No	5
Not sure	2

Q25 **Are you interested in providing land for trials?**
(Those who answered "yes" at q 24):

Number of responses	55
Number of mv	1
Yes	21
No	15
Not sure	19

Q26 **Are you willing to contribute money for research on clubroot?**
(Those who answered "yes" at q 24):

Number of responses	54
Number of mv	2
Yes	15
No	16
Not sure	23

Q27 **Have you heard of IPM?**
(All respondents (n=65):

Number of responses	62
Number of mv	3
Yes	12
No	47
Not sure	3

Q29 **Are you interested in developing an integrated pest management program for crucifers?**
(All respondents (n=65):

Number of responses	62
Number of mv	3
Yes	41
No	7
Not sure	14

APPENDIX II

Report on clubroot workshop at 6th ICPP, Montreal, Canada, 1993

by I. Porter*, G.R. Dixon** and T. Price***
*Institute for Horticultural Development, Victoria, Australia;
**Department of Horticulture, SAV/University of Strathclyde, Scotland
***Department of Agriculture, LaTrobe University, Victoria, Australia

The Chairman, Geoff Dixon, indicated that ICWG meetings are informal gatherings open to all scientists interested in *Plasmodiophora brassicae*, related organisms and the diseases which they cause. Each participant gave a brief account of their work and interests. A summary of current chemical control indicated that in the UK, no effective fungicides are available for commercial crops - thiophanate methyl is still registered but of variable efficacy while calcium cyanamide has been marketed on a limited scale compared with Germany and Japan, in comparison PCNB is still registered as a pre-plant treatment in Australia, fluazinam is being registered and metham sodium is applied by some growers and chlorthalonil is used effectively in Belgium. Other participants noted that seed companies in Japan are developing resistant cultivars and there is support from the Biotechnology Research Centre (RIKEN) to formulate fungicides. In the Philippines there is a joint programme with the German Technical Co-operation Program since clubroot is of major significance in the Highlands, in Canada substantial losses occur in Nova Scotia while a group from Syria indicated that clubroot is of commercial significance. Several participants noted that research into *Polymyxa betae* provides valuable parallel information for clubroot workers.

A review of research over 15 years into the influence and interaction of pH, calcium and boron and their effects on the *P. brassicae* life cycle was given by Geoff Dixon. Improved methods of studying the root hair using Rapid Cycling Brassicas (ex Paul Williams, Wisconsin, USA) all detailed monitoring of infection and sporogenesis. Calcium and pH reduce the rate of sporangial development while boron has a similar effect but also retards morphogenesis in cortical cells. Boron must be present at levels in excess of 15ppm in order to achieve a continuous influence on pathogen growth. Improved methods of sustaining these concentrations are being investigated. Each of these effects is moderated by inoculum potential.

Work at Horticulture Research International, UK, was discussed by Roy Kennedy, where the surfactant Agral provides substantial disease control. This material is most effective when applied as a drench at or before transplanting, it is suggested that the mode of action may result from changes to pathogen adhesion to the root hair surface. Other workers at HRI are developing immunological methods for identifying *P. brassicae* in small soil samples (<5g). Effective stains for resting spores were noted as aniline blue and acetocarmine.

Genetic studies at the John Innes Centre for Plant Science, UK, were described by Richard Mithen, the main thrust is to transfer resistance genes (single genes from *B. rapa*) into *B. oleracea* and RFLP mapping of resistance genes, much work results from mutants of *Arabidopsis* due to difficulties with hairy root culture methods. A co-worker Robert Vrieland has described two pathways for penetration by *P. brassicae* after penetration, one via primary plasmodia, zoosporangia and secondary zoospores and the second via amoeba in root hairs which migrate directly into the stele forming secondary plasmodia and resting spores. The pathogen moves intracellularly and within ten days of infection the spores begin to replicate; infection is normally associated with high concentrations of lipids. Molecular studies include the development of restriction maps and sequence analysis of rDNA (ITS region), chromosome and karyotype specificity, RAPD markers aiming to study genetic diversity and horizontal DNA transfer and the uptake of hose DNA by *P. brassicae*.

Typing of *P. brassicae* isolates was described by Afra Neuvel, The Netherlands, the problems of working with mixed isolated was discussed and the need for standardised methods of specifying physiological races which would relate results from the European Clubroot Differential Series (ECD) with DNA typing identified. Also discussed were the problems encountered with vital stains, tetrazolium chloride had given difficulties and there was a preference for fluorescein diacetate.

The potential for biological and cultural control was highlighted by Helmut Bochow, Germany, catch crops and bacteria may be used to reduce inoculum potential. A 90% reduction in inoculum potential was achieved with Chinese cabbage, used with bacteria obtained from suppressive soils reduced the size of resting spore masses by chitinolytic activities. Inhibition of secondary root infections by colonising bacteria which cause nutrient competition was discussed, drenches with *Pseudomonnas fluorescence* and 2% Neem oil substantially reduced disease.

Solarisation has proved to be effective in Australia as described by Ian Porter, but the treatment is expensive and will not provide year round control. Placement of dazomet (< 100kg/ha) is used by growers on sandy soils but is ineffective on clay soils which have higher inoculum concentrations. Metham sodium is still used in Victoria but public attitudes to agrochemicals are forcing growers to seek alternative systems and less noxious chemicals.

In general discussion participants agreed there were needs to:-

1. reassess the alternative hosts for *P. brassicae* and define their role in the carryover of disease, particularly identifying their influence on primary and secondary invasion,

2. understand more fully the modes of effect of soil components such as calcium, pH and boron,

3. identify the complete life cycle and the role of the root hair stage, especially the importance of primary zoospores,

4. understand how the organism moves within the host,

5. develop an understanding of the role of movement in free soil water and the mechanisms of survival in the absence of *Brassica* hosts,

6. standardise methods of typing and provide more rapid and accurate assays for detection,

7. circulate information concerning the importance of clubroot to crop production around the world and views of current research, a particular lack of knowledge of work in Japan was identified.

This meeting was attended by 30 workers drawn from 12 countries.

The organisers and participants wish to express their gratitude to their Canadian colleagues for permitting this meeting to accompany the 6th International Congress of Plant Pathology and noted the affiliation of ICWG with the International Society for Plant Pathology. Particular thanks go to Dr Michele Heath, University of Toronto, who expertly organised the timing and facilities for this meeting.

Meetings in 1994 will be held in association with the International Horticultural Congress, Kyoto, Japan and Crucifer Genetics Symposium, Lisbon, Portugal.

APPENDIX III

Publications Arising from Project VG306

CAN CLUBROOT BE CONTROLLED EFFECTIVELY?
Sue Cross, Ian Porter, Nkrumah Asirifi and Wendy Morgan

Article published in the VGA Newsletter May 1994

Clubroot severely affects nearly all commercially grown crucifer varieties. The pathogen which causes the disease, *Plasmodiophora brassicae*, is a soilborne fungus which survives in soil for many years. When plants are affected the roots become packed with millions of spores of the fungus and consequently swell. Once clubs develop water transport is affected and the plants wilt prematurely on dry days.

Last year a major research project on improving control of clubroot of crucifers was commenced by the Department of Agriculture at the Institute For Horticultural Development, Knoxfield. So far a survey has been conducted of all Victorian crucifer growers and two trials set up at Werribee to evaluate fumigants and fungicides. The long term affects of organic treatments is also being evaluated. The survey showed that at least 70% of growers were affected by clubroot and that only 30% had a method which gave reasonable control.

The trials at Werribee showed that Terraclor applied as a combined transplant dip and drench and a new fungicide recently developed by ICI gave excellent control. Over 70% of treated plants were marketable compared to 30% in lime and metham treated plots, and only 5% in untreated plots. Increased gross income from the fungicide treatments was up to $6,000/ha!!

Income was calculated, based on the purchase cost of treatments and receipts of $1/kg for the trimmed broccoli heads. Overall substantial benefits arose from treatment with lime, metham sodium, Terraclor and fluazinam, compared with no treatment.

CAN CLUBROOT BE CONTROLLED EFFECTIVELY?

By
Sue Cross, Ian Porter, Nkrumah Asirifi and Wendy Morgan

Article published in the "Gippsland Farmer", newspaper, 1994

Introduction:
Clubroot is a disease of crucifers caused by the soilborne fungus (*Plasmodiophora brassicae*) which occurs in most crucifer growing countries around the world. The disease was first reported in Australia over one hundred years ago.

The resting spores of the pathogen are stimulated to germinate in the presence of certain plant roots (mainly crucifers). Germination and infection are also affected by soil temperature, pH and soil moisture, with the most severe infection likely to occur in warm, acidic and moist soils. Several weeks later distinctive "clubs" develop on roots. The formation of the clubs is due both to the rapid growth and division of the pathogen as it absorbs plant nutrients, and the plant's own response to the presence of the pathogen. The uptake of water is impeded by the disease and infection is often first recognised when plants prematurely wilt on warm dry days.

The pathogen completes its life cycle within the roots, forming resting spores several weeks after the first infection. These resting spores are released into the soil when the roots later decompose, increasing the chance of infection of subsequent susceptible crops. The spores can survive in soil for many years, although in the absence of host crops or weed species, the level of inoculum will slowly decline. The disease can be spread to new areas by introduction of infected plant material or by movement of spores in infested soil (eg. tractors and bulk bins) and in water.

Clubroot Research at IHD, Knoxfield:
In 1993 a 12 month clubroot research project commenced at the Institute For Horticultural Development, Knoxfield. During the course of the project a survey of Victorian crucifer growers was conducted to gauge the extent and current status of the disease, and field trials were established at Werribee, to determine the efficacy of existing and novel treatments for the control of clubroot.

Grower Survey:
The majority of respondents to the survey were broccoli growers (66% of crucifer growers), followed by cauliflower (58%) and cabbage (34%).

Approximately 80% of cauliflower and broccoli growing properties and 67% percentage of cabbage growing properties were affected by clubroot. Of the properties with a history of clubroot, 86% were affected in the preceeding twelve months (June 1992 and May 1993), and crop losses of up to 20 acres per property were recorded. Sixty nine percent of properties with a history of clubroot were reported to be affected by the disease every year. Over 45% of growers sowed another crucifer crop within six weeks of harvesting a clubroot infected crop, although almost 40% of growers would wait a year or more before sowing the same variety that had been infected.

Only 26% of growers from clubroot affected properties felt they had a method to effectively control clubroot. The most commonly cited methods for clubroot control were lime (81% of clubroot affected growers) and crop rotation (56%). Other control methods included fumigation (37%), fresh soil (35%) and fungicide (28%). The majority of users rated the performance of each control method as average (50 to 77% of users). Greatest satisfaction was achieved using fresh soil for the control of clubroot. Crop rotation most commonly involved one non-cruciferous (break) crop between crucifers (56% of growers), while 17% of growers grew continual crucifer crops.

Approximately 50% of growers estimated that they spent between one hundred and five hundred dollars per acre on clubroot control methods per year.

Field Trials:

A range of organic and chemical treatments were evaluated for their control of clubroot and effect on broccoli yield in a field trial at an infested site at Werribee in 1993. Severe infection occurred in untreated plots, affecting plant growth, marketable head production and yield. The fungicides, Terraclor (PCNB) and Shirlan (Fluazinam) (registration pending) were highly effective in the control of clubroot and substantially improved final marketable yield, when applied as seedling treatments at transplanting. Shirlan caused some early set back of plants, but this effect was fully compensated later in the season due to its superior control of root infection. Pre-transplanting soil applications of lime (GBA) or Metham (metham sodium) were also moderately effective in increasing marketable head production and yield (figure 1).

Benefits of treatments were also considered in dollar terms. Returns for each treatment were calculated based on the measured marketable yield achieving $1/kg, less the purchase cost of treatments. Overall substantial benefits (up to $6000/ha) arose from treatment with Shirlan, Terraclor, Metham and lime, compared with no treatment (figure 2).

A second field trial is currently in progress, in which the application method of the fungicide treatments is being investigated.

Future Direction:

With the support of growers clubroot research at IHD will continue for at least a further three years. During the course of this program the evaluation and development of viable control methods and techniques will continue. Further work will also be conducted to identify variation in the pathogen between crucifer-growing areas and to screen potentially clubroot resistant cultivars against Australian "isolates" of the clubroot causing fungus.

CLUBROOT AND THE VICTORIAN BRASSICA INDUSTRY

Cross, S.J.*; Porter, I.J.; Asirifi, N. and Morgan, W.,

Abstract of a paper presented at the ISHS symposium/ 9th crucifer genetics workshop, Lisbon, Portugal, November, 1994

Brassica crop production in Victoria primarily services the domestic market, with current annual production of approximately 80,000 tonnes. Clubroot is the most serious soilborne disease affecting the brassica industry in Victoria, with over 70% of properties affected. Although clubroot occurs throughout the year, incidence is highest during the summer months. The majority of growers grew a single non-cruciferous break crop between brassica crops, although 17% grew continuous brassicas. Methods used to control clubroot included crop rotation, lime, metham sodium and fungicide (Terraclor and Stand) applications, but only 26% of growers felt their control methods were effective. The annual cost of clubroot control was estimated to be in excess of AU$500/ha by 28% of growers on clubroot affected properties.

In a field trial on a naturally infested site, several organic (chicken manure, stable manure, rice hulls and lucern hay) and chemical treatments were evaluated for control of clubroot in broccoli. The fungicides Terraclor (PCNB) and Shirlan (fluazinam - registration pending) significantly reduced the severity of infection, and increased marketable yield from 0.3 t/ha to 4.2 and 6.2 t/ha, respectively. This effect was due primarily to a greater percentage of plants producing marketable heads (approximately 70% vs. 5%). Organic treatments were ineffective in reducing disease severity, and had no effect on yield (0.04-0.6 t/ha). Lime and metham sodium treatments improved marketable yield (1.8 and 2.5 t/ha, respectively) but there was no significant reduction in disease severity.