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International Plant Protection Conference and organic amendments for potato pest and disease control

A report of a confernece and study tour to the Netherlands and USA

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PT517

Know-how for Horticulture™

John Matthiessen
CSIRO Division of Entomology

FINAL REPORT

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POTATO SOIL PEST AND DISEASE MANAGEMENT - TRENDS & DEVELOPMENTS

Report of a conference and study tour to the Netherlands and the USA.

July 1995

John N Matthiessen

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Perth, Western Australia

CSIRO AUSTRALIA

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Horticultural Research & Development Corporation Report

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Report to Potato Industry Sponsors

HRDC Project Number PT517

Potato Soil Pest and Disease Management - Trends and Developments.

Report of a conference and study tour to the Netherlands and the USA - July 1995

by

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Introduction

Recent joint CSIRO/Western Australian Department of Agriculture research has shown that metham sodium, in addition to its known ability to control soil-borne diseases and weeds, is also effective in controlling soil insects such as whitefringed weevil. It has been quickly adopted for this purpose. From figures supplied by local merchants, usage in the Manjimup/Pemberton district in WA rose from zero in 1989 to 300,000 litres in 1993. This is equivalent to treatment of the total table potato production area there. Many accounts indicate that metham sodium use is also on the rise in other parts of Australia for control of soil-borne pests, diseases and weeds in various ground-crop systems, but absence of a national reporting system for pesticide use means that specific figures on usage trends are not available.

Metham sodium (active ingredient synthetic methyl isothiocyanate) is expensive (c. $700/ha), unpleasant and dangerous to use, and must be correctly applied in large quantities to be effective. While it appears free of noxious residues, there are concerns about the sustainability of its use environmentally because of its broad-spectrum impact on soil biotic diversity and possible induction of secondary pests and diseases. Also, published Dutch research has shown that methyl isothiocyanate is often degraded more rapidly in soils that have previously been treated with metham sodium, leading to lessened effectiveness. Furthermore, there has been a recent move to legislative action to severely reduce the use of such pesticides in countries such as the Netherlands where usage has been particularly high.

Recent research, primarily in the USA, has focussed on the use of soil amendments derived from cover crop residues or other biological sources as alternatives to synthetic chemical fumigants. In the case of cover crops, this is based on the knowledge that certain genera of plants produce biotoxic volatile compounds as their residues break down. An example is the production of a wide range of isothiocyanates (80+) by *Brassica* plants, and cyanide by some grasses.

Most attention has been directed at nematode and fungus suppression by research groups in Washington state, Idaho and Oregon, but recently an entomology group in Idaho led by Dr Joseph McCaffrey published the first account of toxicity of allyl isothiocyanate-amended soil to soil insects. The field success of synthetic methyl isothiocyanate applied specifically for the control of whitefringed weevil in Australia and the experimental US work suggests that biologically-derived soil fumigants offer scope to control not only microorganisms but larger soil pests such as insects. The latest work has shown that aromatic isothiocyanates are 50x more effective than aliphatic isothiocyanates such as the commercial methyl isothiocyanate. This indicates potential to customise soil amendments by selecting appropriate plants for optimal effect on specific pests or diseases.

A team led by Dr Rodrigo Rodríguez-Kábana at the Biological Control Institute at Auburn University, Alabama USA, also has a leading role in the development and application of natural-product pest-control compounds, in this case for suppression of phytonematodes, and has pioneered the use of microplot systems for evaluation of agents under field conditions. Whitefringed weevil is also a major problem in the south-eastern USA and Dr Geoffrey

Zehnder at Auburn University is researching IPM systems and biologically-acceptable alternatives for its control in sweet potato, where expensive soil fumigants are not economically viable.

The International Plant Protection Congress, with the theme 'Sustainable Crop Protection for the Benefit of All' was held in The Hague, the Netherlands in the first week of July 1995. This was a major international conference and forum for policy-makers, researchers and industry representatives working on developing more efficient and environmentally and socially acceptable pest control.

Objectives

- Attend the International Plant Protection Conference, present and discuss research results, and obtain information on current world trends in pest management.

- Study visits to two key Netherlands research institutes long noted for investigations into the effects of fumigants in soil and the development of efficient application strategies and techniques.

- Study visits to university groups carrying out research on soil fumigation and alternatives for the management of soil-borne pests and diseases, and biological studies of pests and diseases, in the south-east and north-west of the USA.

The broad purpose of the tour was to enhance existing research being carried out in Australia, and facilitate future developments, through acquisition of knowledge and the forging of collaboration with researchers overseas. The primary emphasis was on investigating current issues relating to the management of soil-borne pests and diseases in potato production, with a focus on development of biofumigation and organic-amendment techniques as alternatives to fumigation with costly chemicals.

Particular attention was devoted to developing an understanding of the theoretical and practical issues involved in achieving effective fumigation with synthetic fumigants. This had a two-fold purpose - to determine whether improvements could potentially be suggested to make existing practices in Australia more efficient, and to develop an understanding of what will be required for biologically-based alternatives to fumigation with synthetics to be effective.

Inherent in these investigations was development of an understanding of contemporary social, environmental and efficacy issues stemming from the wide-scale and heavy use of pesticides, fumigants in particular, over long periods in the intensive agricultural systems of the Netherlands and the USA. This was done with a view to anticipating and avoiding potential problems in Australia, and evaluating what will be required of alternative methods of soil-borne pest and disease management as they evolve.

Visits to groups researching biologically-based and integrated pest management systems, particularly for soil-borne pest and disease management, were aimed at studying the approaches to research, key findings, methods being developed, the types of systems at which the new strategies were aimed, and problems encountered. The objective was to build interactions and collaboration to enhance the knowledge base and gain future benefits from direct links to current research relevant to the integrated pest management programs and the new biofumigation approach being pursued in Australia.

Itinerary

The duration of the tour was 1-31 July 1995.

1 July:	Perth - The Hague.
2-7 July:	International Plant Protection Congress, The Hague, the Netherlands.
10 July:	H. L. Hilbrands Laboratory, Assen, the Netherlands.
11 July:	Winand Staring Centre, Wageningen, the Netherlands.
12 July:	Amsterdam - Auburn.
13-18 July:	Auburn University and field sites in Alabama, USA.
19 July:	Auburn - Moscow, Idaho.
20-26 July:	University of Idaho, Moscow and field sites in southern Idaho, USA.
27-29 July:	Washington State University, Prosser, Washington, USA.
29-31 July:	Prosser - Perth.

Acknowledgements

I am grateful for the funding support for this tour provided by the following:

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CSIRO Division of Entomology overseas travel fund
The Smith's Snackfood Company
The Edgell Birdseye Company

I am also grateful to the researchers overseas who so generously gave of their time for discussions, and organised field visits and meetings with colleagues:

Nol Mulder, H. L. Hilbrands Laboratory, Assen, the Netherlands
Johan Smelt, Winand Staring Centre, Wageningen, the Netherlands
Geoff Zehnder, Auburn University, Auburn, Alabama
Joe McCaffrey, University of Idaho, Moscow, Idaho
Gerry Santo, Washington State University, Prosser, Washington

International Plant Protection Congress

This congress was held in The Hague between 2-7 July 1995 and was attended by approximately 900 delegates from around the world.

The lead theme for the congress was 'Sustainable crop protection for the benefit of all'. The program was broad in scope, encompassing policy and industry developments and their associated social and political issues, as well as more specialised sections for reporting of specific research findings in both oral presentations and very large poster sessions that changed daily. Usually six oral presentation sessions were running concurrently.

I presented a poster entitled 'Challenges in implementing IPM for low economic threshold soil insect pests', and another in association with colleagues John Kirkegaard and Jim Desmarchelier entitled 'Biofumigation - using *Brassica* species to control pests and diseases in Australian agriculture and horticulture'. The abstracts of these poster presentations are attached (Appendix 1).

Summary of some issues raised at the congress, and related information

There is a range of policy developments that are happening in other parts of the world and which, if history is an accurate predictor, could either eventually be invoked in Australia or directly or indirectly impact on Australian agricultural industries. The following is a summary of some information and developments to provide an overview of the situation elsewhere. Most is derived from presentations at the congress, but where applicable the information has been supplemented with material collected during subsequent parts of the tour.

The Netherlands

- **Pesticide use**. Dutch agriculture is highly specialised and intensive and pesticide usage is high. During the period 1984-1988 it amounted to about 10kg of active ingredient per hectare per year. The opinion was expressed that Dutch agriculture had become 'addicted' to pesticides.

- **Restrictions**. Public opinion and export concerns forced the Dutch to restrict pesticide use. In 1990, the Multi-Year Crop Protection Plan was launched by the Dutch government, with the objective of halving 1984-88 pesticide usage levels by 2000, and restricting emissions by 90%.

- **Reduction plan**. A covenant has been made between the government and the agricultural and pesticide industries in order to implement the Plan, and Parliament is informed annually of progress. The overall objective is a more environmentally benign agricultural production system to be achieved in three ways: by reducing dependence on chemical pesticides, reducing the quantities used, and reducing emissions into the environment beyond the target site.

- **Implementation.** Policy instruments used to implement the Plan are legislation, extension, education, research and incentives. Methyl bromide use has been banned, and one of the most significant items of legislation has been to allow use of soil disinfectants (fumigants) only on prescription and with strict conditions. A certificate of competence for the application of pesticides is required.

- **Progress.** Pesticide volume has already declined 50%, which is ahead of target. The great majority of the reduction has resulted from a tremendous decrease in the quantity of soil disinfectants, largely used for nematode control, which has declined 75% against a target of 45%. In 1990 8,937 tonnes of soil disinfectants were consumed in the Netherlands; this had fallen to 2,420 tonnes in 1993. Herbicide and insecticide use is also down, but fungicides are proving most difficult to reduce, and now constitute the largest class of pesticides used.

- **Other factors.** The reduction in soil disinfectant use, however, appears to have come less from the legislation than from other factors, such as the use of nematode-resistant plants and a lessened ability to afford the high cost of fumigants with diminishing 'social embedding' (as it was expressed) of agriculture. Potato prices in particular are low.

- **Emissions.** Pesticide emissions, especially into groundwater (which is extremely shallow, and commonly exposed in ditches in the Netherlands) have not declined in proportion to the reduction in quantity used, and this appears to present a major challenge with significant implications in the future.

- **Motivation.** An important question being investigated is how farmers can be motivated to reduce the use of hazardous pesticides and to adopt methods of crop protection that have a lower environmental impact. Imposition of laws or rules does not necessarily motivate producers to change their farming practices, and may be counter-productive in causing them to put more energy into attempting to circumvent regulations. Regulation is only effective in situations where control is easy to carry out; in crop protection and pesticide use these situations are rare.

  Motivational strategies being explored are in three steps: (1) making the environmental burden of pesticides quantifiable ('environmental impact points' are assigned to various agents so as to obtain an Environmental Yardstick), so that a farmer becomes aware of the problems and can see the results of his efforts; (2) translating results of research to practical advice at farm level, usually through study groups; (3) giving financial incentives.

- **Minor use.** The costs of pesticide registration have increased substantially, causing greatly reduced applications for approval to use in minor crops. The government and the agricultural and pesticide industries are working to formulate a policy to allow specific regulated uses within the legal framework, perhaps through prescription and controlled distribution.

- **Potato production**. Annual potato production in the Netherlands is around 5 million tonnes of ware potatoes, worth around $A1.5b, grown on 75,000 ha. The area planted to seed potatoes is 40,000ha.

The USA

- **IPM policy**. There are quite dramatic policy changes on plant protection and pesticides occurring in the USA at present. A target has been set by the Clinton administration of attaining Integrated Pest Management on 75% of total crop acreage on US farms by the end of the decade. While IPM doesn't preclude the use of pesticides, the clear objective is to lessen dependence on chemical agents.

- **Past policies**. The view is that previous pesticide policies have failed both producers and consumers.

- **National plan**. IPM research and extension has been re-organised and a nationwide strategic plan for IPM activities has been formed.

- **Biotechnology**. Particular attention is being paid to policy options concerning the applications of biotechnology. A key issue is the imminent (1996) commercial release of the first pesticide-engineered crops.

  I was able to visit a field day in southern Idaho where NatureMark potatoes, a Monsanto subsidiary, were demonstrating a commercial-size planting of their NewLeaf Russet Burbank™ genetically-modified variant of the Russet Burbank potato variety. The genetically-modified variety expresses the *Bacillus thuringiensis* (Bt) toxin within its leaves at 200x the typical foliage spray application concentration, for Colorado potato beetle (CPB) control. Unfortunately for the company representatives, the area chosen for the demonstration did not develop a beetle population (not uncommon in Idaho where CPB is sporadic and not yet as resistant to insecticides as populations in the eastern USA), and so there was no convincing demonstration on the day of the capabilities of the new variety (which appeared to leave some of the farmers nonplussed). There is, however, no doubt about the effectiveness of the variety, but also little doubt in the minds of many that resistance to the plant will develop. Seed of the variety is currently being produced throughout North America.

- **Industry role**. The US National Potato Council has taken a key role in the development of a Pesticide Environmental Stewardship Program. This has stemmed from a National IPM Forum in 1992 identifying that the primary constraint to further adoption of IPM was a lack of national commitment (the impetus for the 75% implementation commitment - see above). The potato industry is one of the first commodity groups to become a partner with the agricultural and regulatory authorities in the program, having insisted that the program be a 'stewardship' effort, rather than a 'pesticide use/risk reduction'. Their position is based on the premise that good management practices are not totally dependent upon blanket reductions in the quantity of pesticide used. They recognise the need for better targetting and more precise application, and research for and education about alternatives.

- **Information**. The IPM push in the US is leading to a flood of information and, in keeping with the times, an array of Internet sites for dissemination of the material has sprung up.

- **IPM implementation**. It was pointed out by a Californian IPM coordinator that a comprehensive and successful IPM program for an agricultural system requires willing and cooperative growers, support of organisations that market or purchase the products, dedicated research and extension personnel who can produce a body of relevant information concerning farming practices, pest biology and management tactics, and a supportive regulatory structure. It was noted that it is a complex area with an intensive emphasis on management, and that it requires individuals who wish to apply it to understand broader ecological relationships in addition to crop production practices. It is clear that to regard IPM as another 'product' or 'silver bullet' is naive and a recipe for failure.

- **Success factors**. In California, pesticide applications by a farmer can only be made on the written recommendation of a certified Pest Control Adviser (PCA), and approval of that recommendation by local regulatory officials. The PCA's have been the main target audience of educational programs on IPM. The most widely-adopted IPM programs tended to be those that had been available the longest, those that had been actively demonstrated by extension IPM staff and those that involved the researcher in the field as well as at the laboratory level. The message is clearly that short-term or stop-start IPM projects, and those not underpinned by combined solid research and extension, are unlikely to succeed.

International

- **International agreements**. The last few years has seen an unprecedented level of international agreement and commitment to the development of sustainable pest management as an essential element of agricultural growth and environmental protection, highlighted by two elements of the UN Conference on Environment and Development - Agenda 21 and the Biodiversity Convention. Agenda 21 sets ambitious targets for development of IPM at national levels.

- **Third world**. Pest control in some third-world countries is often a disaster. Highly potent chemicals are often used ignorantly with no regard to personal safety or preventing contamination during use or in disposal of containers. There are suggestions that there is some transfer of operations from first-world countries to third-world countries to circumvent restrictions such as the methyl bromide reduction policy.

- **Free trade**. Freeing of international trade is creating problems in preventing the spread of exotic pests into new localities. This has particular relevance to Australia.

General

A presentation that I found of particular interest was that by David Dent of the University of Wales in which he expounded the view that research specialisation is a constraint to integration. A copy of the abstract of his talk is attached (Appendix 2). While in my view he makes a valid point, he did not address the difficulty of maintaining high quality research under a situation where researchers may be under pressure to be 'jacks-of-all-trades', being expected to do extension and implementation as well as trying to maintain an up-to-date level of expertise in their discipline to ensure continued capacity to carry out rigorous research. Critical mass is impossible to obtain in an individual.

The answer, in my view, is to ensure that systems are put in place to facilitate the coming together of multi-disciplinary teams, both *laterally* in the spectrum (eg. entomologists teaming with pathologists) and *vertically* in the spectrum (ie. basic/strategic researchers teaming with applied researchers and extension personnel). This seems to be a general feature, and a significant strength, of the research and extension system in the USA. **Both the encouragement, and facilitation, of team-based research, development and extension across geographic and organisational boundaries should be a high priority for research and development funding agencies such as the Horticultural Research & Development Corporation.**

Netherlands study visits

Laboratories visited and personnel

The laboratories visited were the H. L. Hilbrands Laboratory for Soil-Borne Pests and Diseases at Assen in the north-east of the Netherlands, the Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO) at Wageningen, and the Research Institute for Plant Protection (IPO-DLO), also at Wageningen.

The Hilbrands Laboratory is in an area where potato production (60,000 ha) is principally for the starch industry. The laboratory was set up in the 1960's totally by grower efforts and financial support. It has always had an applied focus, but this has been underpinned by strong interactions with more basic researchers to ensure developments have a sound theoretical basis. It is now 50% funded from government sources, but that appears set to change under the effects of economic rationalisation. It appears to be somewhat unique in still remaining outside the broader Dutch research organisation known as DLO-NL (the Agricultural Research Department of the Netherlands) which is composed of twelve research institutes (two of which are mentioned above). That too, is to become more market-oriented organisation with a mixed clientele.

The Winand Staring Centre focusses on environmental issues, and has a strong chemistry-based arm currently specialising in the measurement of pesticides in the soil and water environment. The Research Institute for Crop Protection is responsible for strategic research to promote economical and socially acceptable ways of protecting against pests and diseases in all fields of cropping.

The Managing Director of the Hilbrands Laboratory is Dr Arnold (Nol) Mulder, a nematologist with over 30 years' experience in applied research and management. In particular, he has a wealth of knowledge on the use of fumigants for nematode control. Much of his research has been carried out in collaboration with Mr Johan Smelt, a chemist at the Winand Staring centre and who, with Dr M Leistra, pioneered the detailed evaluation of fumigant diffusion through soil in the 1970's and 1980's. Improvements in application techniques for fumigants leading to greater efficacy and the use of reduced quantities have stemmed from the close teamwork of the chemists at the theoretical level with the applied nematologists and agricultural engineers. At the Crop Protection Institute, Drs C Schomaker and T Been, mathematical modellers, have developed methods for sampling nematodes, which are patchily distributed. Their methods define the distribution, allowing much more precise control methods to be used.

The following section summarises various aspects of soil pest management and fumigant use from information obtained at the three institutes.

History of fumigant use

- **Metham sodium.** Metham sodium was approved for use broad-scale agriculture in the early 1970's after previously being limited to particular horticultural applications. The main target was potato cyst nematode. Considerable research was carried out during the 1970's on the chemistry and diffusion of metham sodium in soil, optimum soil conditions and application methods.

- **1,3-D.** 1,3-dichloropropene (1,3-D, trade name of latest variant is Telone II) has been in use for many years as a nematicide. It started as DD (dichloropropene + dichloropropane), but the dichloropropane component was found to have adverse effects on plants (especially wheat, causing only partially-formed seed heads). It evolved to Telone, which apparently still had some adverse admixtures, and has now evolved to Telone II which is almost pure 1,3 dichloropropene.

  (Note: 1,3-D is not registered in Australia, having been voluntarily withdrawn by the company in the late 1980's after laboratory tests on rats in the US showed it was potentially carcinogenic. It would seem that with the Australian market being very small the company withdrew it as a precautionary or rationalisation measure. Opinion is that re-registration attempts are unlikely).

Nematode problems and fumigant use

- **Soil.** Much of the Netherlands has fine sandy soils, low in organic matter. For example, soils of the Assen area are a fine wind-blown loess which has a pore-size distribution that particularly favours nematodes. Nematode problems are greater in alkaline soils.

- **Crop cycle.** Potatoes are grown on a two-year rotation. While nematode-resistant varieties are in use, nematodes build tolerance to them within around six crops. Also, the use of such varieties can lead to shifts in the species-mix (eg. *Globodera rostochiensis* being replaced by *G. pallida*).

- **Control objectives.** Research in the past aimed at improving fumigant application methods so as to achieve at least 80% control of nematodes in an area to be cropped, through use of either 1,3-D or metham sodium, and based on a statutory soil sampling protocol. These agents cannot be mixed without expensive emulsifiers, which makes the resulting product too costly to use.

- **Relative efficacy.** 1,3-D has a higher vapour pressure than metham sodium and hence will diffuse further in the soil. When applied by blade injector at about 20 cm depth, 1,3-D will diffuse to around 60 cm whereas metham sodium will diffuse to about 45 cm. This is important for nematodes which can exist deep in the soil and migrate upwards. Metham sodium is about 10x more soluble in water than 1,3-D, and hence needs drier soil than 1,3-D to ensure sufficient diffusion occurs. If the soil is too wet, diffusion is inhibited; if it is too dry, diffusion is too fast.

- **Toxicity.** 1,3-D is toxic to nematodes, weeds (not oilseeds), and nitrifying bacteria. The latter has implications for cereals in that fumigation in autumn, the typical timing, prevents nitrification, but in spring the nitrifying bacteria resurge causing an overshooting of nitrification. It is possible to save 40 kg N/ha with 1,3-D and 20 kg N/ha with metham sodium, and it is necessary to allow for this extra N in a following cereal crop. The effect is greater with a higher organic matter content in the soil. Neither fumigant is effective against the sclerotes of rhizoctonia, but rather the effect of fumigant on this organism is the result of removing a host.

Application methods

- **Rotary hoe.** Dutch experience with rotary hoe incorporation of fumigants is that even with cultivation to 20 cm depth, the only effect of the fumigant is in the top 8 cm, so it is seen as an inefficient method.

- **Injection.** Injection of fumigant under a blade was found to be more effective than rotary hoe incorporation, but had the main deficiency of not providing adequate control in the higher layers of the soil. Typical injection depth is 18-20 cm. Going deeper causes too low an effect in the shallow part of the soil which has been significant in allowing 'escape' of target organisms. Figure 1a is taken from a Dutch publication by Dr Mulder and shows the concentration profile of 1,3-D in the soil 1,7 and 14 days after application, when applied using a blade injector. Figure 1b shows the dose profile of the of the fumigant (concentration x time product - CxT, which determines its effect), with the lethal level for nematodes marked. It can be seen that the dose in about the top 5 cm of the soil is insufficient to kill nematodes. It is relatively easy to get a high fumigant dose deep in the soil, but much more difficult to adequately treat the top layer.

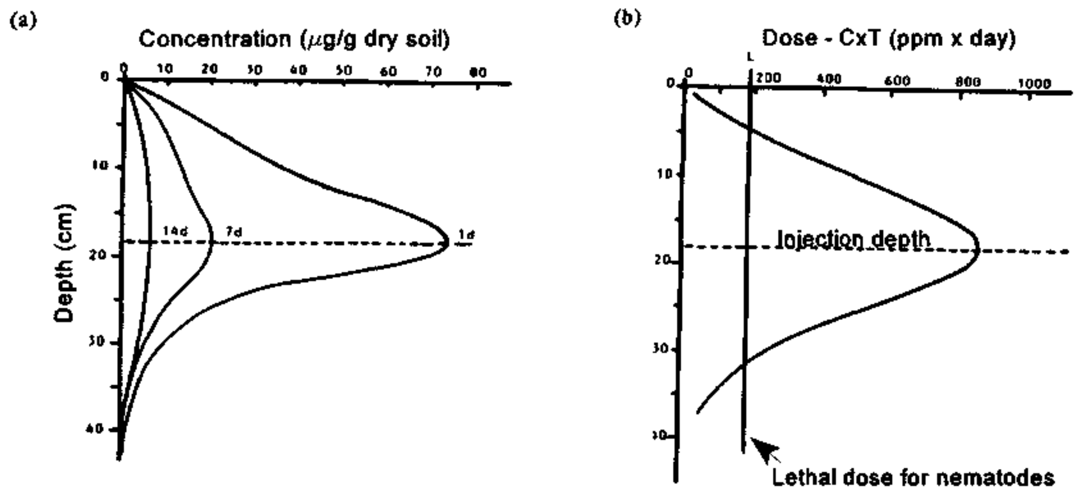

Figure 1. The concentration of 1,3-D in soil not adapted for enhanced degradation 1, 7 & 14 days after application by injector at 18 cm depth (left). The dose profile of the fumigant in the soil relative to the lethal dose for nematodes (right). Note the poorly-dosed area down to about 5 cm depth. Figure taken from a H. L. Hilbrands Laboratory report in Dutch by A Mulder, J Roosjen & A Dijksterhuis.

- **Spading.** The most recent innovation for more efficient application of fumigants is what is known as a 'spading machine'. Fumigant is applied at about 10 cm depth through large 'goose feet' blades which are 75 cm wide, with 5 cm between. It is then incorporated into the soil with the spading blades which rotate at 80 rpm, compared to 200 rpm in the case of a rotary hoe. These blades mix the soil, a following roller with shallow pointed tynes that curve around the roller works the top layer of soil to a fine texture, with a final power-driven roller then achieving a good sealing of the surface. It is essential for the final roller to be powered to ensure correct rotation speed and prevent surface skidding breaking the seal.

As the autumn is the typical time to apply fumigants, I was unable to see a spading machine in use and the one I saw was in the shed and in pieces for the summer. Essential elements of the device are shown in the photographs. It is an expensive machine and requires a heavy-duty tractor (at least 140 hp) to operate it in the flat landscape of the Netherlands and in their very light soils. All such operations are carried out by contractors.

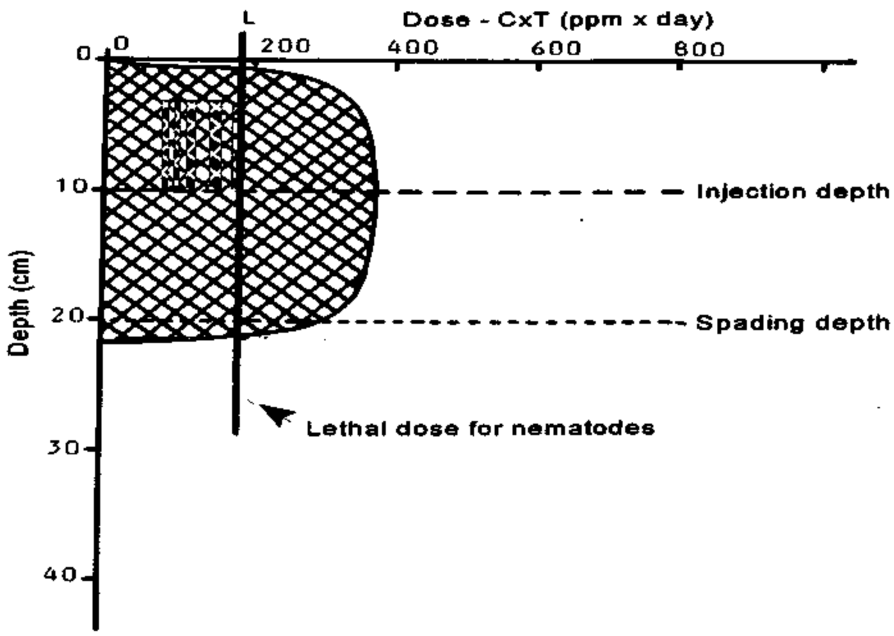

Figure 2. The dose profile of fumigant in the soil achievable using the spading injector, relative to the lethal dose for nematodes. Injection depth is a shallower 10 cm and the spading tynes incorporate the fumigant evenly in the top 20 cm, while the rollers seal the surface. Figure from same source as Figs. 1 & 2.

Figure 2 is also taken from a publication by Dr Mulder and shows the pattern of fumigant distribution in the soil profile achieved with the spading device. The distribution of the fumigant achieved concentrations above the lethal dose for nematodes much more uniformly in the soil profile, especially in the top layer.

It was pointed out that the best method for pumping the fumigant was to use a pressurised stainless steel holding tank, rather than a mechanical pump. This ensured a more even flow with less chance of blockages.

Enhanced degradation

- **The problem**. Enhanced degradation occurs with most soil-applied fumigants and pesticides that do not have a halogen (eg. chlorine, bromine) atom in their molecule, and refers to the ability of soil microbes to adapt to using the chemical as an energy source. The microbes then break down the chemical too quickly for it to be effective in controlling the target pest. The effect most often occurs after repeated applications of the pesticide and it can be spread in soil. The enhanced degradation effect is more prone to developing in soils high in organic matter, and lasts longer in high pH soils. Soils will 'recover' over several years if application of the pesticide is ceased.

  Enhanced degradation is a significant problem in the Netherlands, occurring for 1,3-D, metham sodium, ethoprofos (Mocap) and aldicarb (Temik), the latter two being an organophosphate and carbamate soil pesticide, respectively. These too can be used to limit nematodes, but their mortality effect is not high, so if enhanced degradation occurs it renders them almost totally useless for that purpose. Apparently a high proportion of soils are adapted for enhanced degradation of ethoprofos.

  Alternation of 1,3-D with metham sodium, and ethoprofos with aldicarb can limit enhanced degradation by alternately removing the specialist adapted organisms, but it is a 'pesticide treadmill' approach.

- **Causes**. Development of enhanced degradation is greatest in parts of the soil that receive the lowest concentration of the chemical, hence the attention given to methods to make incorporation of fumigant more uniform. Non-fumigants need to be in the soil for around two months to affect nematode populations, hence enhanced degradation is more critical in the case of those agents.

- **Legal limits**. In the past, the recommendation for frequency of fumigant use was one year in four. As part of the pesticide reduction strategy, and in order to limit the development of enhanced degradation, that recommendation has become a legal limit for fumigation in the Netherlands. This is to be changed to one year in five after 2000. Growers cannot afford to make a mistake when applying fumigants, hence the emphasis on efficient application methods, and the development of assay and sampling systems to ensure effective use.

- **Diagnosing**. The presence of enhanced degradation can be determined using analytical techniques (gas chromatography), but this is expensive and needs trained people which adds further expense. A less expensive bioassay using cress sown daily into gas-tight flasks has been developed, but calibration curves based on analytical methods are needed first. It is necessary to recognise that it is sometimes possible to get fast degradation because of physico-chemical factors, usually high pH, which may be wrongly ascribed to enhanced degradation.

Figure 3a, again from Dr Mulder's work, shows the concentration profile over time for 1,3-D in adapted soil (compare to Fig. 1a). Figure 3b shows the dose profile in relation to that required for nematode mortality in adapted soil (compare to figure 1b). It can be seen that the zone of insufficient dose is much greater in the adapted soil.

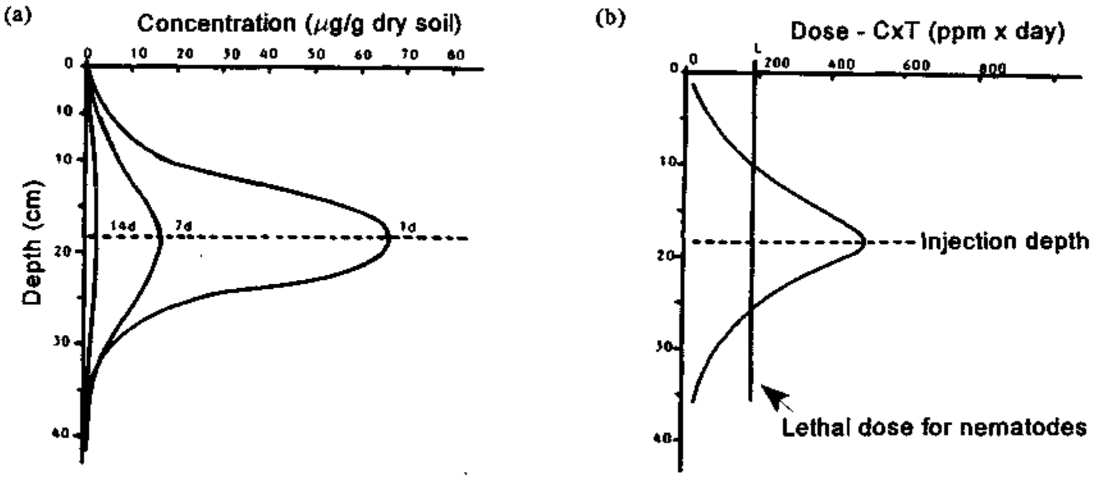

Figure 3. The concentration of 1,3-D in soil adapted for enhanced degradation 1, 7 and 14 days after application by injector at 18 cm depth (left). The dose profile of the fumigant in soil relative to the lethal dose for nematodes (right). Note the much smaller volume of adapted soil maintaining a lethal dose. Figure from same source as Fig. 1.

Optimising control of nematodes

- **Sampling method**. Nematodes are patchily distributed. The method developed by Drs Schomaker and Been was devised to be able to detect small infestations with a predefined probability so that farmers could stop applying soil fumigants as a precaution. Also, by localising the foci, the method allows minimal treatment of the infested area only. It also allows use of other control methods apart from fumigation which has a poor cost to benefit ratio.

  Extensive sampling on a grid, using an automated collection device on a vehicle, semi-automated extraction of nematodes from the soil and mathematical modelling of their distribution and abundance, showed that the one detection method was applicable to all growing areas in the Netherlands.

- **Implementation.** A pilot version of the method has been implemented. It allows decisions to be made on the need for control measures, cropping frequencies, the use of resistant cultivars, and yields, taking into account economic factors, thereby optimising the whole production system in relation to nematode control. In comparison to the reference years of 1984-88, soil fumigant use has decreased by 60-90% where the method is in use.

Alternatives for limiting nematodes

- **Break crops.** A range of plants is being examined at the Hilbrands Laboratory for their potential to limit nematode populations. It appears that most emphasis is on ascertaining their potential value as a break to the nematode cycle. With the intensity of cropping in the Netherlands it seems that a break crop would also need to be an economically viable rotation crop.

  It is understood that in other parts of Europe there is considerable use of rotation crops for limiting nematodes, particularly in sugar beet production. There are commercial seed companies selling various *Brassica* and other plants specifically bred for their ability to interfere with nematode breeding. These are known as trap crops.

  It is evident that there is considerable pressure to move in the direction of utilising antagonistic or trap plants for ameliorating soil pest and disease problems, driven by the push to cut back on fumigant use. It would appear that increasingly serious thought is being given to such alternatives. They will be more difficult to implement in the sense that, unlike a chemical fumigant, a single product is not going to be the universal solution. Cultivars appropriately adapted for different climatic conditions and cropping systems will be required. However, there is wide recognition of this trend and the groundwork for obtaining appropriate plants and developing appropriate systems is clearly being laid.

Photographs

The following photographs provide a pictorial summary to indicate various aspects studied during this tour. I have a more extensive set of slides on each of the subject areas, and also a video obtained in the USA and converted to PAL format entitled 'The proper handling and application of Telone' This was produced by the Dow Chemical Company, and although Telone is not registered for use in Australia, the methods are illustrative of and generally applicable to the use of metham sodium.

Copies of slides and the video can be provided on request.

Plate 1. Microplot used for studying the effect of various growing plants on nematodes under field conditions at Auburn, Alabama, USA. The terracotta sleeve is buried about 60 cm in the ground. Nematodes are introduced into the plot in an agar gel suspended on a fine mesh screen.

Plate 2. Microplots in the field at Auburn with various test plants growing in them. The natural conditions allow perennial plants to be grown over a long period more readily than in pots in a glasshouse.

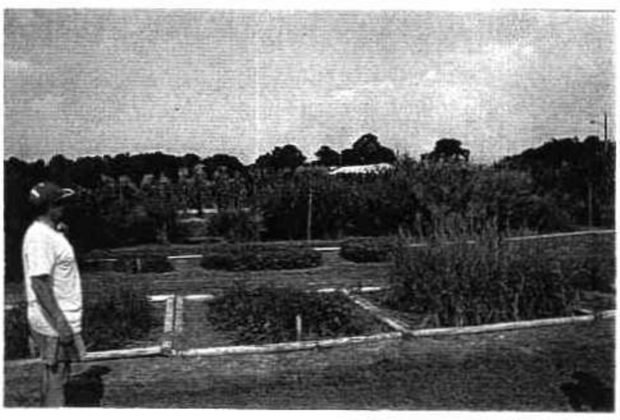

Plate 3. Large field plots of various plants being evaluated for their potential as nematode suppressors at Auburn, and to determine agronomic characteristics and suitability for use as rotation or break crops.

Plate 4. Plots of various plants being tested for their suppressive effect on potato cyst nematodes adjacent to, and in rotation, with a potato crop at Assen in the Netherlands.

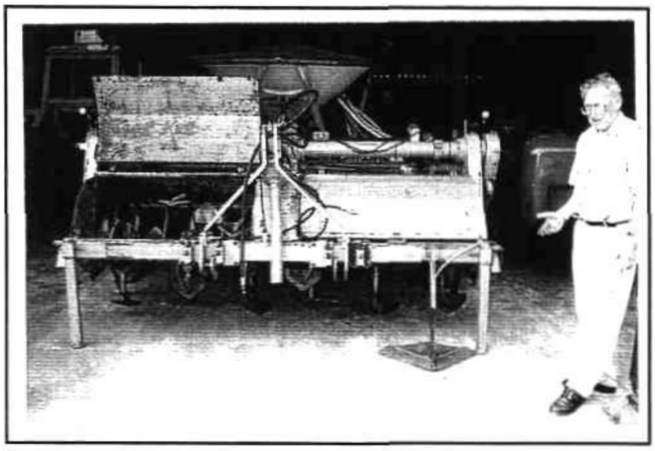

Plate 5. Spading machine used for applying soil fumigants at Assen in the Netherlands. The device was partly dismantled for the summer, as it is also used as a seeder. One 'goose foot' has been placed in position on the right and the left side hood lifted to reveal the spading blades.

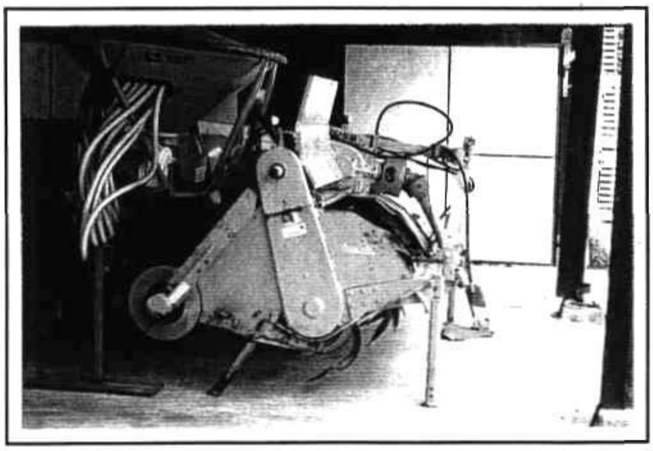

Plate 6. A side view of the spading machine, indicating the degree of curvature on the spading blades.

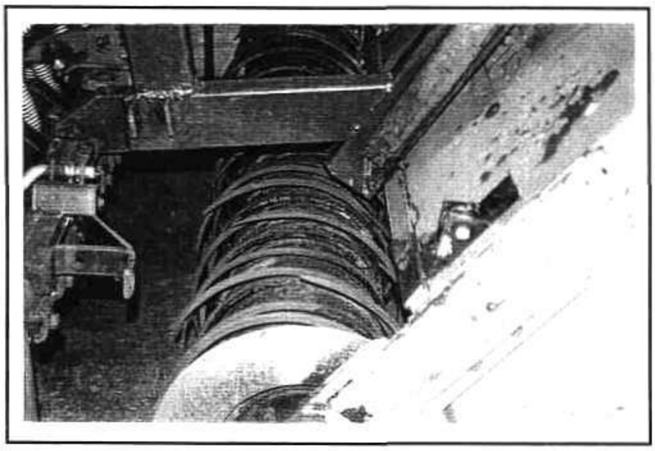

Plate 7. The tyned roller immediately at the rear of the shrouded spading compartment, indicating the long slender and highly curved tynes that are used to finely till the surface layer which is then compacted by the following powered roller. The roller is not shown as it had been removed, but it about the same diameter as the tyned roller.

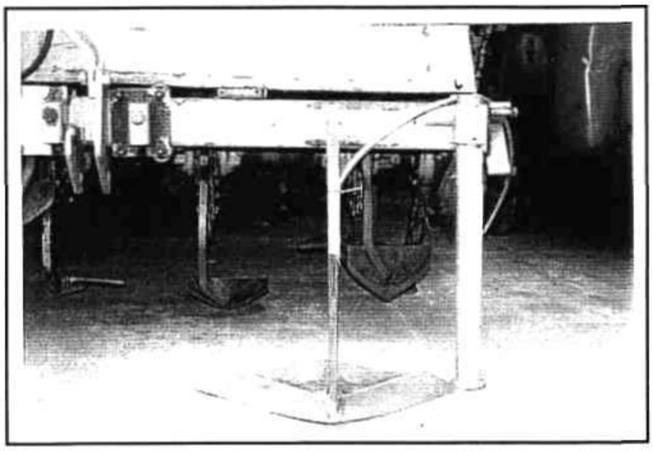

Plate 8. A closer view of a 'goose foot' and the shape and orientation of the spading blades.

Plate 9. The shape of the 'goose foot'. It has a single spray nozzle mounted near its centre. The fumigant is held in a pressurised tank, rather than being mechanically pumped to the nozzles.

Plate 10. Rig used for shanking 1,3-D fumigant into the soil at Prosser in Washington. This rig is used for fumigating experimental plots, hence the small size of the tank which is pressurised from a gas cylinder mounted alongside the engine of the tractor on the left side.

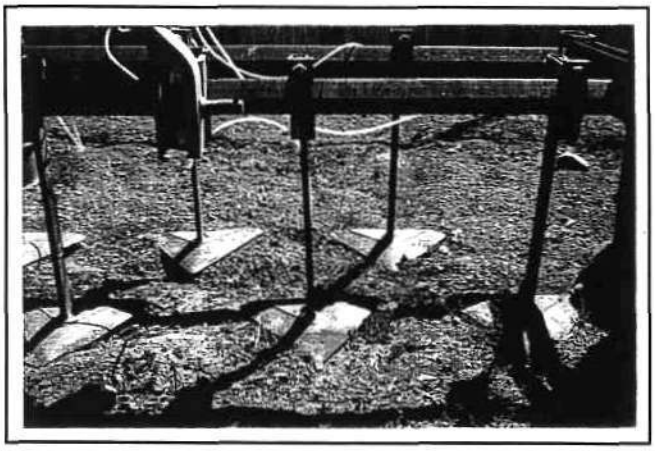

Plate 11. A 'goose foot' - style fumigant injecting rig at Prosser.

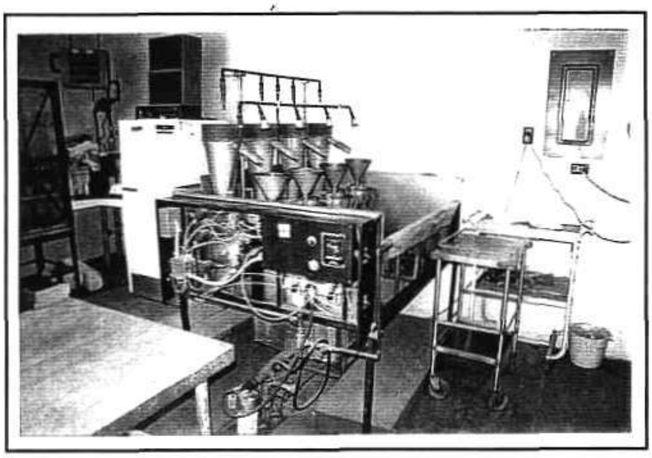

Plate 12. An elutriator for semi-automatically processing soil samples for nematode counts at Prosser. Similar devices were also used in the Netherlands.

Plate 13. Pitfall trap for determining direction of movement of whitefringed weevil adults from land planted to sweetpotato the previous season to a new crop growing adjacent. The Z-shaped sheet metal barrier funnels weevils into the apex where a pitfall trap is situated. The aluminium plates are rain covers.

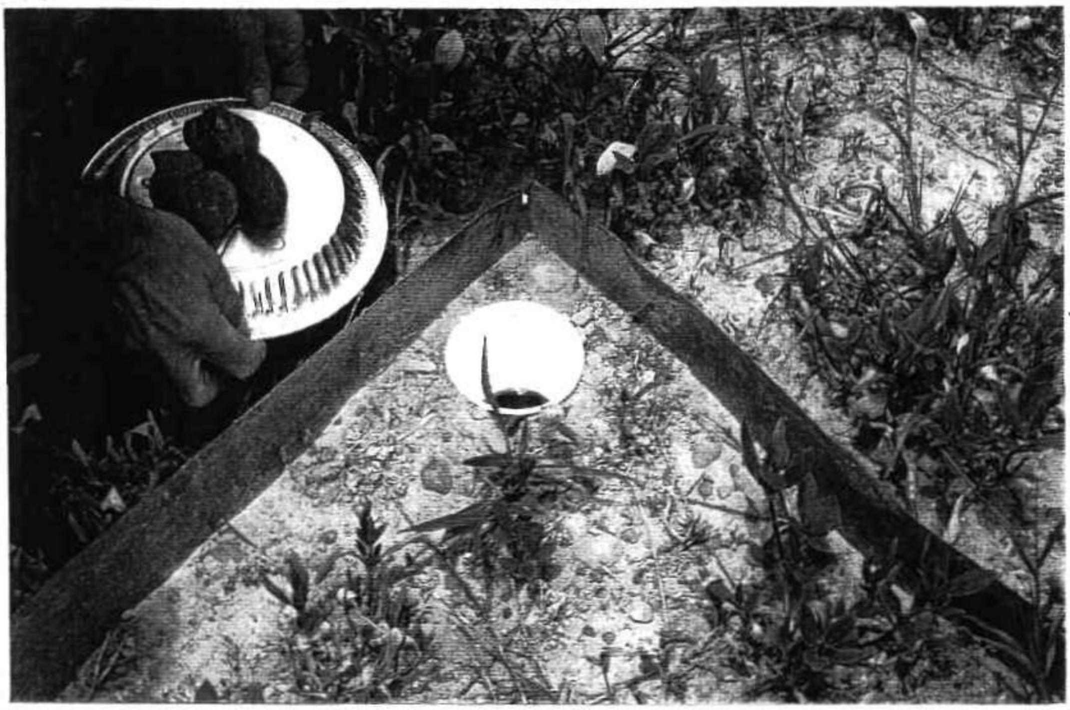

Plate 14. Close-up of the pitfall trap in the apex of the metal barrier.

Plate 15. Insecticide trial for Colorado potato beetle in potatoes in southern Idaho. The area of stubble in the background was where a potato crop had been grown the previous year. Beetles were moving in from that side and causing heavy damage, indicated by the browning of the crop area in the background.

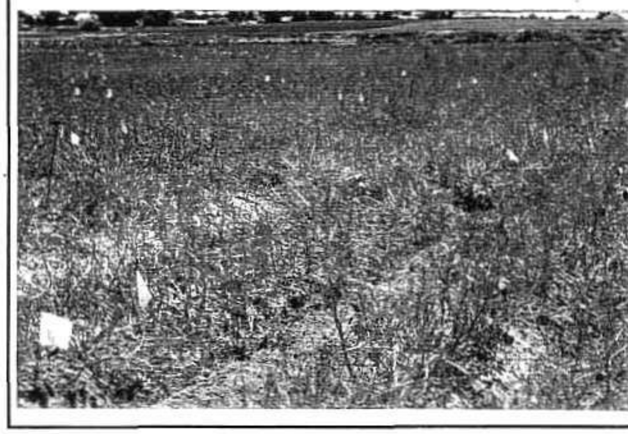

Plate 16. Closer view of the trial area where it was most heavily attacked by Colorado potato beetle. The mature plants were almost totally defoloiated by the heavy infestation of beetles.

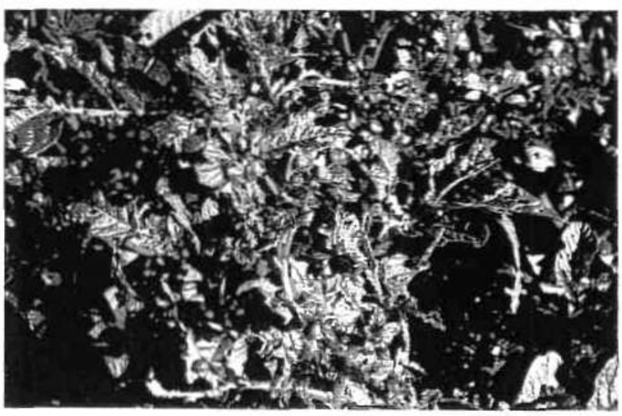

Plate 18. Colorado potato beetle larvae feeding on mature potato plants. Eggs are laid in clusters and the larvae move out over the plant as they feed. All stages of the insect are readily seen, so it can be effectively scouted. The critical problem with this insect is its capacity to rapidly develop resistance to insecticides.

Plate 17. One of the first commercial-scale plantings of the genetically modified NewLeaf Russet Burbank potato variety at a company field day. The plant is agronomically identical to the conventional Russet Burbank, but contains the gene causing it to express a *Bacillus thuringiensis* endotoxin at high levels, particularly in the leaves, thus making it toxic to Colorado potato beetle.

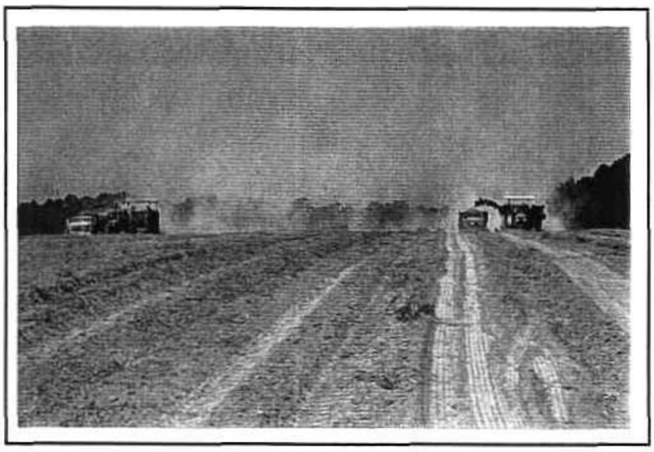

Plate 19. Harvesting potatoes at a relatively small (by northern US standards) operation in northern Alabama. Two twin-row diggers were moving through the dry, light soil at a high speed. Potato moth is not a problem in the area as it is elevated and cold during winter, so the soil can be left to dry.

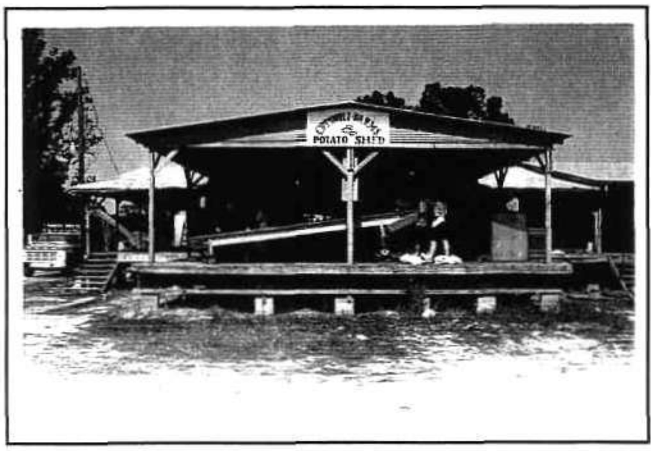

Plate 20. An on-farm washing and packing shed in northern Alabama, taking advantage of a narrow market niche for fresh redskin potatoes in June-July. The potatoes from the harvesters were trucked straight to the shed and unloaded into a washing sluice.

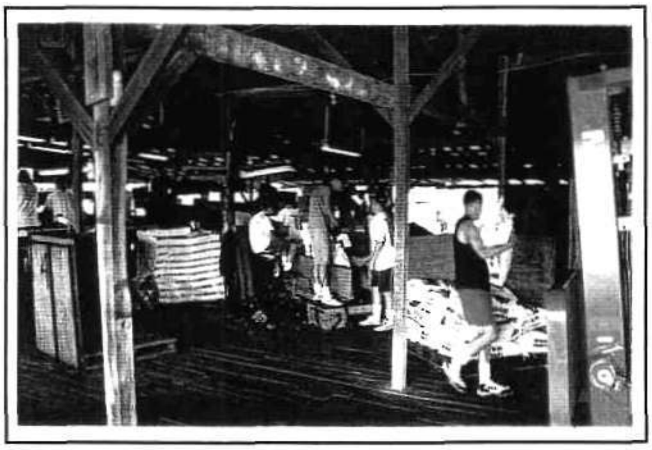

Plate 21. The potatoes coming up from the washing sluice at the rear are dried in sponge rollers, graded for size and quality, packed into 50 lb paper bags, sown and packed on palettes for immediate shipment to market. From field to bag could be as little as 15 minutes.

USA study visits

Laboratories visited and personnel

The laboratories visited were Auburn University at Auburn, Alabama, the University of Idaho at Moscow, Idaho and several of the University's field stations in southern and south-eastern Idaho, and the Washington State University Irrigated Agriculture Research and Extension Centre at Prosser in Washington State.

At Auburn University, Dr Geoff Zehnder is a research and extension entomologist responsible for development of Integrated Pest Management programs in vegetable production. He is the Alabama state extension IPM coordinator. Each state has a person filling this role as central contact for the state in IPM matters. A major pest is whitefringed weevil, which attacks a range of crops in the south-eastern USA, particularly sweetpotato and peanuts. Dr Rod Kábana is a nematologist with considerable experience in the assessment of plants with potential as alternative crops or rotations for management of various nematodes.

At the University of Idaho main campus at Moscow in northern Idaho, Dr Joe McCaffrey is Professor of Entomology and has recently worked in collaboration with Dr Matt Morra, Associate Professor of Soil Biochemistry, Postdoctoral fellow Dr Vladimir Borek, and PhD students Paul Brown and Jim Gardiner), chemically profiling and quantifying the isothiocyanate degradation products of various Brassicas, their site of production and patterns of release, and in association with Research Associate Leslie Elberson, their toxicity to soil insects.

At various research and extension centre (R&E) field stations of the University of Idaho in the south of Idaho in the major irrigated agricultural production regions of the Snake River valley, various researchers and extension specialists are investigating management methods for insects (Drs Craig Baird and Tom Mowry - Parma R&E; Dr Bob Stoltz - Twin Falls R&E), nematodes (Dr Saad Hafez - Parma R&E) and weeds (Dr Charlotte Eberlein - Aberdeen R&E) in potatoes. The Idaho state coordinator for IPM is Dr Ed Bechinski, based at UI Moscow. The University of Idaho also has a *Brassica* breeding program (Dr Jack Brown, Dr James Davis) at Moscow.

The irrigated Agriculture Research and Extension Centre at Prosser in the Yakima Valley of Washington state is a substantial field station of Washington State University which has its main campus at Pullman, further east in Washington. The facility is shared by the university and the US Department of Agriculture Agricultural Research Service (USDA/ARS). Dr Gerry Santo is Professor of Nematology and in collaboration with colleague Dr Hassan Mojtahedi has carried out studies on the management of nematodes with fumigant and non-fumigant chemicals, problems of nematode control caused by enhanced degradation, and is examining the potential of green manure crops for suppression of nematodes. A systems engineer/plant pathologist with USDA/ARS at Prosser, Dr Sally Schneider, is researching precision farming systems.

The following section summarises various aspects of soil pest biology, management and fumigant use from information obtained at the three institutions and associated field and R&E station visits.

Whitefringed weevil

- **Species.** The south-eastern USA has two whitefringed weevil species occurring together - *Graphognathus leucoloma* (which occurs in Australia) and *G. peregrinus*, a generally smaller species. There appear to be differences in their biology such as development duration.

- **Pest status.** The two whitefringed weevil species are general pests in the SE USA. The main crops affected are sweetpotato and peanuts, but reports of damage to crops as diverse as watermelons occurred in 1995.

- **Biology and management.** Geoff Zehnder's current studies are focussed on determining the distribution and movement of whitefringed weevils in and near sweetpotato crops, in order to develop crop rotation guidelines and for optimal timing of benign, foliar insecticides for the reduction of adult populations and subsequent egg-laying. Traps are placed to determine whether adults move from fields rotated from previous-years' sweetpotato land, which is kept fallow, into an adjacent new sweetpotato planting. Movement of adults within the newly-planted sweetpotato field is also being studied to determine whether there are any patterns relative to damage or management. Soil insecticides are also being tested (primarily fonofos), with and without foliar sprays of Imidan for adult control.

  Because of the sub-tropical climate in the SE USA, and the growing of crops during summer, whitefringed weevils emerge early during crop growth, feed on the foliage, and lay eggs which develop immediately into larvae which are large enough to damage the crop later in its life. This is in marked contrast to the pattern of whitefringed weevil biology in the cooler temperate potato-growing regions of southern Australia, where whitefringed weevil larvae from eggs laid 6-8 months earlier cause damage in spring potatoes, with no adults being evident in the foliage of the crop. However, any success with strategic foliar insecticide application to reduce adults and subsequent larval abundance could provide some useful pointers for Australia, as we have so far had inexplicable difficulty with this approach in pasture prior to cropping.

- **Predictability.** As in Australia, studies of whitefringed weevil in the US have often been hampered by unpredictability of population development in a given area. Areas apparently free of the insect can suddenly become infested, while areas infested in one season may be free of it in the next. Unlike Australia, the economics of production do not allow for prophylactic application of expensive controls such as fumigants.

- **Biotypes**. Specimens of both whitefringed weevils from the SE USA have been sent to our mutual New Zealand collaborator on the International Collaborative Research Program, as part of the effort to determine genetic diversity among populations in Australia, New Zealand and the USA. The inclusion of specimens of the second species, *G. peregrinus*, from the US will provide a very useful means of checking whether the DNA primers being used are appropriate.

Nematodes

- **Pest problem**. Root-knot (*Meloidogyne* spp.) and some cyst nematodes are important yield-limiting soil-borne pests in the production of many vegetables, potatoes, peanuts and soybeans in the USA. In potatoes, the Pacific North West area is heavily afflicted, especially in the eastern part of Washington where climatic conditions allow a longer growing season and favour development of extra generations, particularly of the Columbia root-knot nematode (*M. chitwoodi*) because of its lower temperature requirements, and the soils are light. Potatoes are grown there on a 3-4 year rotation.

  The end-market driven preoccupation with the Russet Burbank potato cultivar in those areas adds to the growers' difficulties as it is particularly susceptible to exhibiting symptoms of nematode attacks. Nematodes cause warts on the surface of tubers and brown spots within the flesh which dramatically lowers tuber quality, especially for processing. The economic threshold for *M. chitwoodi* is 1 juvenile/250 cc of soil.

- **Chemical control.** Chemical control with fumigants or nematicides is normally limited to higher-value crops such as potatoes and peanuts, or where there are no alternative control methods. Chemical use is high in the Pacific North West, where a combination of fumigant (1,3-D or metham sodium) and non-fumigant (ethoprofos (Mocap)) nematicides are used in the most heavily infested areas. Telone II is applied in the autumn and Mocap pre-planting. In Washington, 70-80% of potato crops receive nematicide treatments at an annual cost of around $US20M.

  Telone II is more effective at greater depth in the soil, and is more consistent than metham sodium, giving 'control' rather than 'suppression'. In the late 1970's metham sodium was shown to control *Verticillium* when applied in irrigation water and use increased. The fine sandy soils favour this method of application, and the application can be done directly into undisturbed cereal stubble, minimising soil erosion. Metham sodium applied in this way is effective high in the soil.

  Telone is often applied using shank injectors. The shanks are typically 60 cm apart, with application at 35-45 cm depth. It is important to close the channels caused by the shafts of the shanks to avoid losses of the fumigant by a 'chimney' effect. This is accomplished using a 'cultipacker' which is wheels with bars across, followed by a roller to seal the surface. There is a general move to ensure emissions are minimised as part of good practice and good citizenship.

I was not able to see one of the latest devices which sounded somewhat similar, at least in principle, to the Dutch spading device, as the local implement was fully pulled down for summer maintenance. A 'Noble plough', which has a broad wing-shaped blades with nozzles underneath is also used for fumigant injection.

It appears that, at least in parts of Washington, that as part of a potato grower's contract with a processor, it is a requirement to fumigate for nematode control. Telone II (1,3-D) use has been banned in California because of health and environmental concerns.

- **Rotation crops**. Rod Kábana's group at Auburn University are examining many different and often unusual plant species for their potential to suppress nematodes, and also the effect of organic amendments. Particular attention is directed at tropical and sub-tropical species because of the climate in the SE USA. Rotation crops have typically been of low value and a key element in the research is to find alternatives that are antagonistic to nematodes and offer prospects of being crops with reasonable value in their own right, or as a higher-protein stock fodder.

A recently-developed method for delivering nematode inoculum into soil in field plots on alginate films suspended on fine mesh has proven very successful in allowing evaluation under field conditions of the effects of the test plants and amendments.

The use of 'microplots', which consist of earthenware sleeves in the soil, allows testing of full-size plants under field conditions while maintaining good control of the nematodes being tested by utilising artificial infestation. This system would seem to have considerable potential for testing biofumigation plants against soil insects in the Australian program, as it confines soil-dwelling stages such as larvae, while allowing soil moisture and temperature conditions, and plant growth to be largely unaffected. The system offers significant advantages over pot experiments in the glasshouse, and has been used with considerable success by Rod Kábana's group for a very large range of test plants over both short and long-term studies.

These studies have found that it is not enough simply to have non-host plants to suppress nematodes, but the plants need to be 'active' in producing products that are toxic, such as cyanide, polyphenolics or those that favour antagonistic microflora. Several crops have been found to be as effective as aldicarb (Temik) for reducing juvenile population densities, and yields of peanuts have been as good as with aldicarb. Some tropical legumes gave good suppression when root-knot and cyst nematodes occurred together. This is useful in soybean production as few soybean cultivars have combined resistance. It is not economic to use chemical nematicides in peanut.

At Parma in Idaho, Saad Hafez has worked on the effectiveness of trap crops for nematodes. There is a range of trap crop cultivars commercially available, through Hilleshog (Sandoz Seeds). These are all Brassicas, being several radishes and mustards. The Humus fodder cultivar is commonly used and is given about ten weeks' growth before being ploughed in. The trap crops work by producing the hatching factor exudate from their roots, the females are unable to form the nutritive giant cells, and sexual differentiation becomes heavily male-biased (100:1). As a consequence, reproduction is severely inhibited, and the population declines. Reductions range from 50-75% and yield increases from 15-50%.

At Prosser, Gerry Santo's team have examined rotation and green manure crops for effects on nematodes. Rapeseed gives more consistent results than Sudangrass. Sudangrass is a poor host, and when incorporated further reduces nematode populations. It was initially thought that the cause was production of hydrocyanic acid, but high and low HCN sudan grass cultivars give the same level of suppression of nematodes. Sudangrass is becoming more popular as a break crop and it usual to get one cut of hay then incorporate it into the soil in autumn. It is essential to get a dense plant stand for good effect against nematodes. When green manure crops have been used in conjunction with the non-fumigant, Mocap, results comparable with use of the fumigant Telone II have been achieved. Rapeseed was better than Mocap alone. Planting rapeseed in autumn for incorporation in spring helps minimise soil erosion caused by high winds which are common in potato-growing regions of the Pacific north-west.

Another rotation is wheat or sweetcorn, which are short-season crops, followed by sudangrass which is incorporated and then followed by potatoes in spring. This reduces nematodes and give soil benefits by increasing organic matter and improving soil structure. If fumigants are removed, it is felt that green manures in combination with contact nematicides (ethoprofos - Mocap) would be an effective management method.

Various other potential green manure crops are being examined, such as lupins which are being assessed on the basis of variation in their alkaloid content, also meadowfoam (*Limnanthes alba*) which is like rapeseed and is grown for industrial oil. Its seed meal is a potent nematicide and weed killer.

- **Problem soils**. The phenomenon of 'problem soils' occurs in Washington state, and refers to the situation where fumigants are ineffective. It was first noted about 10 years ago, but it is now evident that the phenomenon occurred earlier. Initially it was thought to be a case of enhanced degradation. It now appears that the phenomenon is something inherent in the soils in which it occurs.

When tested in soil columns taken undisturbed from the field, with fumigant added to the top, nematodes were controlled only in about the top 30 cm. Even if the soil was mixed and re-packed into the columns, the effect was the same. Different wetting agents had no effect. Examination by soil scientists has failed to shed light on the phenomenon and at present it remains unexplained.

Typical enhanced degradation occurs in the US. In Washington, it has occurred with ethoprofos after two consecutive year's applications.

- **Plant growth-promoting rhizobacteria**. A field of research being very actively pursued is the application of plant growth-promoting rhizobacteria (PGPR) in agriculture. PGPR are a diverse group of beneficial rhizobacteria that actively colonise plant roots. Beneficial effects include the suppression of pathogens, direct growth promotion, increasing nutrient availability, enhancing legume inoculation by *Rhizobia*, and inducing systemic disease resistance. Hence the ability of these bacteria to promote growth of plants. Recent studies have even shown that PGPR can exert a negative effect on a leaf-feeding insect.

  The growth promotion effects of PGPR can be quite spectacular, and application of specific strains has resulted in increased yields in various crop plants. Several PGPR-based inoculants are commercially available, including a product known as Kodiak which is registered in the US for use on cotton and beans to suppress *Rhizoctonia solani* infection. Tests with promising results have also been carried out using a PGPR applied to seed potatoes that are green-harvested (to avoid the use of herbicide desiccants) and then re-buried to mature, to suppress bacteria associated with potato blackleg disease.

Biofumigation

- **Glucosinolate chemistry**. The multi-disciplinary team at the University of Idaho has over the last several years concentrated heavily on fundamental research into the chemistry of glucosinolate breakdown into isothiocyanates. Established analytical methods allowed quantification of glucosinolates in soil, but not the biologically active breakdown products.

  The Idaho team has successfully developed comprehensive analytical techniques and procedures for the analysis of a wide variety of glucosinolate-derived chemicals in soil. The techniques use established gas chromatography-mass spectrometry methods. The refinements have been in developing systems to measure the particular glucosinolate and isothiocyanate compounds. The types of degradation products produced, the conditions leading to particular degradation pathways, side reactions and transformations of the resulting toxic compounds following their formation have all been the subject of detailed study using the techniques developed.

- **Role of degradation products.** Determining the role of glucosinolate degradation products is complicated by potential effects of other compounds, side reactions leading to less toxic non-isothiocyanate products, and rapid transformation of isothiocyanates into non-toxic products because of chemical reactions with the mix of plant and soil. The Idaho group has directed major efforts at understanding the effects of isothiocyanates on target organisms, so as to better be able to predict the effects of soil amendments of *Brassica* species plant material.

- **Toxicity against soil insects**. The Idaho team is the only research group that I am aware of that has investigated in detail the effects of glucosinolate breakdown products from *Brassica* plant residues against soil-dwelling insects. It is only because of the multi-disciplinary research approach of entomologists teaming with chemists that they have been able to couple bioassays with chemical analysis of glucosinolates and their degradation products to determine specific, new details of interactions that offer potential to be exploited to enhance toxic effects on soil-borne pests. Most significant among these is the recent finding that isothiocyanates containing an aromatic moiety (phenyl, benzyl and 2-phenylethyl) are considerably more toxic to insects than those containing an aliphatic moiety (methyl, propyl and allyl).

  The main soil insects that have been used in tests are wireworms and the black vine weevil. Wireworms were a convenient easily-handled insect suitable for initial robust bioassays to gauge initial effects. The black vine weevil is a major pest in plant nursery production and is the subject of fumigant treatments, often with methyl bromide, which will eventually be banned. Current studies are investigating the toxicity of various isothiocyanates against the black vine weevil, as a precursor to testing appropriate plant residues as an agent for managing the insect. It was these studies that revealed the greater toxicity of the aromatic isothiocyanates.

  Notably, of twelve organic isothiocyanates tested for contact toxicity to eggs of the black vine weevil, methyl isothiocyanate was the <u>least</u> toxic. This very recent result is of particular interest as our recent studies in Australia have shown that methyl isothiocyanate, which is the breakdown product of metham sodium, is highly toxic to whitefringed weevil larvae, more so than other non-isothiocyanate fumigants, including methyl bromide. The knowledge that the quite potent toxicity of methyl isothiocyanate can be substantially exceeded by other plant-derived isothiocyanate forms is highly encouraging news. It appears that plant tissues containing higher molecular mass isothiocyanates may have greater insecticidal toxicity.

  Further, more fundamental, studies have recently been carried out by the Idaho group to determine the quantitative relationship between the structure of organic isothiocyanates and their contact toxicity against black vine weevil eggs. Highest contact toxicity resulted from the most hydrophobic or lipophilic isothiocyanates, those being ones with higher numbers of carbon atoms in the molecule or those bearing sulphonyl, thin or aromatic moieties.

- **Plant selection**. Tests of the toxicity of soil treated with seed meal from commercial rapeseed cultivars showed mortality of black vine weevil larvae, but at quantities of seed meal too high for practical use. This was not unexpected, as commercial rapeseed is not particularly high in glucosinolates, but it did demonstrate that soil can be made sufficiently toxic to kill insects. Plant breeders have the capacity to select for cultivars high in glucosinolates, as they have done to reduce them in edible-oil Brassicas. The knowledge that particular isothiocyanates are more toxic than others will help breeders produce cultivars with appropriate glucosinolate profiles.

- **Root exudation.** Investigations have also been carried out into methods for measuring for the release of glucosinolates and formation of isothiocyanates in the soil around growing roots of *Brassica* plants. The types of glucosinolates present in plant (rapeseed) roots, their quantitative shifts with plant development and the release patterns and types of isothiocyanates have been measured in very recent studies. Plants grown in sand in large syringe-like devices allowed air to be passed through the soil and analysed by gas chromatography-mass spectrometry.

  Eleven different glucosinolates were measured in the roots, but almost none occurred in the soil around roots. However, isothiocyanates did occur in the soil, principally the 2-phenylethyl form. It is speculated that myrosinase, the enzyme present in cell walls that catalyses the breakdown of glucosinolates to isothiocyanates, may be released in root cells sloughed off as the plant grows and are rapidly reacting with the glucosinolates to produce the isothiocyanates. This would account for the virtual absence of glucosinolates in the soil in the root zone.

  It is unclear how the glucosinolates are exposed to myrosinase, whether it is in the soil or simply as cells are damaged as the plant grows. This work would appear to have only scratched the surface of defining the production and release patterns of isothiocyanates into soil during plant growth. The implications of isothiocyanate production during growth could be highly significant for temperate systems where whitefringed weevil occurs because of the presence of the small hatchling larvae for several months during winter when a *Brassica* break crop would be grown.

Potato insects

- **Foliage and soil insects.** Trials being carried out by Craig Baird and Bob Stoltz are examining a large range of pesticides ranging from conventional chemicals to Bt formulations and azadirachtin (Neem seed extract) against foliage-feeding and soil insects in potatoes. As it was mid-summer at the time of my visit, crops were in full growth, with most around flowering and trials had yet to be evaluated.

  Some spectacular examples of Colorado potato beetle (CPB) damage were observed on Craig's plots. Defoliation was almost complete in untreated plots with gradations of effectiveness in treatments often being visually very evident. Several agents with new chemistry were under trial against CPB. It is easy to see why CPB is such a feared pest. As was mentioned above in relation to policy issues and trends in the conference summary section of this report, I attended a field day demonstrating commercial plantings of the transgenic Bt-enhanced potato, but the absence of a local CPB infestation nullified its impact.

The main soil pest is wireworms. It appears not to be severe on a wide scale, but rather seems specific to certain areas. Trials concentrated on chemical control agents, azadirachtin and methods of application. Aphids were also targetted in the trials.

Precision farming

- **Possible trends**. While the work being carried out at Prosser by Sally Schneider was not presently directly related to potatoes, it was revealing to get information on the extent to which global positioning system (GPS) has advanced. It is now possible to obtain precision of location to within 8 cm. This sort of technology clearly has implications broadly in agriculture in the longer-term, with precision pest management being an obvious area where applications are likely to be found.

Potato farm - Alabama

- **Alabama harvest**. While in Alabama, I visited a potato farm in the north of the state during harvesting. While potato production is relatively minor in Alabama, the growers take advantage of a profitable, brief market niche for fresh-market table potatoes between the finish of harvesting in areas further to the south and the commencement of harvesting in areas further north and west. During a few weeks it is possible for the Alabama growers to receive high prices for their potatoes.

  The farm was owned by Rex Cresswell, who has served as the Alabama representative on the National Potato Council, and is the immediate past-president of the national Potato Promotion Board. Because of the brevity of the market niche, the desire to exploit it maximally, and because of the relatively small scale of production, the potatoes (red skinned variety) were being washed and immediately packed into 50 lb paper bags under various labels on-farm and trucked out. The operation was relatively labour-intensive, but because it coincided with summer holidays, quite a large number of teenage students were employed in the washing, grading, packing and bag-sowing operation and throughput was high. The peak price received was $12 per 50 lb bag.

Other

While overseas, I presented three seminars on the Australian soil pests and diseases biology and management program at Auburn University, the University of Idaho and at Washington State University, respectively.

Discussion and recommendations

Fumigant use

There are significant moves away from the use of fumigants for the control of soil-borne pests and diseases in potatoes and other ground-crops in several parts of the world. Most notably this is occurring in countries (eg. the Netherlands) or regions (eg. California) where usage has for some time been extremely high. In large part, this trend is probably a backlash from societal trends that in many parts of the developed world seems to devalue agriculture or see it as a polluting ogre to be restrained. But it probably also partly reflects excessive or ill-founded use of such chemical agents, perhaps driven largely by promotion of the promise of the 'silver bullet' that will miraculously solve complex problems in a simple way. **We in Australia must be cognisant of such trends overseas, and be cautious in dismissing them as peculiar to certain abnormal or unusual situations.**

While Australian use of soil fumigants is undoubtedly low by world standards, it appears to be growing at a rapid rate. The absence of a central database of pesticide use in Australia does, however, make it exceedingly difficult to obtain such information. This particularly has adverse ramifications for pest management researchers attempting to develop research projects for industry with the rational and economically-based focus demanded. Furthermore, it makes it difficult to put Australia into perspective with other countries, and could make for difficulties in substantiating a 'clean and green' image. **The absence of a central source for obtaining up-to-date information on pesticide usage in Australia is a serious deficiency that urgently needs redressing.**

As other nations limit their use of fumigants, there seems to be a likelihood in the long term that pressure could mount internationally to restrict more widely the use of such agents. With growing globalisation, the freedoms of nations to follow their own agendas is diminishing and can be restrained by formal international agreements or the use of the non-tariff trade barrier weapon.

While the use of fumigants (excluding methyl bromide) in Australia seems unlikely to encounter international sanctions in the near future, it behoves Australian industry to recognise the potential of overseas trends, some of which are quite aggressive, to impact on practices here whether they be based on a rational assessment of the Australian situation or not. Any health or safety 'scares' with fumigants overseas potentially could see companies withdraw the agents from this small market for prudence, as appears to have happened with 1,3-D (Telone II). It is also important to remember that fumigants such as metham sodium are expensive and diminished margins from cost-price pressures could put pressure on the viability of use in the longer term. **We in Australia need to be aware of, and prepared for, the possible spillover pressures of aggressive limitations on fumigants elsewhere, in the long term.**

Overseas fumigant application practices have been tuned for high efficiency as the result of a long period of basic and applied research, but the equipment that has evolved is very expensive and contractors carry out most applications. There would seem to be scope for increasing the efficiency of fumigant application, at least in parts of Australia. While this could probably be achieved by importing expensive application equipment, it may be possible to adapt or modify present methods to enhance their efficiency based broadly on knowledge of the principles of fumigant diffusion through soil gained from the overseas studies. Fumigant chemicals have a place in horticulture, but over-use or mis-use will draw criticism and a potential backlash. **Awareness of efficient fumigant application practices should be heightened, for its immediate value and to demonstrate responsible policies.**

One of the greatest problems with managing soil-borne pests is that very often it is not known whether a damaging population is present in a field scheduled for planting to a crop, or damaging densities may be localised to small parts of the field. The problem of knowing whether a pest population is actually present is particularly acute with soil pests that are usually present in very low abundance. It has been found in many instances of control 'failure' overseas that, in fact, the 'successful' control was simply because the pest was not present.

These 'failures' often revealed the presence of the enhanced degradation phenomenon (see below). However, when 'successes' were checked it has been found that soils in those areas were also adapted for enhanced degradation. In such instances the apparent 'success' of control was a fortunate instance of the absence of the pest. In such cases the need for pesticide application was not required and could have possibly saved considerable cost, and excessive use.

The development of effective sampling schemes for determining the real need to apply fumigants has further enhanced the efficiency of fumigant use in countries such as the Netherlands. The schemes rely on efficient methods for taking soil samples and processing them to determine the level and pattern of nematode infestation, and are again carried out by contractors. Is it easy to envisage in the future the application of precision farming technology to map the precise location of individual soil samples and then to apply pesticides just where they are needed. In the case of nematodes in the Netherlands, these can be highly localised small areas within a large field. If such methods for the use of fumigants had been available in the beginning, one could conceive of over-use having not become an issue. **There are many aspects of achieving effective targetting of soil pesticide treatments that the horticultural industry in Australia needs to be aware of, even if there is not the economic or technical wherewithal to implement them at present, as they are certain to evolve in the longer term.**

Enhanced degradation

The development of enhanced degradation of soil-applied pesticides (with the except of methyl bromide because it is non-organic and halogenated) has occurred widely in Europe and the USA. Frequently it has not been readily recognised because of the absence of the pest organisms to cause damage, and hence in the process reveal that the pesticide no longer has pesticidal efficacy (see above).

Enhanced degradation occurs most readily where the pesticide is used frequently. I am not aware of enhanced degradation having been identified or reported in Australia, but with increasing use of metham sodium it is important to recognise the very real potential for the phenomenon to develop. **People in contact with industries using soil pesticides need to be attuned to reports of 'control failure' as overseas experience indicates that these are the first indication of enhanced degradation and the development of so-called 'problem soils'.**

The best defence against the development of enhanced degradation is to ensure that the pesticides are not used too frequently on the same area of land. At present, with relatively long rotations for potatoes, at least in Western Australia, the likelihood of soils developing enhanced degradation would appear to not be very high. However, nothing is known about the capacity of these soils to change, and how or how quickly their microbiological biota responds to fumigant application. **As a rule of thumb to avoid development of enhanced degradation, application of metham sodium to an area should ideally be little more than one year in about four or five.**

Biofumigation and organic amendments

The work that has been carried out by particularly by the multidisciplinary group in Idaho has concentrated on basic studies of chemical composition, breakdown products, release patterns and toxicity of isothiocyanates. These studies are unique and have been of fundamental importance in indicating the positive potential of the biofumigation approach as a weapon in the management of soil-borne pests and diseases. Findings such as that aromatic isothiocyanates are markedly more toxic to insects than aliphatic variants, and the release of isothiocyanates by growing roots are highly significant as they indicate the potential to manipulate the appropriate plants and develop systems appropriate for particular pest organisms.

The Idaho group appears to have now reached a first point of maturation of their work. Several PhD students are finishing their theses and the group has a considerable number of scientific papers in press and in preparation. They appear now to be at a stage where testing of various aspects of their basic findings against various pests in different systems is required, and they are keen to identify appropriate systems. In my seminar presentation I detailed the biology of whitefringed weevil and outlined our present conceptual notion of how the biofumigation approach may be applied in our system. Discussions with the Idaho investigators concurred with my view that, on the basis of the insect spending several months during winter in the soil as small first-stage larvae, it would seem that we have an ideal system to evaluate the concept as far as soil insect management is concerned.

Black vine weevil, which is the major test insect for the Idaho group has hatchling larvae that are extremely sensitive to desiccation. This makes the carrying out of assays against the larvae and obtaining details of how the biofumigant agents are working particularly difficult. The resistance to desiccation of hatchling whitefringed weevil larvae makes them an ideal soil insect with which to carry out *in vitro* assays which are an essential first step in testing and measuring effects as it avoids the complication of extracting the insects from soil. This attribute has already been used with success in our evaluation of a range of pure fumigants against whitefringed weevil (paper submitted to the Journal of Economic Entomology in June 1995, and the information summarised in an article in the WA 'Potato Grower' magazine, May 1995).

The studies carried out by the Idaho team were aimed at revealing details of the types and release patterns of different isothiocyanates from Brassicas, and to indicate their relative toxicity. This analytical approach is a major step forward from the empirical approaches that, although valuable in indicating the potential and usefulness of rotation and green manure crops, were unable to offer specific explanations for the effects observed or to aid in understanding what might best improve the effects. Such information will have greater prospects for leading to customising plants for enhanced performance. The Idaho group's approach is philosophically similar to ours in Australia and highly complementary. The contact will be fostered with a view to potential collaboration for mutual benefit.

The work of Rod Kabàna at Auburn University concentrated on screening a wide array of plants, mostly of tropical and sub-tropical origin, for their effects on nematodes while growing. By using a recently-devised and unique method for placing known samples of nematodes in the root zone, and using microplots, his group has been able to carry out examination of effects under more realistic filed conditions. The approach of using such microplots appears to be applicable to other organisms, notably whitefringed weevil. The idea of restraining the insects in the root zone, while probably fraught with more difficulties than restraining microscopic nematodes in a gel, is worthy of consideration as a means to avoid destructive sampling.

The extensive array of plants identified at Auburn as being toxic to nematodes begs the question as to what agents are present in the plants to cause such effects. It seems that there is great potential for chemical studies of these plants to answer such questions as the implications could then probably spread more widely.

The use of organic amendments for nematode control such as the chitin-based commercial product Clandosan, which was developed by the Auburn group requires large quantities and is therefore only applicable to intensive situations.

The use of trap crops for suppression of nematodes is now well established in Europe and the USA, with significant commercial involvement by seed companies. At present, it seems to be primarily used in the sugar beet industry, but the success there should spawn applications outside that niche. At the least, it demonstrates that the technique is effective and workable. Because most of the trap crops are Brassicas, it will not be surprising to see studies being undertaken to examine in more detail some other possible effects such the combination of the trap effect and effects of isothiocyanate release, which could lead to selection of trap crop cultivars that are also high isothiocyanate producers.

The screening of potential break and green manure crops being carried out in the Netherlands and the USA should begin to be enhanced with the increased knowledge of the fundamental chemical processes becoming available. This information will help define details of the mechanisms underlying observed effects and provide opportunities and the impetus to better tailor plants and systems for greater impact.

This tour has indicated that there is a growing need and pressure for alternative means of managing soil pests and diseases to the use of chemical fumigants, whether the needs be relatively urgent in situations where fumigant reductions are mandated, or where a view of the future suggests that exploration of alternatives is prudent. It is clear that there is significant potential to select and enhance plants for their biotoxic properties, based on sound information about their properties and those of the target organisms so that they may be most effectively applied. It is a developing field that Australia has the potential to be in the forefront of, so maximising the opportunities to collaborate with leading overseas groups at an advanced level, for mutual benefit.

The field of research into plant growth-promoting rhizobacteria (PGPR) is likely to burgeon as an increasing number of positive attributes of these organisms is revealed and more are isolated. Whether there is likely to be applicability in the potato industry is unclear at this stage, but it is a developing area worth keeping a watch on.

Effective research programs

An aspect of potato-related research in both the Netherlands and the USA that stood out was the strong degree of interdisciplinary integration and collaboration amongst researchers. While the scale of operations in the USA, for example, is often large enough to support strong interdisciplinary teams at University Research and Extension Centres ('Field Stations'), there is still often strong collaboration between researchers located at geographically separated sites. This may be within or between states, and within or between organisations. The major push towards the implementation of integrated pest management over much of US agriculture will be heavily dependent on high levels of collaboration laterally between disciplines and vertically in the research-development-adoption spectrum.

There appears to be a strong desire and commitment at the researcher level to integrate more basic or strategic research with applied studies to address issues and problems in a comprehensive way. What was noticeable was that no one person or small group seemed to be placed in the position of having to know (or do) everything. Hence there seemed to be less demand for being expected to be a jack-of-all-trades and master of none, which has the potential to risk diminution of fundamental expertise and innovative capacity in the longer term. Teamwork and partnership was the order of the day, and it showed in the common-good nature of the outcomes.

Research, development and transfer to industry based on a multidisciplinary team approach should be encouraged in Australia. Collaborative research across state or organisational boundaries is eminently possible in the modern world. Such approaches need to become part of the industry/research ethos in Australia. With it, however, care needs to be taken not to lose the capacity to carry out more fundamental and longer-term strategic research in a rush for 'silver bullet' answers to complex problems, as they generally do not exist or those that appear so are seldom durable. Clearly, nowadays a culture of multidisciplinary research, development and adoption can most readily be guided, fostered and facilitated by funding agencies such as the Horticultural Research & Development Corporation.

Appendices

Appendix 1

Abstracts of the posters presented at the International Plant Protection Congress.

Appendix 2

Copy of the abstract of a paper by Dr David Dent commenting on the issue of research specialisation and integration for pest management.

J N Matthiessen
August 1995

Appendix 1

European Journal of Plant Pathology

XIII INTERNATIONAL PLANT PROTECTION CONGRESS

THE HAGUE — THE NETHERLANDS — 2-7 JULY 1995

ABSTRACTS

Kluwer Academic Publishers

CHALLENGES IN IMPLEMENTING IPM FOR LOW ECONOMIC THRESHOLD SOIL INSECT PESTS

J. N. Matthiessen

In parts of Australia soil-dwelling insects are major pests of potatoes where production is rotated with pasture. The main species are the accidental introductions African black beetle, *Heteronychus arator* (Fabricius) and whitefringed weevil, *Graphognathus leucoloma* (Boheman). Both have a capacity to be highly damaging in low abundance. On average, a single insect of either species attacks from two to seven tubers, rendering them unsuitable for the market, and African black beetle adults attack stems causing yield reduction. As few as one or two insects per metre of crop row causes substantial economic loss in the potato production system which has a low tolerance for losses because of the high cost of production and the high value of the product.

Damage is primarily caused by insects resident in land to be cropped, imposing a need for pre-cropping control measures. The patchy distribution, low abundance, small size of many stages and concealment and protection by soil makes both scouting for prediction of the threat and management difficult. These factors have given rise to reliance on soil-incorporated prophylactic control measures, typically with the most potent agents available, in order to minimise the risk of damage occurring. A recent trend has been the use of expensive soil fumigants as a control agent. The long-term sustainability of such an approach is questionable.

The challenge for researchers seeking to devise alternative, integrated-style management strategies for such soil insects with extremely low economic thresholds is to ensure a very high degree of efficacy while minimising undesirable effects. Sound biological knowledge, meaningful not just in the context of the potato cropping phase which is transient relative to the insects, is seen as essential for devising soundly-based management methods that may be unconventional, and helping to convince producers of their worth. A significant challenge is to establish a mind-set in which reducing soil insect populations can be viewed as a longer-term commitment, not solely an immediate component of crop husbandry.

For such pests, few totally environmentally benign control techniques such as classical biological control are, in isolation, likely to be effective in sufficiently reducing populations. They could only be conceived of as a component of an integrated management strategy with a focus on the longer period of the insects' life-cycle that typically occurs in the pasture phase of the rotation. Strategic use of relatively 'soft' insecticides, applied perhaps some time before the potato crop is planted and carried out without undesirable soil-incorporation, offers one such means of population reduction through targetting of pre-breeding populations. A strategy seen as particularly worthy of attention is the use of rotation crops that do not favour the insects, or the use of break crops specifically selected to have biotoxic properties against them.

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BIOFUMIGATION - USING *BRASSICA* SPECIES TO CONTROL PESTS AND DISEASES IN AUSTRALIAN AGRICULTURE AND HORTICULTURE.

J.A. Kirkegaard, J.N. Matthiessen and J.M. Desmarchelier

Brassica plants release biocidal compounds, principally isothiocyanates (ITCs) produced during the breakdown of glucosinolates in crop residues. These compounds are known to suppress a range of insects, nematodes and fungi. *Brassica* species and varieties differ in the type, concentration and distribution of glucosinolates in their tissues which provides an opportunity to select or breed varieties with enhanced pest control properties. An understanding of the distribution in plants, the release pattern into soil and the efficacy of the chemicals is necessary to fully exploit the potential of "biofumigation" as a part of an integrated pest and disease management program. We discuss the results of current research in Australia which aims to determine the potential of biofumigation by brassicas in the cereal and potato industries.

Recent field experiments have shown that wheat grown after brassicas outyielded wheat grown after other break crops such as oats or linseed (Angus *et al.* 1991, Kirkegaard *et al.* 1994). In addition early growth and yield of wheat following Indian mustard was significantly better than wheat following canola. Angus *et al.* (1991) speculated that improved growth may have resulted from suppression of soil-borne wheat pathogens by ITCs released from *Brassica* residues and that the higher levels or different types present in Indian mustard were responsible for its superior break crop effects. This hypothesis was supported by the results of experiments investigating the suppression of the take-all fungus (*Gaeumannomyces graminis* var. *tritici*) by *Brassica* root pieces *in vitro* (Angus *et al.* 1994). Further *in vitro* studies have indicated the effectiveness of ITCs released from *Brassica* residues on a range of soil-borne fungal pathogens and differences in the sensitivity of fungal species to the ITCs (Kirkegaard and Wong unpub.).

Biofumigation using *Brassica* crops is being investigated as a part of an integrated pest management strategy for the control of soil insect pests of potatoes. Potato growers currently use synthetic ITCs at a cost of $600 ha for control of white fringed weevil (*Graphognathus leucoloma* (Boheman)) and African black beetle (*Heteronychus arator* (Fabricius). The adults of both species attack tubers and cause significant economic damage in low abundance. The small larvae of the whitefringed weevil hatch with the first autumn rain and remain in this state during the cool winter months. They may be vulnerable to ITCs released from a *Brassica* green manure crop planted in autumn and incorporated before potatoes are planted in spring. The African black beetle spends winter in the adult stage, however brassicas producing high levels of glucosinolates could drive them away or interfere with their breeding in spring. Several soil borne diseases of potatoes (e.g. *Rhizoctonia)* may also be candidates for control or suppression using biofumigation.

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Appendix 2

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ABSTRACTS

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RESEARCH SPECIALISATION: A CONSTRAINT TO INTEGRATION

D R Dent

Scientific training equips scientists for specialist research, while existing qualification and reward systems seek to promote specialist endeavour in preference to more generalist approaches. IPM is dependent for it success on multidisciplinary research inputs, but pest management research is essentially divided along strict disciplinary lines. Scientists from entomology, plant pathology and weed science specialise, for instance, in subjects such as chemical control, hostplant resistance or cultural control. Within this framework even further levels of specialisation occur as scientists address particular pest problems. The consequence of this emphasis on research specialisation is the development of specific terminologies, jargon and concepts, as well as different modes of enquiry and standards of proof. While such specialism promotes communication and understanding within a discipline the same process causes compartmentalisation, reduces communication and inhibits collaboration between disciplines. Such factors limit the likelihood of successful interdisciplinary collaborative IPM programmes and hence, the development of integrated solutions to pest management problems. There is a need to address some of the institutional constraints which maintain this situation and introduce new structures, mechanisms and approaches which promote interdisciplinary enquiry in pest management.

The key institutional requirements for improving opportunities for interdisciplinary research in IPM may be classified under three headings (i) appraisal and reward systems (ii) organisational structures and (iii) training in interdisciplinary research management.

The limitations and means by which scientific achievement is measured and rewarded in terms of specialists, generalists and interdisciplinary research is considered and suggestions for changes to existing arrangements are put forward.

Fixed organisational structures are inappropriate for scientists involved in interdisciplinary collaboration. Alternative, more open and flexible structures which promote interdisciplinary enquiry are outlined.

The management of interdisciplinary research represents one of the most challenging of human resource management activities. The techniques for integration of inputs from disparate specialist groups are described, in particular those required for the establishment of a shared paradigm, appropriate communication networks and programme planning and monitoring procedures. The need for training scientists in the use of these techniques of research management are discussed.

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