COMPUTERISED DECISION SUPPORT FOR IPM IN NEW ZEALAND APPLE ORCHARDS

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Terrence Mark Stewart

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ABSTRACT

New Zealand apple growers face a dilemma. Export fruit must be of the highest possible quality and free from quarantine pests, but contain increasingly fewer pesticides in lower amounts. The objective of this study was to define and develop decision support tools that may assist in the improved timing and/or reduction of pesticide usage.

Fifty randomly selected growers were interviewed in 1992 to determine their pest and disease problems, use of existing IPM methodology and requirements for an improved decision support service. The survey found more then 20% of growers had difficulties with common pests and diseases and many used IPM techniques. Most growers perceived a problem with pesticide residues and pest and disease resistance; they also expected to reduce pesticide usage and better target applications through improved technology in the future. Decision-support using fax and computer technology appeared feasible, subject to support from their advisers.

In 1993, twenty-seven Hawkes Bay apple pest and disease control "advisers" were interviewed to determine their role in growers' pest and disease spray decision-making. Horticultural merchant representatives believed they were the main spray decision-maker for 40% of growers, and half of the latter expected the horticultural merchant representatives to know more about the problems in the orchard than they did. Other advisers played an important role in strategic pest and disease advice to the industry. Introducing more complex spray-saving techniques, or taking full advantage of those that already exist, would require many growers either to upskill themselves, or employ consultants to manage their orchards. Basic pest and disease identification and biology, together with knowledge of pesticides were regarded as being essential to manage pests and diseases successfully. Nutritional problems and resistance development were two particular areas where growers required more knowledge.

Using the survey findings, a problem tree was created focussing on the question "Was pesticide use excessive in New Zealand apple orchards?". This conceptual model showed that pesticide use was excessive, and better grower education and training may

partly alleviate the problem. Using the data from the surveys, two computerised training tools were defined and developed to assist with this solution viz SPRAYCHECK and DIAGNOSIS.

SPRAYCHECK was developed to analyse grower black spot fungicide spray programs during the period of primary inoculum release. Using a series of models, incorporating weather data, infection periods and information from growers' spray diaries, grower black spot control decision-making was analysed and a recommended spray schedule for the season in question provided. Model construction revealed a lack of quantitative information on fungicide behaviour and the levels required to fully protect against black spot on apple foliage. A sensitivity analysis showed the rate of cover decay was very important in determining the number of fungicides required to fully protect a crop.

DIAGNOSIS is a training aid for teaching pest and disease diagnosis skills to crop protection trainees. This program simulates field and laboratory scenarios, in which trainees must actively seek clues and interpret observations on the cause of plant problems, in apples or other crops. Once trainees have recorded their diagnosis, justification and recommendations for action, they receive an automatic de-briefing on their problem-solving approach. Trainee input is recorded to disk for later tutor assessment.

Two decision-support tools were defined, developed and validated. One has been commercialised and the models in the other are likely to be used in an existing Decision Support System. During this exercise, knowledge was gained regarding the New Zealand apple industry in Hawkes Bay, in particular the close relationship between the growers, and horticultural merchant field representatives and their advisers. This relationship could either help or hinder IPM and improved decision support in the future.

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CHAPTER 1

GENERAL INTRODUCTION

This chapter introduces the thesis, and outlines the work undertaken.

1.1 Introduction

Despite the significant contribution pesticides have made to increased global food production and the well-being of millions of people, concerns about their side effects have become an increasingly important issue in the last 30 years. This awareness has seen a change in attitude to these products, which have been used, as major tools to control plant pests, diseases and weeds. This change is now being reflected in the laws and consumer preferences of many countries.

New Zealand has an export-based economy with 70% of all overseas earnings coming from the agricultural sector (Statistics New Zealand, 1997). Pesticides are used in all of these industries but especially in horticulture, where exports must be of the highest quality in order to compete on international markets.

To achieve this, exporters of horticultural products face a dilemma. On one hand, crops must be of the highest quality and contain no passenger pests, but on the other hand consumer demand dictates they are free from excessive residues. Integrated Pest Management (IPM) is a partial solution to this but inputs in terms of labour and expertise are generally higher than for conventional methods and control levels may not satisfy phytosanitation requirements. Nowhere is this dilemma more apparent than with export apples.

1.2 The New Zealand apple industry

The New Zealand apple industry has earned an average of $524.7 million per year, over the period 1992-1996 in export sales (New Zealand Apple and Pear Marketing Board, 1996). Being export-oriented, New Zealand apples are in competition with product from the rest of the world, but in particular Southern Hemisphere countries such as Argentina, Australia, Brazil, Chile and South Africa.

1.3 What is the main problem?

The wet spring conditions and the relatively mild climate of New Zealand means that many pests and diseases plague the apple crop. Some of these, such as native tortrix moths, are quarantine pests with a zero tolerance in some overseas markets such as the USA. Hence they require almost absolute control. Other problems, such as the disease black spot (*Venturia inaequalis*) must be controlled annually, otherwise quality is lost.

Pesticide usage in apple crops therefore, is very high with an average of 15 insecticides/miticides and 23 fungicide applications a year (see chapter 5). With other trading entities, such as the European Union moving towards Integrated Fruit Production (IFP), the pressure is on to reduce application (and hence residue) levels. Similarly, in the USA, pesticide de-registrations mean that many of the chemicals traditionally available and used by New Zealand growers are being withdrawn from the marketplace. This therefore poses a dilemma for the New Zealand apple industry, as it endeavours to reduce pesticide levels while ensuring the highest fruit quality and an absence of quarantine pests.

1.4 Study objective and thesis context

The apple industry has a goal of reducing pesticide use. The work in this thesis aims to provide decision-support tools, which may contribute towards this goal.

The objective of this study was to do the following...

- Based on the needs and observations of growers, specify one or more decision support systems
- Design and construct examples of such systems
- Validate the systems on historical data and test their credibility with experts
- Discuss their possible impact in the field

The thesis is divided into three parts as follows: The first part (chapter 2) is a literature review, which deals with IPM and its development pertaining to apple growing in New Zealand and elsewhere in the world. Within this context, spray decision-making and decision support is discussed.

The second part (chapters 3, 4 and 5) considers survey information about the pest and disease management in Hawkes Bay apple orchards, giving a snapshot of grower concerns, spray decision-making and what kind of decision support might be useful. Conceptual modelling is used to focus on the causes and effects of overspraying.

The third part (chapters 6 and 7) deals with the development of two computerised decision support/training tools, the specifications for which arose out of the surveys and problem analysis for part 2.

This study extended over a five-year period.

1.5 References

New Zealand Apple and Pear Marketing Board. (1996). *1996 Annual Report.* Wellington. New Zealand Apple and Pear Marketing Board.

Statistics New Zealand. (1997). Statistics New Zealand (Principal exports). [Online] Available. http://www.stats.govt.nz/ , April 16th, 1997

CHAPTER 2

LITERATURE REVIEW

In this chapter, IPM and spray decision support in apple orchards are reviewed, with particular emphasis on developments within New Zealand

2.1 The New Zealand apple industry - an overview

Apples are one of the most important horticultural export crops in New Zealand. Exports in 1996 earned $631.6 million dollars, which represents approximately 44.5% of total income from horticulture and 3% of total export income (New Zealand Apple and Pear Marketing Board, 1996; Statistics New Zealand, 1997). The pipfruit industry is a major sector in the rural economy, with orchard assets of over $600 million and an estimated 8,500 people directly employed by it. An estimated 14,000 ha is planted in apples and pears, owned by 1,650 growers.
(New Zealand Fruitgrowers Federation, 1997).

The first apple seedlings arrived with early European settlers who came to New Zealand, in the 1840s. Major fruit growing areas were soon established in Nelson and Hawkes Bay. These regions, with their warm dry summers and cool winters, provided an ideal fruit-growing climate. Local demand was soon fulfilled and a burgeoning export industry was set up.

Because New Zealand was very distant from export markets, growers eventually felt a need to regulate the selling and marketing of fruit. In 1948, legislation was passed which established The New Zealand Apple and Pear Marketing Board (APMB), with the power to acquire and market all apples and pears grown in New Zealand (including those destined for domestic markets). In essence this created a "single selling" desk for all pipfruit coming from New Zealand. The Board lost some of its monopoly powers in 1993, when the local apple and pear market was deregulated. Nevertheless, the APMB is still the sole, marketing authority for export pipfruit. Third parties can export, but they must have permission from the Board.

This strategy of using a monopolistic Producer Board has several advantages for growers, in that quality standards can be set and monitored in a coordinated way, and good prices can be negotiated with overseas buyers without risk of undercutting from other New Zealand outlets. The APMB also plans and executes ventures to increase market share and develop new markets for New Zealand pipfruit. Product is also released onto the market, in a controlled way. Considering that New Zealand supplies less than 2% of the world's apples into an oversupplied market, it can be argued that this strategy of a single selling desk makes good sense.

Figure 2.1 shows the increasing value to New Zealand of export apples. Growers have enjoyed consistently good prices over an extended period. This, together with the concentration of the crop in just a few major areas, means that the apple industry is a well-organised one, with a tight infrastructure. Today, it consists of a total of approximately 1645 growers producing on 14,000 ha of land (Bollard, 1996). The major areas are Nelson, Hawkes Bay and Canterbury (Fig 2.2), which produce 50, 28 and 9 % of the crop respectively.

Figure 2.1. Total revenues from fresh apple exports (in $,000) over the last eight years (New Zealand Apple and Pear Marketing Board, 1996)

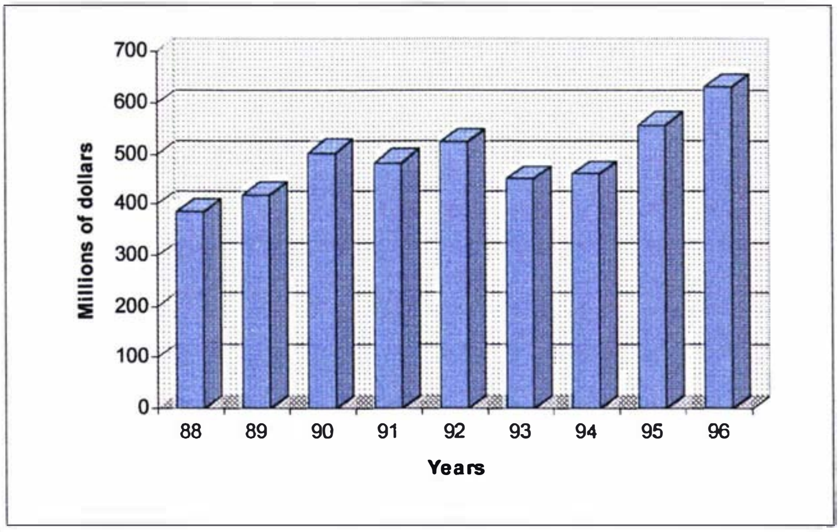
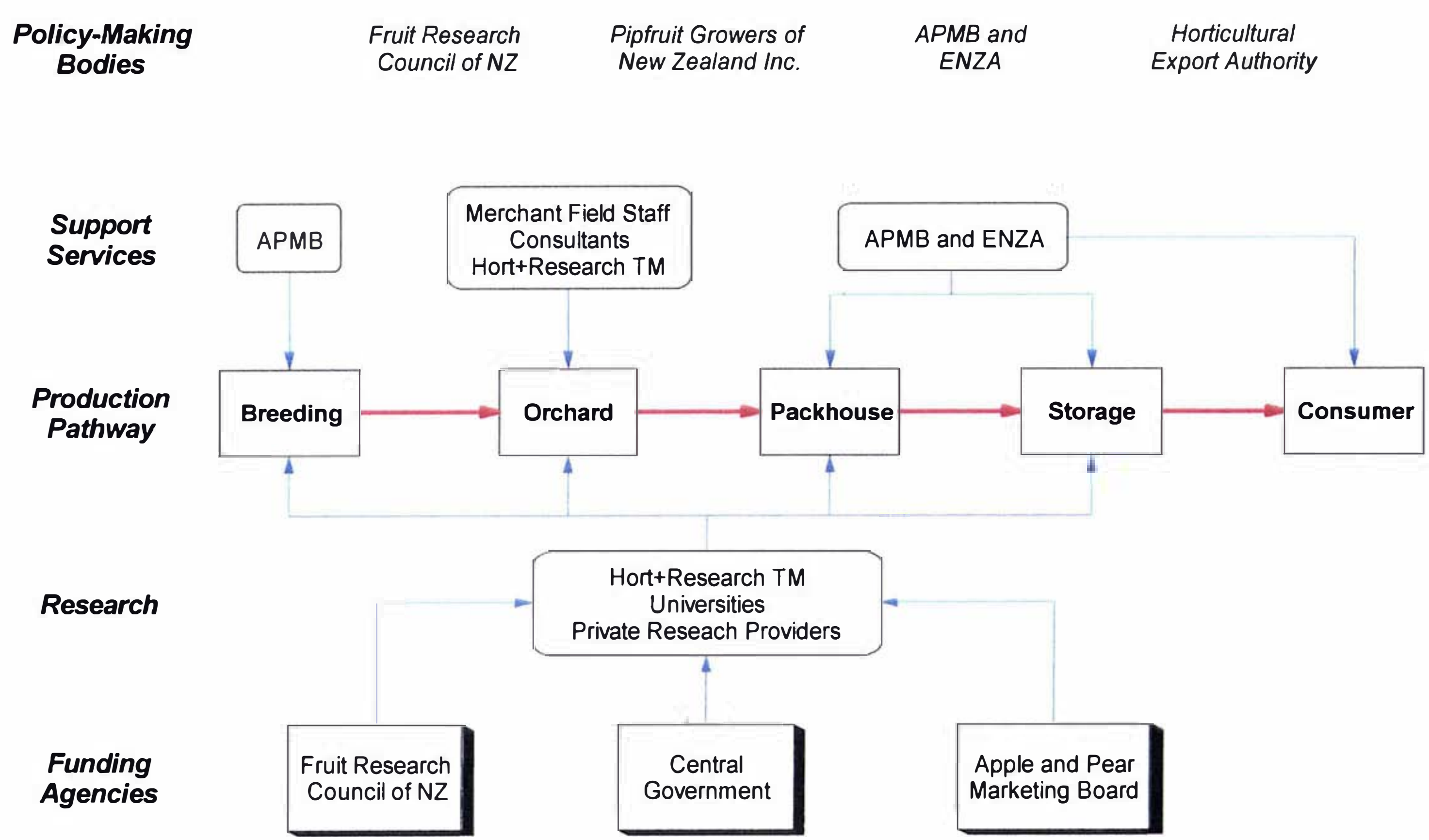


Figure 2.2. Main apple growing areas and number of tray cartons (T/Ctn) produced in 1996. (New Zealand Apple and Pear Marketing Board, 1996).
One tray carton = 18.3kg

Major apple varieties in order of export volume include Braeburn, Royal Gala, Fuji, Red Delicious, Cox's Orange Pippin, Granny Smith and Gala (New Zealand Apple and Pear Marketing Board, 1996). There is an ongoing breeding program which has seen two new varieties recently released, Pacific Rose and Southern Snap.

The pipfruit industry has a number of policy-making bodies, advisory and research organisations and funding agencies. These organisations and how they relate to the fruit production pathway are shown in Figure 2.3.

Figure 2.3. Diagram showing relationship between various advisory, research, funding and policy-making organisations, and the stages of apple production.



2.2 Pest and diseases of New Zealand apple crops, their significance and current control.

Table 2.1 shows the major pests and pathogens found in New Zealand apple crops and their scientific names. The organisms assume importance at different stages of the crop cycle, and also differ in their significance depending on locality.

Table 2.1. Common apple pests and diseases and their causal agents.

Diseases		**Arthropod Pests**	
Bitter rot	*Glomerella cingulata*	**Apple leafcurling midge**	*Dasineura mali*
Crown or collar rot	*Phytophthora cactorum*	**Codling moth**	*Cydia pomonella*
Black spot	*Venturia inaequalis*	**European red mite**	*Panonychus ulmi*
European canker	*Nectria galligena*	**Frogatt's apple leafhopper**	*Typhlocyba froggatti*
Eye rot	*Botrytis cinerea*	**Leafrollers** - Lightbrown apple moth - Brown headed - Green headed	 *Epiphyas postvittana* *Ctenopseustis spp.* *Planotortrix spp.*
Fire blight	*Erwinia amylovora*	**Mealybug**	*Pseudococcus spp.*
Powdery mildew	*Podosphaera leucotricha*	**Noctuid moth**	*Graphania spp.*
Silverleaf	*Chondrostereum purpureum*	**Scale insects** - San Jose - Apple mussel - Oystershell	 *Quadraspidiotus perniciosus* *Lepidosphes ulmi* *Quadraspidiotus ostreaeformis*
		Two spotted mite	*Tetranychus urticae*
		Woolly apple aphid	*Eriosoma lanigerum*

Not all the pests and diseases listed in Table 2.1 require regular pesticide applications. Many, such as Phytophthora crown rot, are worse in certain soil conditions and on certain varieties. Others, such as woolly apple aphids, are considered minor pests but would become major pests in the absence of a spray program, if no other control techniques were substituted.

2.2.1 Black spot of apples (*Venturia inaequalis*)

This pathogen, also known as apple scab in Europe and North America, has been the subject of a comprehensive review by MacHardy (1996).

Black spot is one of the more serious diseases of apple. The fungus overwinters in fallen leaves where it produces the sexual stage in pseudothecia. These mature in the spring to release ascospores, which are actively ejected from the ascocarps during periods of wet weather. In New Zealand, this release period takes place between early September and the beginning of December, with peak numbers occurring within a period of 10 days around full bloom (Manktelow and Beresford, 1993). However, this release period can vary up to a month depending on season and the region concerned (Manktelow and Beresford, 1995).

A condition required for infection by ascospores is that the surface of the host tissue be wet for a certain length of time, with the interval being determined by the temperature (Mills and Laplante, 1954; MacHardy and Gadoury, 1989). These "Mills periods", or "infection periods" are used by growers to time spray applications. If a Mills period occurs, and the grower suspects infection may have taken place in the crop, they can apply an eradicant fungicide, such as myclobutinal.

Fungal infection first shows up as dark green, velvet-like patches on leaves which soon develop into dry, corky black lesions. On fruit, mature lesions appear as brown or black spots, often cracked and surrounded with a grey or black halo (see Plate 2.1).

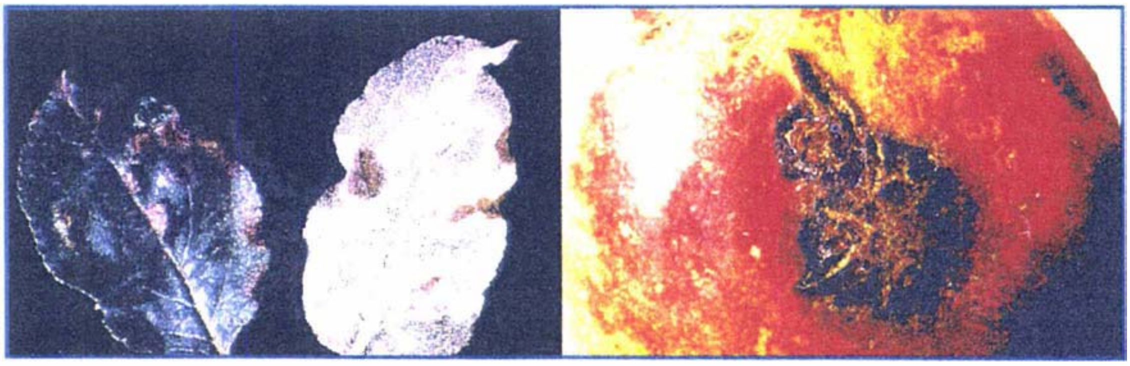


Plate 2.1. Symptoms of black spot on fruit and leaves.

Lesions soon produce asexual spores called conidia, which can be disseminated by rain to cause secondary infections. Infections late in the season may not be visible at harvest and hence may cause postharvest problems (Jones and Aldwinckle, 1990).

Financial losses from the disease are not only from rejected fruit and reduced production, but also from the extra time spent sorting out infected fruit at harvesting and grading.

In New Zealand orchards, black spot is normally controlled by a series of protectant fungicide applications over the primary ascospore release period, combined with eradicant (mixed with a protectant) fungicide applications after periods of wet weather. Applications can be intensive over this period, with fungicides often being applied once a week or sometimes even more frequently.

Beresford and Manktelow (1994) demonstrated that fungicide application has the potential to be reduced by at least 25%, even in a year with a high number of infection periods. Current research on black spot in New Zealand includes ascospore monitoring techniques (Manktelow and Beresford, 1995; Henshall and Beresford, 1996) and infection period forecasting (Tate, Beresford, Wood and Manktelow, 1996) in order to improve spray timing. A breeding program for black spot resistance is also under way (Selby and White, 1993)

A model for reviewing growers' black spot spray programs is the subject of a subsequent chapter in this thesis.

2.2.2 Powdery mildew (*Podosphaera leucotricha)*

This disease, although potentially serious, is regarded as less of a financial threat than black spot.

The pathogen overwinters in dormant buds of twigs and branches. The latter are easily identified by their white, mealy coating of fungal tissue. Once the buds emerge, the fungus reactivates, growing with the infected shoot, and releasing airborne conidia (Plate 2.2). These conidia cause secondary infections when relative humidity is > 90%, although free water inhibits their germination (Burr, 1980).

Plate 2.2. Powdery mildew on a apple stems and leaves

Leaf symptoms include blotching and yellowing together with the typical mealy white spore masses and shrivelling of the tissue. Russetting can occur on fruit if the disease is severe in the tree.

There is a large varietal difference in susceptibility to powdery mildew fungi in apples, and breeding programs through the years have attempted to seek cultivars with a higher tolerance (Mackenzie, 1983; Crosby, Janick, Pecknold, Korban, O'Connor, Ries, Goffreda and Voordeckers, 1992).

In New Zealand orchards, powdery mildew is kept to low levels largely due to the intensive fungicide applications which are mainly targeted at black spot (Manktelow *pers comm*). Most of these black spot fungicides also have some activity against powdery mildew.

As the pathogens concerned have differing environmental requirements, reduction in black spot sprays through better timing therefore has the potential to increase powdery mildew problems.

2.2.3 Fire blight (*Erwinia amylovora*)

Fire blight is a sporadic bacterial disease, which can be severe in seasons with warm (>15 °C) and wet weather over the flowering period (Percy, 1997). The organism overwinters in twig cankers and is rain-splashed onto susceptible blossoms. Once the bacterium gains entrance, it quickly kills the tissue exhibiting a characteristic blight symptom (Plate 2.3). A sticky exudate is usually present.

Plate 2.3. Symptoms of fire blight on pear

Often, a canker will form at the base of a branch and whole sections of the tree can die. It can be particularly devastating on young apple and pear trees.

Control often consists of a regular copper fungicide application at green tip (as a preventative measure), and one or two streptomycin applications over the blossom period, depending on the grower's assessment of risk. A biological control procedure using bees to inoculate the flowers with strains of *Erwinia herbicola* is being trialed (Vanneste, Yu, and Ede, 1995), and much work is going on adapting the fire blight infection model MARYBLYT (Lightner and Steiner, 1990), to New Zealand conditions (Gouk, Bedford, Hutchings, Cole, and Voyle, 1995).

2.2.4 Leafrollers (Lepidoptera: Tortricidae)

The New Zealand apple crop is plagued by five species of leafroller. Four of these are native, and one is an Australian introduction. This latter pest, the lightbrown apple moth (*Epiphyas postvittana*), or LBAM as it is often written, is the most serious leafroller in New Zealand orchards, primarily due to USA phytosanitary requirements.

Lightbrown apple moth (Plate 2.4) attacks the foliage in the early part of the season, migrating to the fruit in the latter half. Although insect damage on the fruit is a cause for rejection, the major impact of these pests is as quarantine organisms. The USA. export market in particular, is very sensitive to any sign of these organisms and discovery of egg cases, or pupae at the port of sale, is enough to cause the whole shipment to be rejected.

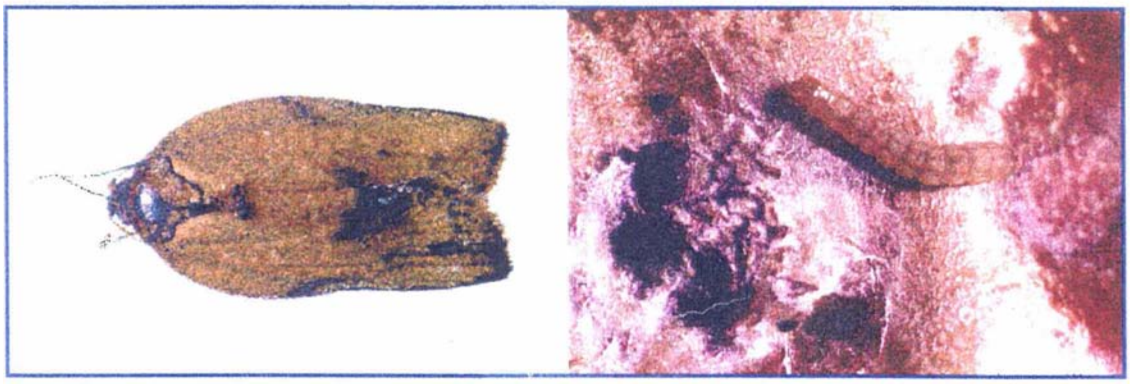


Plate 2.4. Adult and larvae of the lightbrown apple moth

Control is normally by regular applications of organophosphate insecticides from late November onwards. Some growers uses pheromone traps to time early leafroller sprays (Shaw, Cruickshank and Suckling, 1993). Mating disruption has been trialed in several districts (Suckling and Shaw, 1991), but is not yet widespread.

2.2.5 Phytophagous mites

There are two principle phytophagous mites in apples, European red mite (ERM), *Panonychus ulmi* Koch, and the two spotted mite (TSM), *Tetranychus urticae* Koch (Plate 2.5 and 2.6). The former is the more significant, although TSM can be troublesome in warmer seasons. These mites feed on the foliage, hence they affect the vigour of plants but high numbers can also become a serious marketing problem by directly contaminating fruit. In the case of ERM, winter eggs are the problem whereas with TSM, infestation occurs from diapausing females seeking winter resting sites.

Plate 2.5. European red mite adult

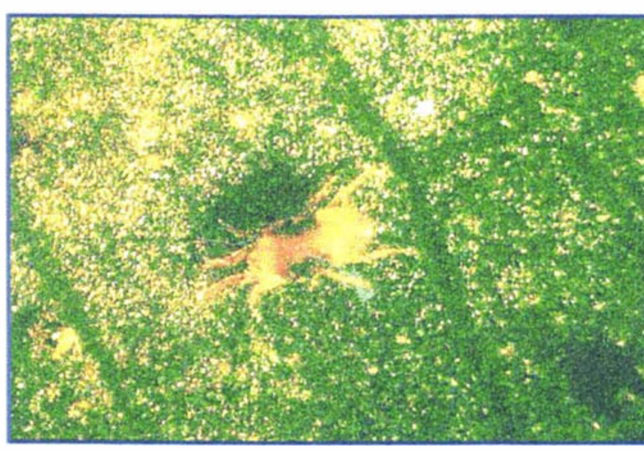


Plate 2.6. Two spotted mite adult

Control of mites is through the conservation of predators, well-timed miticides or a combination of both. The predator species concerned are numerous (Walker, Wearing and Hayes, 1989; Thomas and Walker, 1989), the most important one in commercial orchards being organophosphate-resistant strains of *Typhlodromus pyri*. Research has shown that this predator can be affected by certain fungicides used for black spot control e.g. mancozeb (Walker, Wearing, Shaw, Charles and Hayes, 1989).

Timing for ERM miticide applications is assisted by a simple graphical decision aid (Hayes, Walker, Shaw and White, 1993), which has been derived from a deterministic simulation model (Hayes, 1989).

2.2.6 Mealybugs

Mealybugs, whilst able to severely affect the growth of trees, are more troublesome as a quarantine pest where their presence under the calyces of export fruit is unacceptable (Plate 2.7). With high infestations of the pest, sooty mould (Fam. Capnodiaceae) also occurs.

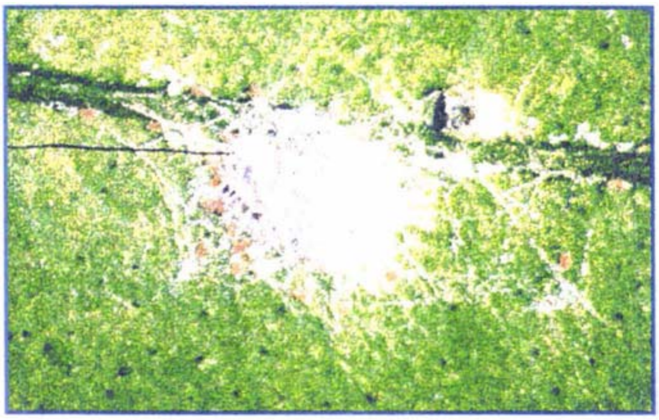


Plate 2.7. Adult mealybug (*P. longispinus*) with young

There are three species of mealybug in New Zealand orchards, *Pseudococcus affinis*, *P. calceolariae* and *P. longispinus*. These insects shelter under cracks and crevices in the bark of trees, and disperse to the foliage and fruit during the growing season.

Standard control for mealybugs in the 1970's and early 1980's was an early season application of an organophosphate insecticide, such as chlorpyrifos, from the dormant to "tight cluster" stage (see Appendix I for apple growth stages), followed by season-long azinphos-methyl applications after flowering. The latter sprays were principally targeted at leafrollers (Charles, 1982).

From the mid-1980's, control of *P. affinis* using this practice became more difficult and it was discovered that resistance to chlorpyrifos was widespread (Charles, Walker and White, 1993). A combination of chlopyriphos and buprofezin has been found to exhibit effective control, and is the recommended strategy at present (Walker, 1995a).

2.2.7 Apple leafcurling midge (*Dasyneura mali*)

This insect, once regarded as a minor pest in pipfruit growing, has recently become more significant. The pest prevents young leaves unfolding, with the rolled leaf providing a shelter for the larvae to feed inside (Plate 2.8). This can cause premature leaf drop, and also stunt shoot growth, especially on young trees. The pupal stage can become lodged in fruit thereby contaminating them.

Plate 2.8. Apple leafcurling midge larve exposed in a leaf, which has been unrolled

Surveys carried out in the Waikato (Tomkins, Wilson, Hutchings and June, 1994) and Nelson regions (Smith and Chapman, 1995) confirm this pest as a major problem. At present, it is unclear as to why this insect has become a pest although changing insecticide patterns could be a factor (Tomkins, 1995). Resistance to insecticides was suspected, but doesn't appear to be the cause in this case (Chapman and Evans, 1995; Tomkins, 1995).

2.3 Pest and disease control in apples. - An historical overview

This section outlines a brief history of pest and disease control in apples, commencing with early records and ending with the decision support tools of the present day.

2.3.1 In the beginning.

The origin of the edible apple is lost in antiquity, but it is appears to have first been domesticated in a region just south of the Caucasus mountains. Even in prehistoric times, apples had spread all over Europe, and from there moved throughout the world with the migration of human peoples (Lape, 1979).

Along with the spread of the apple plant went the pests and diseases that attacked them. Lape (1979) gives a particularly interesting account of codling moth introduction into Tasmania in the late 1800's, an event which lead to the state government passing into law "The Codling Moth Act 1890" to protect the apple crop from this devastating insect.

2.3.2 The golden age of pesticides.

Certain key pests and diseases were always troublesome in apples, and as pesticide technology advanced, growers were quick to take advantages of the new tools. Lodeman, E.G. (1906) writes on the virtues of spraying Bordeaux mixture and the aresenite insecticide "Paris green" on a regular basis for the control of black spot and codling moth. These, and similar inorganic chemicals were the mainstay of apple pesticides until the late 1940's.

The 1950's and 1960's could be termed "the golden age" of pesticides. Effective insecticides and fungicides, based on organic molecules, were released into the marketplace regularly. Spray application technology evolved at a similar rate, with the high volume motorised airblast sprayer replacing hand spraying.

An example spray program, taken from a fruit production manual of the time, recommends DDT, parathion, malathion or oils for arthropod pests, and coppers, sulphur compounds or organic carbamate or glyoxalidine fungicides for disease control (Shoemaker and Teskey, 1959).

2.3.3 Problems with pesticides generally

Pesticides are useful pest management tools, but they do have drawbacks. Many different authors have described these over the years but essentially there are two major problems. First, many are prone to becoming ineffective after a period of use due to resistance development, and secondly, they usually affect organisms other than just the target species.

2.3.3.1 Development of resistance

Resistance to a pesticide was first observed in 1908 for San Jose scale to lime sulphur (Melander, 1914). Cases of pesticide resistance continue to be recorded up to the present day. Resistance development is particularly serious when the chemical concerned is the only method of control and there is an absence of any other controlling agents. In cases like these, resistant pest populations explode causing huge losses.

2.3.3.2 Effect on non-target organisms

The effect of pesticides on non-target organisms can be further broken down into sub-categories. First there is the effect on organisms in the general area where the application takes place. Natural controlling agents such as predators and parasites are often sensitive to most groups of older, broad-spectrum insecticides such as organochlorines, organophosphates and carbamates. A local environment devoid of these controlling agents, usually requires periodic applications of insecticide for control. Furthermore, new pest problems can arise from organisms which have previously been well controlled by natural agents. The latter are often more sensitive to pesticide applications, and their absence can lead to the development of these secondary pests.

Whilst well documented for insecticides, the phenomenon has also been observed with fungicides. Griffiths (1993) cites the case of die-back of apricot (*Eutypa armeniacae*) in South Australia. The disease only became important following the introduction of routine copper sprays to control shot hole disease (*Clasterosporium carpophilum*). It appears that the copper applications depleted pruning wound colonising microflora, which in the past had prevented the pathogen from entering the tree.

The pesticide applicator can also be at risk. Absorption through inhalation or through the skin, can lead to health problems, and protective clothing and other apparatus is often required.

The surrounding environment as a whole may be affected. Persistent pesticides are known to accumulate up the food chain, with detrimental effects to higher organisms. Groundwater can be polluted, and hence harmful chemicals can find their way into wells, rivers and streams. Spray drift can affect crops, animals and humans.

Finally, where application is made to an edible crop, small traces of pesticide are likely to be consumed. Whilst consuming tiny amounts of correctly applied registered pesticides is safe, misuse and over-application can cause excess residues, which can pose a real danger..

In 1962 Rachel Carson published a landmark book, called “Silent Spring”, which essentially launched the environmental movement. The book was emotive and inaccurate in parts, but nevertheless drew attention to the “gung-ho” way pesticides were being applied and many of the creeping environmental problems that were

developing from misuse, overuse and weak regulations. The book sparked a whole genera of claim and counter-claim publications which still persist to this day.
As a result of this ground swell of public concern, pesticide regulations have been tightened considerably. Many products, such as the persistent organochlorine insecticides and mercury-based fungicides have been banned in many countries. Public concern is still very high, and a whole generation now regards pesticides with suspicion, especially residues in or on foodstuffs (van Ravenswaay, 1995). A survey conducted in the United Kingdom showed that 74% of respondents thought that some chemical residues on fresh fruit and vegetables was dangerous to health (cited in Penrose, Thwaithe and Bower, 1994). This public perception of pesticides as a danger is often out of proportion to the real threat but nevertheless, it is a perception that needs to be taken account of.

Many governments now have policies in place to reduce pesticide use by a significant amount. In the USA for example, the Clinton administration has a goal of having 75% of all farms using IPM practices by the year 2001 (Jones, 1995). The Dutch have a similar plan to reduce pesticides (Goewie, 1995) as do Denmark (Warrell, 1990), Sweden (Bernson and Ekstrom, 1991) and Canada (Penrose *et al,* 1994). In New Zealand, legislative changes were initiated after an independent report critical of existing pesticide regulations and practices (MacIntyre, Allison and Penman, 1989). The report found that existing regulations favoured export agriculture over domestic environmental protection and public heath, and that education and training for pesticide users was poor. The authors concluded that continued economic growth in this sector was dependant on export of high-quality, low-and-no chemical residue food products, brought about by NZ-specific IPM technologies.

2.3.3.3 Problems with pesticides in fruit growing

The problems outlined have also appeared in fruit growing. There are numerous examples of apple pests and diseases developing resistance to pesticides in New Zealand and overseas. Table 2.2 records the organisms concerned in New Zealand:

Table 2.2. Examples of apple pests and diseases which have developed resistance to one or more pesticides in New Zealand (Bourdot and Suckling, 1996).

Common name	Species
European red mite	*Panonychus ulmi*
Two-spotted mite	*Tertranychus urticae*
Lightbrown apple moth	*Epiphyas postvittana*
Green-headed leafroller	*Planotortrix octo*
Mealybugs	*Pseudococcus affinus*
Froggatt's leafhopper	*Edwardsiana froggatti*
Black spot	*Venturia inaequalis*

Operator safety has always been a concern given the nature of fruit crops. Spraying trees, often with high volume "airblast" sprayers means the likelihood of operator exposure is very high. Given the high level of pesticide required to produce quality fruit, and that fruit is often eaten in a raw, unprocessed state, the issue of residues and the public perception of them is very important to the orchard industry. This was illustrated by the Alar™ scare in the USA (Fumento, 1993).

2.3.4 The IPM concept

Stern, Smith, Van den Bosch and Hagen first mooted the integrated pest management (IPM) concept in 1959. IPM has become a rather loose term, but in the general sense, it refers to the integration of a variety of techniques to control a complex of pests, in a cropping situation, pests in this case being any troublesome organism, including pathogens and weeds. The term can sometimes be used in a much narrower way, to refer to just one single species of arthropod with the "integration" referring to the control techniques rather than the whole pest and disease complex. Indeed, Zadoks (1989) argues that too little attention was given to pathogens in IPM projects in the past. Also, some definitions of IPM include the concept of economic thresholds (Brader, 1979). However, it is the wider definition given above that the author will use in this thesis.

Inherent in the IPM concept is the minimisation of pesticide use, applying chemicals only at time of need and when they will do the most good. The opposite of IPM is calendar spraying, where applications are made according to growth stage of the crop or a regular time interval with no reference to the pest levels, or controlling agents.

Most people saw IPM as a way to use pesticides judiciously, and therefore negate, or at least minimise, problems associated with such use. Initial IPM programs focused on economic savings but with the continuing and growing public concern about pesticides, combined with increasingly restrictive legislation, the emphasis has shifted more towards IPM as a way to comply with "good growing practice". The aim of the latter is to reduce the risk of resistance, and satisfy environmental and consumer demands.

Adoption of IPM has not been easy or rapid. Researchers have identified many barriers to implementation. These include complicated and time-consuming IPM methods, and a lack of attention to understanding the farmer's needs, perceptions, resources and objectives (Wearing, 1988).

2.3.4.1 IPM adoption in apples internationally

IPM programs for apples commenced in North America in the mid-1970's (Gadourdy, MacHardy and Rosenberger, 1989). In some states, such as New York, a comprehensive program involving the state extension service was developed (Tette, Glass, Bruno, and Way 1979). In the UK, IPM for apples was often termed "supervised spraying" and appeared to target mainly powdery mildew and mite control (Jeger and Butt, 1984 ; Carden, 1987). In this country especially, IPM research has tended to focus on pests and diseases separately. This can cause problems with a crop like apples, where a whole complex of pests must be considered, as pointed out by several researchers (Fenemore and Norton, 1985; Gadoury *et al,* 1989). Recent papers have re-emphasised the need for an integrated approach to fungicide, miticide and insecticide use, and show how this may be achieved (Jones, 1995).

These early IPM programs met with some success, with reports of considerable savings of pesticides (Tette *et al*, 1979; Jeger and Butt, 1984, Carden, 1987, Hardman, 1992; Thompson, How and White, 1980; Funt, Ellis, and Madden, 1990).

In Europe, the IPM concept has been taken further in fruit growing. On this continent, Integrated Fruit Production (IFP) is seen as the next logical step from IPM. IFP is defined as: "the economic production of high quality fruit, giving priority to ecologically safer methods, minimising the undesirable side effects and use of agrochemicals, to enhance the safeguards to the environment and human health". As well as integrated plant protection, the concept also covers:

- Site, rootstocks, cultivar and planting systems
- Soil management and tree nutrition
- Orchard understorey management
- Tree training and management
- Efficient and safe spray application methods
- Crop management
- Eliminating pollination of the fruit from outside sources
- Habitat diversity, land sustainability and conservation
- Fruit quality (postharvest)
- Waste disposal

(Anonymous, 1994)

North America is also showing much interest in this concept (Burkheart, 1995), as is New Zealand (see overleaf).

2.3.4.2 IPM in New Zealand apple crops

IPM in New Zealand fruit crops was first introduced in the mid 1970's using organophosphate-resistant strains of the predator mite *Typhloromus pyri*, to control European red mite (Wearing, Walker, Collyer and Thomas, 1978). The technology grew out of need, when product cancellation and miticide resistance left growers with few options for control (Walker, 1995b). During the late 1970's *T. pyri*, and another predator for two-spotted mite, *Phytoseiulus persimilis,* became well established in the main fruit growing regions of Hawkes Bay and Nelson (Wearing and Ashley, 1982). Economic thresholds were established and integrated mite control, or IMC as it became known, became widely practiced, causing miticide applications in the Nelson region to fall from an average of 3.8 per year in 1975-76 (Penman and Ferro, 1977), to 2.1 by 1980-81 (Hancox and Penman, 1982). Even in the absence of IMC, other IPM concepts, like timing of miticide with relation to the life cycle of ERM, were being promoted (Walker, Ashley, Wearing, Thomas and McLaren, 1979).

IPM techniques to control leafrollers and codling moth, such as using growth regulatory chemicals such as diflubenzuron, and microbial control such as *Bacillus thuringiensis*, were also investigated at that time (Wearing and Thomas, 1978).

In 1984, azinphos-methyl resistance was confirmed in an isolated population of light-brown apple moth, from the Nelson area (Suckling, Chapman and Penman, 1984). This gave impetus to seeking out IPM techniques to control this pest, and led to work on novel insecticides (Suckling, Kuijpers and Rodgers, 1985) and pheromone mating disruption later in the decade (Suckling and Shaw, 1991).

The IPM concept for mite control was given a further boost in 1987, when Chapman, Penman and Walker (1987) recorded organotin miticide resistance in ERM from Hawkes Bay orchards. As it was, the organotin miticides were deregistered soon after due to carcinogenic concerns in the USA. Growers started to switch to the newer ovicides for mite control. At first, control was extremely good, but as reports started to trickle in of resistance to these compounds (Herron, Edge and Rophail, 1993), so growers and consultants started to return to IMC.

IMC was developed more or less in isolation from the fungicide program, although choices of known IMC-friendly fungicides were part of the program (Wearing and Ashley, 1982). Seeing that fungicide programs were starting to favour the use of predator unfriendly chemicals due to apple russet and other considerations, Walker, Bayon, Shaw and Cassidy (1988) looked at formulating a fungicide program to control black spot that was also compatible with IMC. Their recommendation, based on trials, was a demethylation inhibitor (DMI) fungicide such as myclobutanil over the russet sensitive period, with captan at other times to avoid the adverse effects of metiram and mancozeb. The latter compounds were found to suppress predator numbers. Further work by Walker *et al* (1989) confirmed the toxicity of these protectant fungicides to *Typhlodromus pyri*. Here was an attempt to integrate the insecticide with the fungicide program, at least as far as selection of products was concerned.

IPM in mite management moved into a phenological modelling phase in the 1990's culminating with the decision-aids and service mentioned earlier in this text (Hayes *et al* 1993). Success was also achieved in breeding pyrethroid resistance predatory mites, with a view to these safer insecticides replacing the more toxic organophosphates (Markwick, Wearing and Shaw, 1990). However, widespread use of these products in pipfruit orchards has yet to be achieved.

In the mid eighties concerns about pesticide resistance were prevalent, leading to the formation of the New Zealand Committee on Pesticide Resistance (Elliott, Wearing and Suckling , 1987). Interim guidelines for some products were published a year later (Elliott, Moore and Wearing, 1988) and a full report was released in 1989 (Prince, Moore and Wearing, 1989).

During the 1980's, IPM concepts were also being taken up by growers to control diseases, such as blackspot. Targeting applications on the basis of Mills periods was trialed on research orchards and in some regions, such as Nelson and Hawkes Bay, the occurrence of Mills periods was disseminated by radio and newspapers. Towards the late 1980's this work intensified, with researchers investigating the scope for reducing sprays by using a combination of Mills periods and weather forecasts (Beresford, R.M., Salinger, M.J., Bruce, P.E. and Brook, P.J., 1989) and economic analyses of reducing black spot sprays (Beresford and Manktelow, 1994).

The 1990's saw an increase in the research directed towards IPM in pipfruit, driven by market access and environmental concerns (MacIntyre *et al*, 1989; Whalon and Penman, 1991). Programs were established to lower pesticide usage and yet maintain quality and phytosanitary requirements. One of the most serious problems was leafroller moth, as these feed on fruit at harvest and have a nil tolerance for the USA market. Insecticide spraying therefore is needed close to harvest hence compounding the residue problem. Researchers have been investigating the use of growth regulatory compounds to deal with this pest (Walker, Bayon and White 1991) along with mating disruption (Suckling and Shaw, 1991) and pheromone traps for improved timing of pesticide applications (Suckling and Brown, 1992).

Blackspot fungicides were becoming a concern. DMI resistance and product withdrawal lead to programs examining fungicide reductions through inoculum monitoring (Manktelow and Beresford, 1995), and better disease management and decision support systems (Tate and Manktelow, 1992; Laurenson, Buwalda and Walker, 1994).

During the 1990's research efforts were increased on "organic" growing. New Zealand apple growers see this area as a niche market opportunity. Ecology in orchards was studied (Kelly and Scott, 1990) and trials were conducted on granulosis virus for codling moth (Wearing, 1990), naturally occurring insecticides (Rohitha, Pottinger, and Lauren, 1991; van Epenhuijsen, Wright and De Silva, 1992), surfactants for apple pest and disease control (Walker, Shaw and Stevens, 1992) and *Bacillus thuringiensis* (BT) (Suckling, Shaw and Brown, 1993).

Organic control of diseases was also studied, including the natural resistance of some apple varieties (Wearing, Shaw, Walker, Marshall and White, 1995) and alternative chemicals (Beresford, Wearing, Walker, Spink, Marshall and White, 1995; Beresford, Wearing, Marshall, Shaw, Spink, and Wood, 1996).

New Zealand apple researchers are now actively engaged in trialing IFP systems (Walker, Hodson, Wearing, Bradley, Shaw, Stiefel and Batchelor, 1997; Manktelow, Beresford, Hodson, Walker, Batchelor, Stiefel and Horner, 1997). This is considered necessary, in order to maintain continued access to the European pipfruit market.

2.3.5 Decision-making and decision support

Successful IPM relies on good decision-making. These decisions can be strategic; for example choosing a rootstock with resistance to a particular pest or disease, or tactical, i.e. shall I apply a pesticide today or not? Much of the philosophy, literature and principles in IPM decision-making has been reviewed by Norton and Mumford (1993).

Decision-making can be aided by decision tools. These can be divided into two types. The first type are those used to clearly define a problem and can be termed "primary" decision tools (Norton, 1993). They include techniques such as flow charts, historical and seasonal profiles, interaction matrices and decision trees. Problem definition is used to assist in the planning of a research programme (Dent, 1991), determining what "hands on" decision aids might be useful and how they might be designed and implemented.

"Secondary" decision tools are often computer-based and include database and expert systems, simulation and weather models. However, they can be as simple as a chart, which a grower might use to read off a recommendation (Seem and Russo, 1984). Mostly, they are designed to provide specific pest management information to a user.

The literature abounds with examples of models designed to assist in grower decision-making. The reducing cost of the microprocessor led to a number of computer-based systems being developed, from specific "on farm" devices (Jones, Lillevik, Fisher and Stebbins, 1980) , to extensive on-line systems using mainframe computers, on a state by state or country-wide basis. With the latter, the situation in the early 1980's in the

United States was well reviewed by Welch (1984), whilst Epirpre (Rijsdijk, 1983) typified a European example.

There was a lot of interest in these computer-based decision models in the late 1970's and early 1980's, which saw much work taking place. As far as practical usefulness was concerned however, the results were disappointing. Butt and Jeger (1985) found that of 58 pest management models developed in Western Europe, only three were used directly on the farm and a total of 16 were implemented or handled by government advisory services. Reasons given were inappropriateness, poor training and support, and operationally, simply unusable (not enough time to carry out recommendations for example).

In the late 1980's, the new field of expert systems (Denning, 1986) boosted the interest in using computer-based models for decision aids. Unlike a conventional program, an expert system used heuristics and could work with incomplete and qualitative data, much like a human expert. They could usually explain their reasoning and (depending on the system) could be updated easily, as good expert system software would separate the program code defining the rules, or logic (the "inference engine") from the data itself (the "knowledge base").

A number of systems were developed, for use in IPM. These systems were often expensive, but proponents pointed to many potential benefits including minimisation of crop losses, reduction of pesticide inputs, enhancement of IPM training, effective delivery of IPM strategies not possible by other delivery methods and identification of gaps in knowledge to direct research programs (Travis and Latin, 1991).

Despite early excitement, it was found expert systems *per se*, were not the whole answer to decision-making down on the farm. Expert systems by themselves, especially expert system shells, were often too narrow in functionality. Although they were good at structured problem solutions, such as diagnosis or cultivar selection, they lacked the necessary analytical and data assimilation abilities many management decisions require (Sullivan, Ooms and Wilcox, 1989). Validation was difficult, and practical adoption rare (Harrison, 1991).

Expert systems seem to perform best when linked with other models such as databases and those providing real-time information. When expert systems were combined with more conventional models and programs a new model arose - the Decision Support Systems or DSS (Crassweller, Travis, Heinemann, and Rajotte, 1993).

Getz and Gutierrez (1982) wrote an interesting account of modelling approaches, where they used a fruit tree paradigm to describe the relationships between the different techniques. “Pests” and “diseases”, such as the oversimplification virus and cross-purpose wilt encapsulated the problems and pitfalls of each approach. They felt the most important challenge was “how best to utilise data and information of questionable reliability in conjunction with output from models that have not been extensively validated, in order to assist the agriculturalists in making crucial management decisions.” In the 1990’s, well-designed DSS seem to do just that.

2.3.5.1 Decision support systems for apples internationally

In 1990, Huber, Nyrop, Wolf, Ressig, Agnello and Kocach described a decision support system called EASY-MACS for apple growing. The program was developed from 15 years experience of IPM in western New York State, USA. However, the most well known DDS in apple growing is the Pennsylvania State Apple Orchard Consultant (Travis, Rajotte, Bankert, Hickey, Hull, Eby, Heinemann, Crassweller, MaClure, Bowser and Laughland, 1992). This is a comprehensive system, which assists in decision-making on pest and disease control. The system gives site-specific recommendations for timing, application and use of pesticides. Other modules include leaf nutrient analysis, nutrient deficiencies, irrigation scheduling, new orchard planning and weed control. The system was designed with the aid of experts from plant pathology, entomology, horticulture, agricultural engineering, agricultural meteorology, economics and rural sociology. It was one of the few systems where some attempt was made to put a figure on the cost of development; this came to 3,000 hours of experts’ time and was valued at $US 303,160 dollars (McClure, 1992).

2.3.5.2 Decision support systems for apples in New Zealand.

One of the first records of an expert system development in New Zealand apples was a report by Kemp, Stewart and Boorman (1989), describing an expert system for the diagnosis of pests, diseases and disorders in apple crops. The package was a prototype only, and was developed largely to experiment with friendlier interfaces for this kind of technology (Kemp, Stewart and Boorman, 1988)

Computerised decision support in New Zealand orchards, is encapsulated in the "Orchard 2000" concept (Laurenson *et al*, 1994). This is a standard framework whereby orchardists can use a series of modular "tools" for decision support. These tools link to a series of common databases (e.g. orchard profile and pesticide information) and real-time information gathering sources. The system is open, hence encouraging third party development of modules. Laurenson and Beresford (1996) estimated developmental costs to that date as being in the order of $NZ 1.05 million.

Present plant protection models in Orchard 2000 include a black spot monitor, and an electronic spray diary. A model for fire blight, based on MARYBLYT, is likely to be added soon. In the 1995-96 season, commercial users numbered 61, with 50 more growers receiving information from the system via fax. Due to the number of consultants and merchant field representatives using the system, it is felt that most of the Hawkes Bay apple production is influenced by it (Laurenson and Beresford, 1996).

Decision support also incorporates information databases. New Zealand's major research supplier in fruit growing, Hort+Research™, (a Crown Research Institute), has developed an internet site (HortNet™) to aid with this (https://www.hortnet.co.nz/).

2.4 Summary

Export apple growing is a significant earner for the New Zealand economy. Increasing pressure from overseas markets dictates a decrease in broad spectrum pesticides use. In the meantime, quality and phytosanitary requirements must be maintained. IPM has had a long history in New Zealand orchards, but the work has been fragmented and, with the exception of IMC, cannot claim to have reduced chemical use. However, much effort is now going into doing just that and decision support systems, such as Orchard 2000, offer the opportunity to truly integrate and rationalise spray decision-making and research effort. It is with this framework in mind, that the work described within this thesis was carried out.

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CHAPTER 3

PEST AND DISEASE DECISION SUPPORT FOR HAWKES BAY APPLE GROWERS. - A SURVEY

This chapter reports the results of a grower survey, conducted to determine current pest and disease problems, IPM practices, the receptiveness of growers to integrated decision support and the most appropriate delivery system.

3.1 Introduction

As outlined in the previous chapter, problems are foreseen in New Zealand export apple growing, one of the most serious being the tightening of access to external markets for pesticide treated crops (Whalon and Penman, 1991) whilst maintaining phytosanitary and quality standards.

In 1992 when this survey was conducted, the Orchard 2000 concept mentioned in the literature review was still in its infancy (Manktelow and Laurenson, 1990). However, a number of IPM techniques were available to assist growers to improve timing of pesticide applications (and possibly reduce them), without significant economic risk. These were either known to growers or recommended by the consultants and field representatives that advise them. Whilst these decision aids had been developed independently of one another, they often use shared environmental parameters, such as temperature. A decision-support system designed to assist in timing pesticide application, as proposed by Manktelow and Laurenson (1990), seemed to be a useful way of combining these stand-alone decision aids in an integrated way.

In all the phases of IPM development, it is often the implementation stage which proves the most difficult. As discussed in the literature review, one of the main reasons for this appears to be a lack of understanding by researchers as to the perceptions and constraints of the grower, and the nature of the industry (Wearing, 1988; Fenemore and Norton, 1985).

In view of this, a grower survey was conducted with the following aims:

1. To determine which pests and diseases are difficult to control.
2. To determine the use and extent of existing IPM methods.
3. To gauge the receptiveness of growers to integrated decision support and determine the most appropriate delivery system.

Due to time and financial constraints the survey was limited to the Hawkes Bay region. It should be noted that the findings herein represent the situation at the time of the survey (ie. 1992). This thesis is being compiled in 1997, and the author is aware of a few changes pertaining to the findings. These will be mentioned in the discussion. The research documented in this chapter has been published separately (Stewart, Norton, Mumford and Fenemore, 1993)

3.2 Methods

In June 1992 a sample of 50, from a total of 615 export apple orchard owners from the Hawkes Bay region, was randomly selected using a registration list from the Apple and Pear Marketing Board. During June - September 1992, these owners were contacted and survey interviews arranged with the "spray manager" of the properties concerned. This was usually the owner but in some cases a salaried manager fulfilled this role. Data were subjected to univariate and bivariate analysis, the latter using Pearson's Chi-square (X^2), Spearmann Correlation (sp) and the Mann-Whitney U test (mwu) where appropriate. The margin of sampling error was approximately 7%.

The survey form is attached in Appendix II. Growers were asked some personal details such as age, experience, size of orchard and status (owner or manager), any formal training in apple growing they may have had and if their parents or grandparents had been involved in the business. They were then questioned on which pests and diseases they found "troublesome" (i.e. the level of control was not to their satisfaction), which ones they found difficult as regards spray timing (i.e. deciding when to spray) and what decision aids (if any) they used. Also included were questions on their desire for an integrated decision support system, the best way of delivering this, how they would rank provided features of a proposed system, and whether they had, and were comfortable with, the appropriate technology. They were also canvassed as to whether they viewed pesticide residues and pest and disease resistance as significant future problems for the industry.

During the survey, growers were asked to rank the main factors (out of seven provided) which contributed to their "spray decision" for six commonly sprayed pests and diseases, i.e., leafrollers (Lepidoptera: Tortricidae), European red mite (*Panonychus ulmi*), mealybug (*Pseudococcus spp.*), fireblight (*Erwinia amylovora*), black spot (*Venturia inaequalis*) and powdery mildew (*Podosphaera leucotricha*).

One of the factors offered was "monitored data" where growers would take into consideration the results of monitoring or recommendations from a spray decision aid. By allocating a point every time this factor appeared as a consideration in the four highest ranked factors and summing over the six pests and diseases, an "informed spray" score (max. of six points) was calculated for each grower.

Similarly an "advisory" score was calculated as above, depending on whether the factor "advice from someone else" was selected in the top four considerations.

Finally, a "technology score" (maximum of 4) was calculated for each grower if they owned (two points each) or had access to (one point each) a fax machine or microcomputer.

These scores were used to determine if correlations existed between the various factors and other parameters such as grower experience and orchard size.

3.3 Results

3.3.1 Grower and orchard characteristics

The "typical" grower was between 40 and 50 years of age, had been growing for 10 years and did not come from an orchard background (56% of respondents). However, the more experienced growers tended to have parents or grandparents who were also involved in the business (sp=0.39 P=0.04).

A "typical" orchard had around 4000 trees. This is the median rather than the mean as three "corporate" orchards were selected in the sample, with managers having from 20,000-64,000 trees under their jurisdiction. These outliers had a distorting effect on the mean.

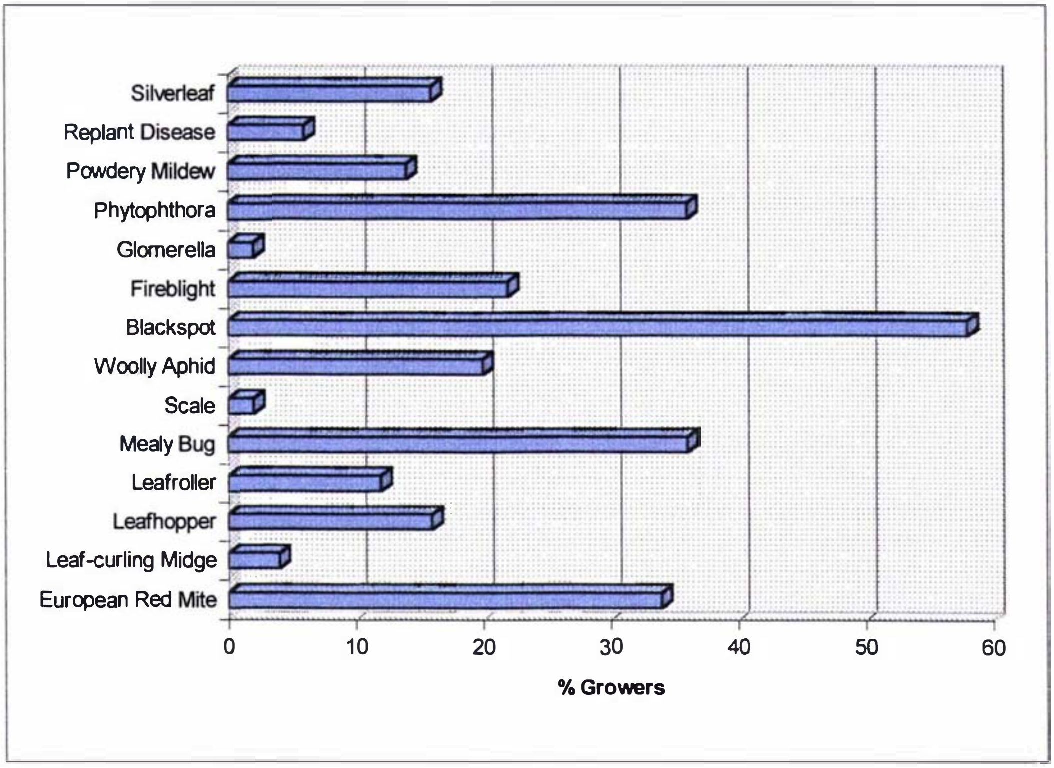
Whilst 80% of those surveyed had no formal training in horticulture, 12% had done courses or gained certificates, 6% had diplomas and 2% (1 respondent) had a horticultural degree. With the exception of one grower, all those who had formal training did not come from an orchard background.

In the surveyed sample, 86% of the participants were owners and 14% managers. Managers were more likely to be younger (mwu $P<0.01$) and have had some form of formal training compared to owners (X^2 $P<0.01$).

3.3.2 Troublesome pests and diseases.

Figure 3.1 shows the responses to the question "Which pests or diseases have been troublesome in the last 5 years".

Figure 3.1. Troublesome pests and diseases of apples in the five seasons (87/88 - 91/92) in the Hawkes Bay region of New Zealand

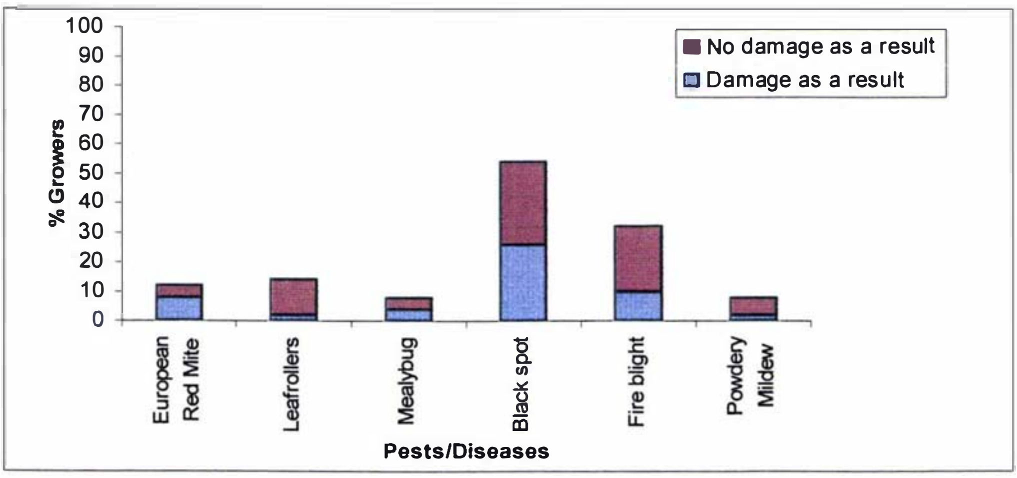


Over half the growers (58%) rated black spot as a major problem. Phytophthora crown rot (36%), mealybugs (36%) and European red mite (34%) also rated highly. Most of the pest or disease problems were ongoing with the exception of black spot and fire blight. Most growers found black spot troublesome only in the 1991/92 season (50% *vrs* 8% for seasons previous to that). Most growers who found fire blight troublesome (22%) cited the 1988/89 season as being the only period where this was so. Mealybugs caused problems mostly in larger trees where spray penetration and/or coverage was more difficult. One grower had a 90% rejection rate on one particular variety due to this pest!

European red mite was less of a problem in 1991/92 when only 6% registered difficulties compared with 28% in previous seasons. Seasonal factors may apply, but the reduction may be partly attributed to some growers who suffered problems with this pest in previous years switching to using ovicides or integrated mite control in the 1991/92 season.

Participants were asked if they had difficulty in timing sprays for six regularly sprayed pests and diseases. They were also asked if this "timing indecision" had lead to a loss of control. Results appear in Figure 3.2. As expected, black spot was the most difficult with regard to timing, the question often being "Has my protective cover run out?" rather than "Has there been an infection period?" About half of these growers considered incorrect black spot timing decisions had lead directly to a loss of control. Thirty two percent of growers considered fire blight spray timing was difficult, although in recent years the disease had not been troublesome.

Figure 3.2. Percentage of apple growers who found spray timing difficult

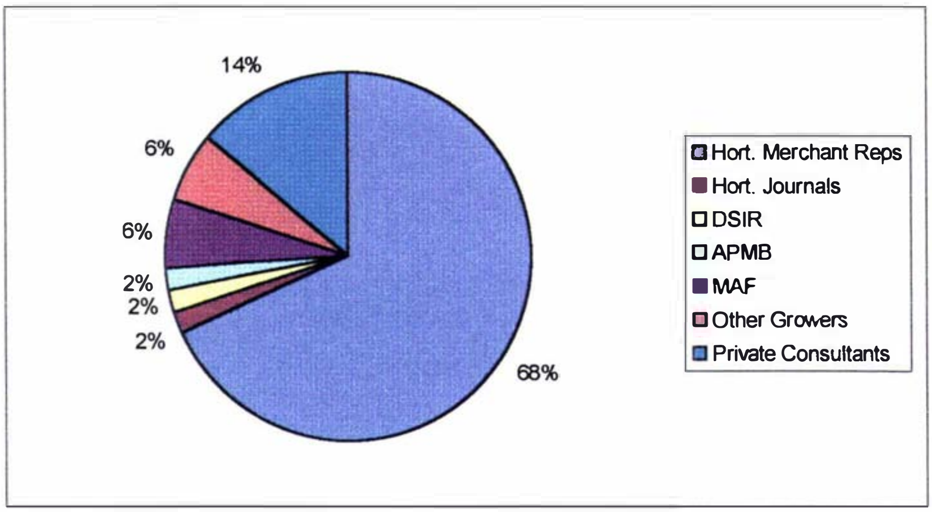


3.3.3 Sources of information

Growers were asked to rank sources of pest and disease information with regard to their importance. Sixty eight percent of growers cited horticultural merchant field representatives as their most important source of pest and disease information. Fourteen percent used private consultants as their main source of advice whilst 6% used other growers (Fig 3.3). Other growers, the Apple and Pear Marketing Board and trade journals were a useful secondary or alternative source of advice to many.

It should be noted here that, at the time of the survey, MAFTech and DSIR (Plant Protection) were separate entities. The relevant sections are now combined in a new organisation, Hort+Research™, a Crown Research Institute.

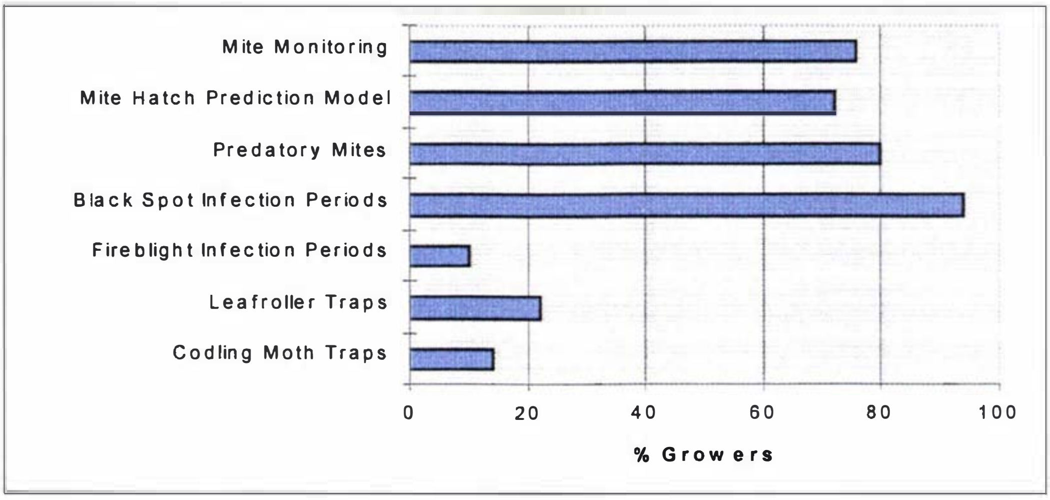
Figure 3.3. Primary sources of advice for apple pest and disease control



3.3.4 Use of existing IPM technology and methodology

The extent to which growers were using existing IPM techniques is shown in Figure 3.4.

Figure 3.4. Percentage of apple growers using pesticide saving or timing techniques



3.3.4.1. European red mite management

Most growers (80%) said they had predatory mites in their orchards although only 64% said they always used predator-friendly chemicals. Of the 36% that did not, most cited using ovicides such as clofentezine as the reason. Interestingly, ovicides were used more by those growers who had a low "technology" score (mwu P=0.01).

Some form of active-stage mite monitoring was undertaken on 76% of the properties surveyed, although more often with the aid of a field representative or consultant than the grower alone.

The DSIR mite hatch prediction model (Hayes *et al* 1988) was used by 72% of growers to time early-season miticides. In the main, growers thought this was a very useful service with users scoring it as either good or very good. The main reason for non-use was that ovicides were being used and therefore these growers did not need it. Users of the mite hatch prediction model had a higher "technology" score than non-users (mwu $P<0.01$). A few growers indicated they intended to alternate their mite control techniques, using ovicides one season and "timed" active-mite sprays the next.

3.3.4.2 Black spot infection periods

Black spot infection periods based on Mills periods (Mills and Laplante 1954) or MacHardy periods (MacHardy and Gadoury 1989) were obtained or measured by 94% of growers. These infection periods were often obtained from more than one source. These included radio broadcasts, the grower's own monitoring, or one of the horticultural merchant firms. Often a representative of the latter would inform their clients if an infection period had occurred.

The daily radio broadcasts were listened to by 62% of growers. In the main, growers found the service useful, the major criticism (by practically all growers that used it) being that monitoring sites were not "local" enough.

Thirty eight percent of growers, particularly those with formal horticultural training ($X^2 P=0.02$), measured their own infection periods either using weather data and an infection period chart (32%), or a specific black spot measuring device (6%).

3.3.4.3 Fire blight infection periods

Only 10% of growers used any kind of quantitative fire blight infection period (mostly watching for temperatures greater than 16°C and relative humidities >70%). Most responded that they did not know enough about such periods (52%) or never felt they needed to monitor for them (30%). As with black spot, fire blight infection periods were more likely to be used by growers with formal horticultural training (X^2 p=0.02).

3.3.4.4 Pheromone traps

A number of growers used pheromone traps for monitoring flights of leafroller (22%) and codling moth (14%). Most of those who used leafroller traps found them useful, although three growers (6%) found that they added indecision to spray application. Two growers (4%) had them on the property but did not use the monitored data for management. Thirty two percent of growers considered that there was no need for any leafroller traps and 26% did not know much about them. Eight percent of growers considered they were not practical. However, 12% of growers surveyed, who were not presently using them, indicated they would use them in the following season. Leafroller pheromone traps tended to be used more in the larger orchards (mwu P=0.01).

Most growers (60%) considered there was no need for codling moth traps.

3.3.5 Factors important in the spray decision

As described in methods, growers were shown seven factors that may contribute to the spray decision and asked to rank them for six pests and diseases. Most growers chose at least four factors as being important. Table 3.1 shows an "average" ranking of these first four most important factors. For leafroller, powdery mildew and mealybugs, most growers followed a regular calendar program based on a spray chart, applying more or less according to qualitative assessment (gut feeling, intuition, experience etc.). The same calendar treatment was carried out for black spot but with this disease, quantitative data (showing occurrence/non-occurrence of an infection period) and advice from a field representative/consultant etc. was also important regarding timing of protectant and eradicant sprays. Spraying for fire blight and mites tended to occur more at specific times of the season, with timing advice often sought or given. Spraying for European red mite was usually determined from either the mite hatch model (early season) or qualitative monitoring (late season), unless ovicides were used. In most growers' opinions, ovicides gave season-long control.

Table 3.1. Factors which contribute to the spray decision, ranked in order of importance for six commonly sprayed pests and diseases of apples.

Pest/Disease	Factors ranked in descending order of importance
Leafroller	Timing taken from spray chart Qualitative assessment (gut feeling, intuition etc.) Advice from someone else (field rep., consultant, etc.) Applied in a tank mix when spraying for something else
Mites	Advice from someone else (field rep., consultant, etc.) Monitored data (counts, results of decision-aid etc.) Qualitative assessment (gut feeling, intuition etc.) Timing taken from spray chart
Mealybugs	Qualitative assessment (gut feeling, intuition etc.) Timing taken from spray chart Advice from someone else (field rep., consultant, etc.) Applied in a tank mix when spraying for something else
Fire blight	Qualitative assessment (gut feeling, intuition etc.) Advice from someone else (field rep., consultant, etc.) Timing taken from spray chart Predicted weather (next 2-3 days)
Black spot	Qualitative assessment (gut feeling, intuition etc.) Monitored data (counts, results of decision-aid etc.) Predicted weather (next 2-3 days) Advice from someone else (field rep., consultant, etc.)
Powdery mildew	Qualitative assessment (gut feeling, intuition etc.) Timing taken from spray chart Advice from someone else (field rep., consultant, etc.) Applied in a tank mix when spraying for something else

("Average" rankings based on medians)

The percentage of growers who ranked monitored data as one of the four most important factors in spray decisions for six pests and diseases are presented in Table 3.2. Quantitative data was commonly used in mite and black spot spray considerations. The "informed spray" score derived from this data (see methods) was higher for growers with formal training (mwu P=0.03) and was positively correlated with the size of the property (sp=0.55 P<0.01). Sixteen percent of growers did not use monitored data for spray decisions for any of the six pests or diseases.

Most growers sought advice from someone for at least four pests and diseases out of the six covered (Table 3.2). There was a weak negative correlation between age of growers and "advisory" score (sp=-.266, P=0.06) although no correlation existed between grower experience and this score. There was a weak positive correlation between orchard size and "advisory" score (sp=.28 p=0.04).

Table 3.2. Percentage of growers who ranked monitored data or advice from others as one of the four most important factors in making spray decisions for six common pests and diseases of apples

No. of pests and diseases	Using monitored data	Seeking advice
1	16	10
2	34	4
3	20	20
4	4	16
5	4	18
6	6	28

3.3.6 Pest and disease decision support service?

3.3.6.1 Desire for service

Eighty two percent of growers said they would support a service "which automatically monitored pests and diseases in the orchard (or a homogeneous area) and could communicate same-day recommendations to them, along with other orchard specific information they might want" if such a service was available (Table 3.3). Of those that said they would not, reasons given were either that the property was too small (4%) or that a consultant/field representative does the same job anyway (12%). One grower said he would not support it on principle unless it was entirely free. In general, the service was supported more by younger growers than older ones (mwu P=0.01) and by growers managing larger orchards (mwu P<0.01). Also, the service was desired more by those growers that ranked high on the "technology" score (mwu P=0.02) and the "informed spray" score (mwu P=0.01).

Table 3.3. Decision support statistics. Figures represent percentage of apple growers

Equipment	Fax	Computer	Telephone
Own	20	46	100
Access only	34	18	0
Preferred delivery mode	68	20	12

3.3.6.2 Existing equipment for delivery

Sixty eight percent of growers felt that a fax machine would be the most appropriate mechanism for delivery of such a service, 20% felt a computer-modem link would be best and 12% opted for the telephone (Table 3.3). Growers were split about 50:50 on whether the existence of such a service would encourage growers to buy a fax machine. Many growers were contemplating buying them for other uses anyway.

Ownership or access to either a fax machine (54%) or microcomputer (64%) was relatively high, and the "technology" score showed a positive correlation with the size of orchard (sp=0.39 P<0.01) and a weak but significant correlation with the informed spray score (sp=0.28 P=0.04). Perhaps surprisingly, age was not a factor in ownership or access to the above technology.

When asked the question "Do you feel comfortable using a microcomputer?" 36% of respondents answered in the negative, mostly those who did not own or have access to one.

3.3.6.3 Importance of selected features for a "hypothetical" pest and disease decision-aid

Growers were asked to rank the importance of five given features of a hypothetical computer-based pest and disease spray decision-support system. From an "average" ranking based on medians, the five most important factors in order of importance were:

1. Reliability
2. Easy to interpret (i.e. at a glance)
3. Automatic monitoring of necessary parameters (e.g. insects, weather)
4. Gives control recommendations (e.g. control options, list of pesticides)
5. Offers an optional educational aspect (eg. info. on insect life cycles)

Correlations were found between the ranked importance of a particular feature and grower or orchard parameters. "Giving control recommendations (and options)" tended to be ranked lower in larger orchards (sp=0.36 P=0.01), amongst growers with high "technology" scores (sp=0.28 P=0.05) and with growers who had formal training (mwu P=0.04). Growers with a high "informed spray" score also considered this feature as less important (sp=0.344 P=0.01).

Experienced growers put less weight on reliability (sp=0.37 P=0.01) but ranked ease of interpretation as a very important feature (sp=-0.36 P=0.01). Growers with high "technology" scores valued educational aspects more (sp=-0.30 P=0.04) and growers with formal training and a high "informed spray" score considered automatic monitoring to be more important than did other growers (mwu P=0.01 and sp=-0.245 P=0.08 respectively.).

3.3.7 Residues and pest and disease resistance – a problem in the future?

Growers were shown two statements saying that pesticide residues and pest and disease resistance would be major problems for the New Zealand apple industry within the next 10 years. Practically all growers agreed (38%) or strongly agreed (58%) residues would be a problem in the future with only 4% of growers unsure. Opinion was more divided on resistance although most growers (78%) felt this would also be a problem. In an open question growers were asked how they saw pest and disease practices changing in the next 5 years. Most said they expected to see less spraying through improved IPM techniques and/or better spray application technology. Many expected to see "greener" pesticides.

3.4 Discussion

The survey was conducted in the Hawkes Bay area hence the results and discussion pertain to that region only. Other apple growing regions, such as Nelson and Canterbury, may differ in their problems, perceptions and use of decision-aids.

3.4.1 Grower and orchard characteristics

The survey showed an industry with many "newer" growers as over half those canvassed had less than 10 years experience and did not come from an orchard background. This influx of new growers during the 1980's reflects the perceived good health and high returns of the industry at that time. It is also an industry where most growers had no formal training in horticulture. There is no reason to believe the situation is any different in 1997 as regards this latter finding.

3.4.2 Troublesome pests and diseases

The results indicate more research into the persistence of black spot fungicides on plant surfaces would assist timing. Mealybug and Phytophthora crown rot (*Phytophthora cactorum*) were cited as troublesome by a significant number of growers and could indicate more research into control is perhaps needed with these organisms. It is now known that the reasons for mealybug problems were probably due to resistance development (Charles, Walker and White, 1993).

3.4.3 Use of existing IPM technology and methodology

The results showed a relatively high use of established IPM technology and strong interest in new techniques (e.g. leafroller pheromone traps) particularly in larger orchards and amongst growers who had received formal training in horticulture.

This is not surprising, as larger blocks have greater spray costs therefore any reduction in spray applications by improved timing would result in significant financial savings. Growers who have received formal training are likely to have covered the benefits of IPM methodology in the course of their studies and so attempt to apply it to their situation.

Whilst they may save on the cost of chemicals, decision aids often make management harder, when compared to following a conservative spray program or relying heavily on advice from someone else. The difficulties involved with this "active" decision-making and its associated risks is a common problem in apple IPM implementation (Fenemore and Norton, 1985). Reducing this risk factor through more accurate techniques and improved decision support should improve uptake of the methodology and lead to overall lower chemical usage.

It is assumed the use of IPM methodology and decision-aids reduces overall pesticide application. This is not always the case. Brenton-Rule (1993) examined spray diaries of 36 of the growers selected in this study (those growing Royal Gala) and found that only 29% of them left their crop unprotected for any length of time. The remaining 71% would maintain a protective cover over the primary ascospore release period with over three-quarters of these using reactive eradicant applications, presumably based on infection period information. Indeed, it could be argued that having more information with regards to when infection periods occur actually increases fungicide use, as risk-adverse growers spray eradicant fungicides “just in case” their protectant cover has been breached.

New pesticides can render IPM techniques less important or even redundant. The ovicidal miticides are a case in point, with a number of growers surveyed having only recently switched to them as a mite control option, and therefore considered they had no need for the mite hatch prediction model. To some growers these chemicals appeared so effective that late season mite monitoring was regarded as unnecessary. However, many of those using ovicides seemed aware of the benefits of using them only every second year, both to prevent resistance and preserve predatory mites.

In fact, the suspicion of resistance has lead to less reliance on just one ovicide application, and more use of integrated mite control in recent years (Walker, *pers comm*).

3.4.4 Impact of the field representative or consultant

The reasons for the considerable input horticultural merchant field representative and private consultants have on growers' spray decision-making, which was apparent from the survey, may include the following. Many growers did not have a long association with the crop and few had tertiary training in horticultural enterprises. Lack of time was a major consideration. Growing apples to export standard is a complex and sophisticated business. Good technical pest and disease knowledge is usually required but often growers are simply too busy to give this area maximum consideration. Leaving part of the decision-making to a trustworthy specialist relieves the burden somewhat. Person-to-person contact can be frequent as the Hawkes Bay apple growing region is small and most representatives or consultants would only need a 15 minutes drive to be on their client's property.

As these people have a major part to play in reducing spray application in Hawkes Bay apple orchards, their role needs to be considered in any IPM development strategy. Their influence could facilitate (or hamper) the adoption of any new techniques. A similar situation exists with "leading" growers. An investigation into the role of the pest and disease “adviser” is the subject on the next chapter in this thesis.

3.4.5 Whither Pest and Disease decision support?

Most growers indicated they would like a "tailored" decision support service to complement the advice already being obtained from field representatives and private consultants. Such a service would need to be very reliable and very easy to use.

A service with different levels of sophistication may be the most appropriate option. At the most basic level, information and regional IPM advice could be available directly to growers on request through a fax machine, essentially similar to the prototype service operated by MAFTech over the 1991/92 season.
At an advanced level, the service could offer the PC-based information management system and interactive models outlined by Manktelow and Laurenson (1990). This service is more likely to be of interest to growers with large orchards, private consultants and field representatives. The latter two would essentially become "IPM managers" for their clients. Software in the system would need to reflect the different levels of use, i.e. single or multiple management units.

3.4.6 Footnote

In fact, as mentioned in chapter two of this thesis, this service has now come to pass and directly or indirectly influences much of the decision making in Hawkes Bay apple crops (Laurenson and Beresford, 1996).

All growers surveyed thought that pesticide residues and, to a lesser degree pesticide resistance, would cause major problems in the future. Nearly all growers felt that techniques to enable reduced pesticide application would continue to develop and improve. The perception existed, therefore, that change in the way pests and diseases are managed is required, and will occur.

Recent developments in the orchard sector have shown that these perceptions were correct. The challenge was to provide reliable, effective techniques and the technology-transfer mechanisms to do this. The creators of Orchard 2000 considered the findings detailed in the above survey, in order to aid implementation of this decision-support system.

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CHAPTER 4

PEST AND DISEASE MANAGEMENT IN HAWKES BAY APPLE ORCHARDS: RESULTS OF AN "ADVICE-GIVER'S" SURVEY

The previous chapter found horticultural merchant field representatives and consultants to be major spray decision advisers. This chapter reports on a follow-up survey to learn more about their role in spray decision-making.

4.1 Introduction

The survey on pest and disease decision support in Hawkes Bay apple orchards, outlined in the previous chapter, found spray-timing techniques in widespread use. Some of these, such as black spot infection period monitoring, were being used more to maximise control, rather than to reduce sprays. Furthermore their use was often recommended or facilitated by the commercial servicing sector.

The apple orchard servicing sector in the Hawkes Bay region is well developed. The growing area is small but very intensive, with approximately 90% of orchards (about 650 growers) lying in area of 20 square kilometres surrounding the city of Hastings. It is a prosperous horticultural area requiring large inputs by way of pesticides, fertilisers and equipment. This combination of wealth, orchard concentration and high inputs has resulted in a service sector which has an extremely strong, competitive infrastructure. It is an area where the growers are very well serviced by horticultural merchant and APMB field representatives, consultants and scientists. Amongst the merchant firms in particular, competition for new clients is intense.

Nearly all growers in the region grow to export. To successfully grow apples to the very high export standards set by the Apple and Pear Marketing Board (APMB), requires technical knowledge and skill. The previous survey showed that the industry has many new growers who have neither a background nor qualifications in orcharding. This being so, it is not surprising that to many growers, horticultural merchant representatives and private consultants are the primary source of their pest and disease advice (Fig 3.3).

Given that these “advice-givers” appeared to have a major role in pest and disease control decision-making (hence the promotion of any spray-saving techniques), it was decided to further investigate the relationship between these “advice-givers” and their clients. To do this, an interview survey of all known consultants and horticultural merchant representatives providing advice to Hawkes Bay apple growers was conducted in the spring and summer of 1993/1994. The purpose of the survey was to determine how much contact these workers had with growers and whether or not they saw themselves as primary spray decision-makers. Also identified were areas where pest and disease management information was lacking, and what skills or knowledge a good orchard manager should have on pests and diseases.

This survey, like the previous one, has been published in the scientific literature (Stewart and Mumford, 1995). Like the growers’ survey, there have been a few changes in the industry since the work was carried out. These are included in the conclusion.

4.2 Method

A list of 30 pest and disease control "advisers" was compiled from various sources. All commercial advice-givers of any significance operating in the Hawkes Bay region were included. From this list of 30, twenty-seven individuals were surveyed and three could not participate. Of those surveyed, 12 were horticultural merchant field representatives from the four major firms (FruitFed Supplies Ltd., Skelton Ivory Ltd., Williams and Kettle Ltd., and Wrightson.), eight were private consultants, five were APMB field representatives and two were Horticulture and Food Research Institute of New Zealand (Hort+Research™) plant protection scientists. Of the three individuals who were not surveyed, two were APMB field representatives and one was a private consultant. The client base for these non-participants was small, and it is unlikely that their input would have altered the findings of this study.

Interviews were conducted over the spring, summer and autumn of 1993/1994. The questionnaire is attached in Appendix III. The age of participants was noted, along with their experience in pest and disease management advice-giving and any relevant tertiary training obtained. They were asked for the number of clients they had, the frequency of contact and how they went about managing pest and disease advice over a typical season. Opinion was sought on the proportion of their clients whom they considered allowed them to act as the major decision-maker; in other words, their advice would almost invariably be followed without question. A related question ascertained the proportion of their clients who expected them (the field representative or consultant) to know more about pests and diseases on their property than they (i.e. the clients) did themselves.

Other questions covered pest and disease problems where information was scarce, and the important information pests and disease managers should know.

Hort+Research™ staff participated in a modified interview, due to the different nature of their advice giving. Often this advice was to representatives and consultants themselves, as well as growers.

4.3 Results and discussion

4.3.1 Horticultural merchant field representative

The typical horticultural merchant field representative was 36 years of age, had an average of seven years consulting experience and dealt with 80 or so clients a year. Five out of the 12 interviewed had had some experience of managing an apple orchard themselves, either as an owner or manager. One came from an orcharding family, and one had experience with vineyards. Eight of the representatives had completed, or were in the process of completing, a relevant tertiary qualification.

The pattern of advice giving was similar for all the field representatives. With one company, representatives were assigned a geographical area to service whilst the other three distributed their staff amongst the clientele, depending on the rapport they had with individual growers.

Before the start of the season, representatives would visit or call on 75-95% of their clients and discuss the coming year. The spray calendar or spray chart was the basis for this discussion. The past year would be reviewed and any problems discussed. Growers would be made aware of new technologies or pesticides that may have a place in the coming season, along with any changes in usage patterns or withholding periods of existing product. Various options, needs and prices were discussed and a spray order would often be taken at this stage.

From this point on, the representative would maintain regular contact with the client. Contact is frequent during the "black spot period" from the beginning of September to early December, reaching a peak during late September-early October when chemical fruit thinners are applied. During this time of hectic activity, representatives provide advice on black spot, fire blight (*Erwinia amylovora*) and thinning sprays. They were always on call via mobile phone, during the day and in the evening. The same grower could call a single representative 2-3 times a week.

All representatives made a point of personally visiting their clients at least once in 2-3 weeks during this busy time but the frequency of contact within this period depended on the type of client. Newer, less experienced growers tended to be visited more often (every week in some cases) along with those people the representatives didn't feel would do the "right" thing due to ignorance or incompetence. Also, those with long-standing large accounts are favoured with frequent "patronage" calls.

In January and February, visits are less frequent although representatives will still drive out to the property and check mite levels and other aspects of crop health. On average, the number of times representatives estimated that they would have contact with their clients during the growing season (Sept-April) came to 21. However, that number would vary considerably depending on the grower concerned.

Table 4.1 shows the statistics associated with pest and disease decision-making. According to the representatives, on average 40% of growers looked to them as being the main decision-maker and 53% of growers expected them to know more about pest and disease levels in their orchards than they did themselves.

Table 4.1. Representatives role in pest and disease control decision-making in the orchard

	Mean	*Minimum*	*Maximum*	*Median*
% of growers for whom rep. was major pest and disease decision maker	40	5	85	40
% of growers who expect rep. to know more about pest and disease levels in their orchard than they do themselves	50	5	80	60

How this relatively high level of "decision-making dependency" has come about is easy to see. Once a new grower commences in the district, the merchant firms are eager to attract them as a client. Usually, the representatives will call on the grower personally once he has come to their attention. Competition means that chemical prices are fairly similar, so the only factor that can give one firm an edge over another is in servicing. Servicing involves developing the spray program, offering advice on timing, and monitoring the orchard for pests and diseases - at no extra cost. This often suits the grower, especially if they do not have the skills, knowledge or confidence in pest and disease management. Also, apple growing is quite a demanding business and it is easier to pass any difficult decision-making onto someone else, if you have confidence in them. Indeed, many growers appear to expect this level of servicing and will change firms if they don't get it.

Asked about whether or not they tended to give just a single recommendation or a range of options to the grower, the response was similar from all representatives Usually they had a 'most favoured ' option they would give. Whether or not other options were discussed seemed to depend mostly on the type of grower concerned e.g. how knowledgeable they were, how financially stressed they were, and whether they wanted to discuss other choices. Also relevant was the pest or disease concerned, as control options were fairly limited with some. Three representatives mentioned that new entrants to the industry especially seemed to want single, uncomplicated recommendations.

Representatives were asked whether, given the nature of their jobs, there was a tendency to be more conservative in their recommendations than a grower would be (i.e. minimise risk at the expense of cost). Nine replied a definite yes, whilst the three remaining replied sometimes. The latter remarked that the recommendation depended entirely on the grower. If they had confidence in their technical ability, then they could be a little less conservative. Many representatives commented that there was a safety margin built into their recommendations that took account of the grower. Generally, the larger the safety margin (i.e. the less knowledgeable and competent the grower appeared), the more sprays applied.

The primary concern of the merchant representative is to ensure a pest and disease-free crop for their clients. This fits well with the goal of their company, which is to sell pesticides. By following a conservative, no-risk approach to pest and disease control based on calendar spraying, they can fulfil both of these objectives. Furthermore, the less knowledgeable the grower is, the more conservative the spray program is likely to be. Being in the position of the main decision-maker, field representatives will understandably cover themselves and their company by applying insurance sprays, hence minimising any "idiot-factor" on behalf of the applicator (i.e. the grower).

Given the pressures for conservative calendar spraying therefore, do the field representatives recommend spray-saving techniques? The answer is yes, providing such techniques are prescriptive (i.e. simple recipes), easy to implement and carry no risk of pest or disease infestation. An example is timing early season mite sprays using the mite model mentioned previously, and spraying on the basis of predicted or actual black spot infection periods.

Although the representatives' primary role is to sell products, many see themselves as acting in the grower's interests. More importantly, they must be seen to be acting in the grower's best interest, otherwise their clients may go elsewhere. This prevents representatives from recommending pesticide applications when they are obviously unnecessary, e.g. a long dry spell in spring when some black spot cover spray residue may be still present. Also, it is in their interests to be skilled in the latest control techniques. The issue is one of credibility, and few companies would survive if their representatives were not seen to be acting for the grower, acting responsibly, and saving them money from sprays where they could.

With regard to other data collected, when asked to list pest or disease problems where information appeared to be lacking, the representatives' responses reflected the current problems in the district at the time of the interview. Nutritional problems, chemical thinning, and fire blight control were mentioned in at least three different interviews. It was generally felt this information was simply not known, rather than being hard to obtain.

Representatives were asked what they considered the three most important things pest and disease managers needed to know. Eight out of the twelve rated pest and disease identification as being very important, particularly in the early stages of infestation or infection. Other important areas, cited in at least three different interviews were pesticide product knowledge, knowing the conditions conducive to attack, a knowledge of pest and disease life cycles, sprayer calibration and pesticide safety.

4.3.2 Apple and Pear Marketing Board field representatives

Five of the seven APMB representatives working in the Hawkes Bay region were interviewed. Ages ranged between 24 to 34 years. One representative was a trainee with only six months experience but the others had had between two and a half to nine years in an advisory role.

For the purposes of servicing the industry, the APMB has split the region into quarters based on grower numbers. Two representatives; one senior and one junior normally manage each quarter (about 220 growers). Their role is to implement and police APMB policy. During the harvest season, packhouses are monitored for crop quality. Where recurrent pest and disease problems are found, this is followed up with a visit to the grower to determine where the problem lies. Strategic advice on pest and disease control may then be given. In the off-season, time is spent on preparing technical bulletins (e.g. "Pipmark®") or "orchard walks" with growers and merchant field representatives. During the growing season, visits to orchards are made to determine crop loading and some pest and disease advice may also be given.

The APMB policy over the past year has been to move away from providing day-to-day tactical pest and disease control advice during the growing season. Growers who ring with a query will be serviced, but the strategy is to educate orchardists through technical bulletins and off-season courses. Given that a large body of new, untrained growers exists in the Hawkes Bay region, this would seem a worthwhile approach. Consequently, APMB representatives did not feel they had much influence in tactical pest and disease decision-making by the grower. Two representatives felt that they were the major decision maker for 5% of their growers, whilst the other three gave a value of 1% or 0%. In response to the question, "What % of growers expect you to know more about pest and disease levels in their orchards than they do themselves", one representative gave 10%, one gave 5% and the other three gave 0%.

Responses to the questions regarding control recommendations were similar to those given by the horticultural merchant field representatives. In brief, a range of possible options was covered, with an endorsement given to a particular one. How much of an "idiot-factor" was built into the recommendation depended on the representative's perception of the grower's competence.

The APMB representatives cited few pest and disease problems where they felt information was lacking. However, apple leafcurling midge (*Dasyneura mali*) was mentioned by three of them.

When asked what important information managers should know about pests and diseases, the responses were similar. Detailed knowledge of pest and disease biology, lifecycles, when to expect outbreaks and what stages are vulnerable to control were considered crucial. Pest and disease identification was also important, as was a good knowledge of control options.

The APMB representatives all held tertiary horticultural qualifications. Two had degrees, two had diplomas and one had completed a cadetship through a polytechnic.

4.3.3 Consultants

Horticultural consultants and horticultural merchant field representatives have an uneasy relationship. If a grower has a consultant, many representatives just provide the chemicals without advice. Others will give recommendations, knowing that the grower may well get a second opinion from the consultant.

Eight consultants from five companies were surveyed. The consultants varied considerably in the way they conducted their business, even within companies. In three companies, the consultants provided day-to-day pest and disease management advice. In another company, much of this advisory work was left up to the horticultural merchant representative but one consultant of the two in that company made regular visits and gave a second opinion when necessary. The second consultant in this company and both consultants in the final company surveyed did not participate in any day-to-day advising; rather they acted as trouble-shooters. They were called in when problems occurred.

This latter group was not so relevant to the survey, and many of the questions regarding pest and disease advice-giving could not be answered by them. Unless otherwise indicated therefore, the results below relate only to the five consultants who provided routine management advice, as opposed to simply being called in to diagnose problems.

Ages for consultants ranged from 28 to 55 with the average at 42 years. Their experience varied, with the lowest being four years and the highest being 30 years (Table 4.2). In general, those with the most experience had the most clients. Client numbers varied enormously from four to 150 and represent approximately 33% of the total Hawkes Bay apple grower population. All of the five consultants surveyed had tertiary qualifications.

Table 4.2. Consultants - Statistics on age, experience and estimated client numbers

Consultant reference no.	*Company reference no.*	*Age*	*Experience*	*Estimated number of clients*
1	1	42	20	150
2	1	37	12	30
3	2	33	6	20
4	3	55	13	40
5	4	28	4	4

Only consultant 4 met with clients at the start of every season to plan out a pest and disease programme. During this process he would review problems from last year and make up a spray chart. The growers would be asked what they wanted to do e.g. try integrated mite control using predatory mites, or remain with chemical control. This consultant would then make regular visits to all clients during the season; at least once a week during the August-December period. In essence this consultant "managed" his client's pest and disease programme.

Of the others, consultants 1,2 and 5 would spend a considerable amount of time with their clients when they first took on their business. Consultants 1 and 2 provided their own export spray chart. All three would leave day-to-day pest and disease management to the horticultural field representative if they had confidence in them. In this situation, the consultant would concentrate more on the overall strategy and monitoring the orchard's performance, although they would be available if a second opinion were needed. New clients would receive more attention, including regular visits at critical times of the season (eg. September-November).

Consultants 1 saw himself as having an educational role as well as advisory and aimed to upskill the grower so they could mostly manage pests and diseases themselves by the third year.

Consultants' opinions of who was the major pest and disease control decision-maker in the orchard (themselves or the grower) appear in Table 4.3. Some carried out almost all the decision-making in the orchard whilst others will took a "hands-off" approach, the grower contacting them only if there was a problem.

Table 4.3. Consultants' opinion on who decides on pest and disease control in the orchard

Consultant reference number	*% of growers for whom consultant was major pest and disease decision-maker*	*% of growers who expect consultant to know more about pest and disease levels in their orchard than they do themselves*
1	20	20
2	10	10
3	50	50
4	90	100
5	50	100

Consultant responses were similar to those of the field representatives when asked whether they tended to give just a single recommendation or a range of options to the grower. With some growers, a range of options was discussed with a single one being recommended, whilst others were given just a single recommendation. In the case of consultant 1, usually a single recommendation (i.e. the best option in his opinion) was sought and provided.

Like the representatives, consultants were asked if, given the nature of their job, they tended to be conservative in their control recommendations. Consultant 1 and 4 replied in the negative to this question, whilst the rest replied yes. However, on analysing their comments, it seems all consultants would recommend a non-spray if they did not think the application was necessary, but none of them practiced any sort of risk management. Programmes may be a little less conservative than the merchant field representatives' but in essence they were largely preventative with the usual "idiot factor" built-in, the degree of which largely rested on their assessment of the grower's competence.

Asked about pest and disease problems where information is lacking, the consultants came up with a list of topical problems, similar to that of the representatives. Pesticide resistance, in the case of fire blight and apple leafcurling midge was cited in at least 2 interviews.

As with the representatives, consultants were asked what they considered to be the three most important things managers needed to know regarding pests and diseases. Responses were similar to those of the merchant field representatives.
As they charge for their services, consultants must be seen to offer more than the merchant field representatives. One selling point is their impartiality when it comes to chemical selection. They also make a point of trying to save the growers money by reducing the spray application where they can. One consultant remarked that he would aim to at least save the grower the equivalent of his fee.

The demand for consultants seems to be increasing in the industry, with no shortage of new clients for those consultants actively seeking them. This is an indication of the increasingly technical nature of export apple growing and the large number of new unskilled growers. Consultant 1 for example, by his own admission, had more clients than he could handle.

4.3.4 Apple plant protection scientists

The Hort+Research™ entomologist and plant pathologist responsible for apple orchard plant protection in the Hawkes Bay region were asked questions that differed to those put to the two groups above. These questions took into account the different nature of their duties and the fact that they were often "advising the advisers". They were aged 31 (pathologist) and 41 (entomologist) with four and 12 years experience respectively.

To ascertain their input into the knowledge base in the region, questions were asked related to the frequency of this information transfer. Results appear in Table 4.4.

Table 4.4. Frequency of information transfer from Plant Protection Scientists

Scientist	*Extension meetings spoken at per year*	*Number of field reps. who seek advice on a regular basis*	*Number of consultants who seek advice on a regular basis*	*One-to-one meetings with others per year*	*Do recipients of advice pay?*	*Extension articles written per year*
Path.	10	5	6	8	Yes	1
Ento.	8	5	6	7	No	2

Extension articles by both scientists were published in the Orchardist of New Zealand. The entomologist also wrote material for the APMB's Pipmark® bulletin.

Most extension seminars given are regular annual events but a local crisis (e.g. hail damage) can lead to extra meetings being held. Usually there are four to five grower seminars and three or so meetings with horticultural merchant representatives (one meeting a year with two of the major merchant companies and one meeting with a consultancy company). One or two meetings per year with APMB field officers is not uncommon. Also, the scientists meet with a group of 20 or so growers trialing the Orchard 2000 information delivery system at least twice a year (Laurenson *et al*, 1992).

From time to time, field representatives, consultants and some growers would visit the researchers or phone them to seek advice. Representatives from two of the three major firms would do this on a regular basis (i.e. approximately. 40% of the total horticultural field representative population). The firm that did not do this regularly had stronger research and development resources than the others. They had their own technical officer who would organise field trials and collect advice from a wide variety of sources, including Hort+Research™ if necessary. This information would then be made available to their own representatives.

Consultants would seek advice from scientists once or twice a year, as would a handful of growers who had developed a good rapport with the research staff. The rapport usually arose from trial work being conducted on the growers' properties. Mostly, these growers could be termed "influential" in the district.

The scientists felt that contact with the field representatives, consultants and growers was important and that they often learned much about what was happening in the region from them.

Other advice seekers included APMB staff, private horticultural firms growing other crops (eg. vegetables) and Area Health Boards.

Payment for advice is *ad hoc*. The horticultural field merchants initially contributed a few hundred dollars; records are kept of advisory work done and charged against this amount. When it is all used up, the firm is re-invoiced for it. Seminars to the merchant firms are charged for by the hour but grower seminars are free.

The monthly grower publication "Orchardist of New Zealand®", and the APMB "Pipmark®" technical bulletins, are the two main vehicles for written extension advice. The "Pipmark®" bulletins are not in the public domain, being available to apple growers only. One of the scientists produces on average three or four contract reports for the APMB based on experiments conducted. The results of these are not always made public.

The two scientists interviewed appeared to make a major contribution to the technology transfer in the region. Contact with representatives, consultants and industry leaders was frequent, either through meetings, seminars or personal contact. Their research programs were of a very applied nature and they were also locally based, features which enhanced their effectiveness.

Scientists were asked for their views on the effectiveness of their information transfer. Prescriptive, recipe-type recommendations and techniques were well publicised and taken up by growers. Examples are the summer egg-hatch warnings for European red mite and black spot infection periods mentioned previously. The technology-transfer in this case worked well, largely because the techniques were simple to follow. Other techniques however, such as the use of pheromone traps to monitor leafroller flights, were more complicated. In order to get growers to use these, a prescriptive approach had to be taken which was not entirely suitable given the phenology of the moth. Both scientists felt that a computer-based delivery system such as Orchard 2000 would assist growers, consultants and field representatives with more complex decision-making. This was because the computer would assist with the analysis of the situation and present it to the grower in an easily comprehended form.

Given that grower education seems to be an important priority for the APMB, joint extension activities with this organisation and Hort+Research™ would be appear to be of value, and should be encouraged.

When asked what pest and disease problems need further research, the answers generally reflected the areas the scientists were working in. Resistance status of pests and diseases, spray application techniques, black spot infection period information transfer, the phenology of leafcurling midge, *Graphania* (cutworm) species and oriental fruit moth (*Cydia molesta*) were mentioned.

Asked what aspect of pest and disease management growers seemed most ignorant about, scientist 1 cited spray application...because the experts are also ignorant. Scientist 2 felt that growers were well informed but that they varied in their ability to use the knowledge.

The plant protection scientists experienced a sense of frustration with some aspects of their duties. The lack of resources to research current problems (e.g. possible resistance in apple leaf curling midge) was one. Another was the *ad hoc* nature of advice being given by representatives and consultants when the fundamentals had not been researched (e.g. spray application). Both scientists appeared to enjoy the extension work, but felt the organisational structure of Hort+Research™ did not adequately recognise these duties.

4.4 Conclusions (and update)

Merchant field representatives and consultants are the pest and disease management decision-makers for a significant number of growers. Given the nature of their job, recommendations are generally conservative and risk-free, more so where the grower is seen to be unskilled or unknowledgeable.

Risk management of pest and diseases in high value crops such as apples is very difficult. From a growers point of view, a zero risk system is easier (and often less costly) to manage. However, even within the confines of a zero-risk strategy there is scope for pesticide reductions, given better grower education. With skilled clients, advisers would no longer have to incorporate a large safety buffer into their recommendations. Hence growers, together with their field representatives or consultants, could then fine-tune their programs to minimise sprays whilst maintaining excellent control.

The survey indicated that it would be desirable for the industry as a whole to focus on grower training by way of seminars, workshops or decision-support tools such as Orchard 2000. At the time of the survey, the APMB was emphasising a more educational role for its field staff. However, in 1997 this is no longer the case, as the Board has withdrawn from this extension effort (APMB *pers comm*). Some of the suggestions in the survey conclusions (Stewart and Mumford, 1995) are now coming to pass however. There is a far greater emphasis on technology transfer by Hort+Reseach™, and they have initiated many of the activities listed above (e.g. workshops) thereby assisting grower education. These activities are also helpful in maintaining close links with growers, advisers and plant protection researchers. Packhouses companies and co-operatives are also taking a much greater role in extension, than in the past.

4.5 References

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Stewart, T.M., and Mumford, J. (1995). Pest and disease management in Hawkes Bay, New Zealand apple orchards: results of an "advice-givers" survey. *New Zealand Journal of Crop and Horticultural Science 23*, 257-265

CHAPTER 5

PROBLEM DEFINITION

This chapter uses the information obtained in the literature review and previous surveys and, utilising a primary decision tool, defines the problem in order to identify solutions.

5.1 Introduction

The surveys outlined in the previous chapter, together with a study of the literature give a good picture of the industry and problem it faces as regards IPM implementation and pesticide usage. In this chapter, an attempt is made to clearly define the issues, with a view to specifying useful tools that may assist with solving the problems.

5.2 Is pesticide usage excessive?

5.2.1 Definition

Just what "excessive pesticide application" means is a moot point. Firstly, is it the total amount of pesticide (in kg/ha) applied over the orchard during a season, or is it the number of applications? The two normally relate directly to one another, but may not be the case where lowered rates are being used.

Secondly, it may depend on just who is making the judgement. For example, the APMB may feel that the high number of applications hinders its selling effort. Overseas buyers could feel there is something "environmentally unsound" with a product that requires so much pesticide use, leading to the buyer's own customers favouring the same product from a competitor, where less spraying has occurred. Here, pesticide usage is compared with other suppliers of apples and if the number of applications New Zealand growers make is higher than South African, Australian and Chilean growers, then New Zealand pesticide use can be deemed "excessive". Another example is that of a local district council, fearing groundwater pollution or problems from angry ratepayers who have observed spray drift. They may consider just a few applications to be "excessive spraying", especially if drift is visible to the populace in general.

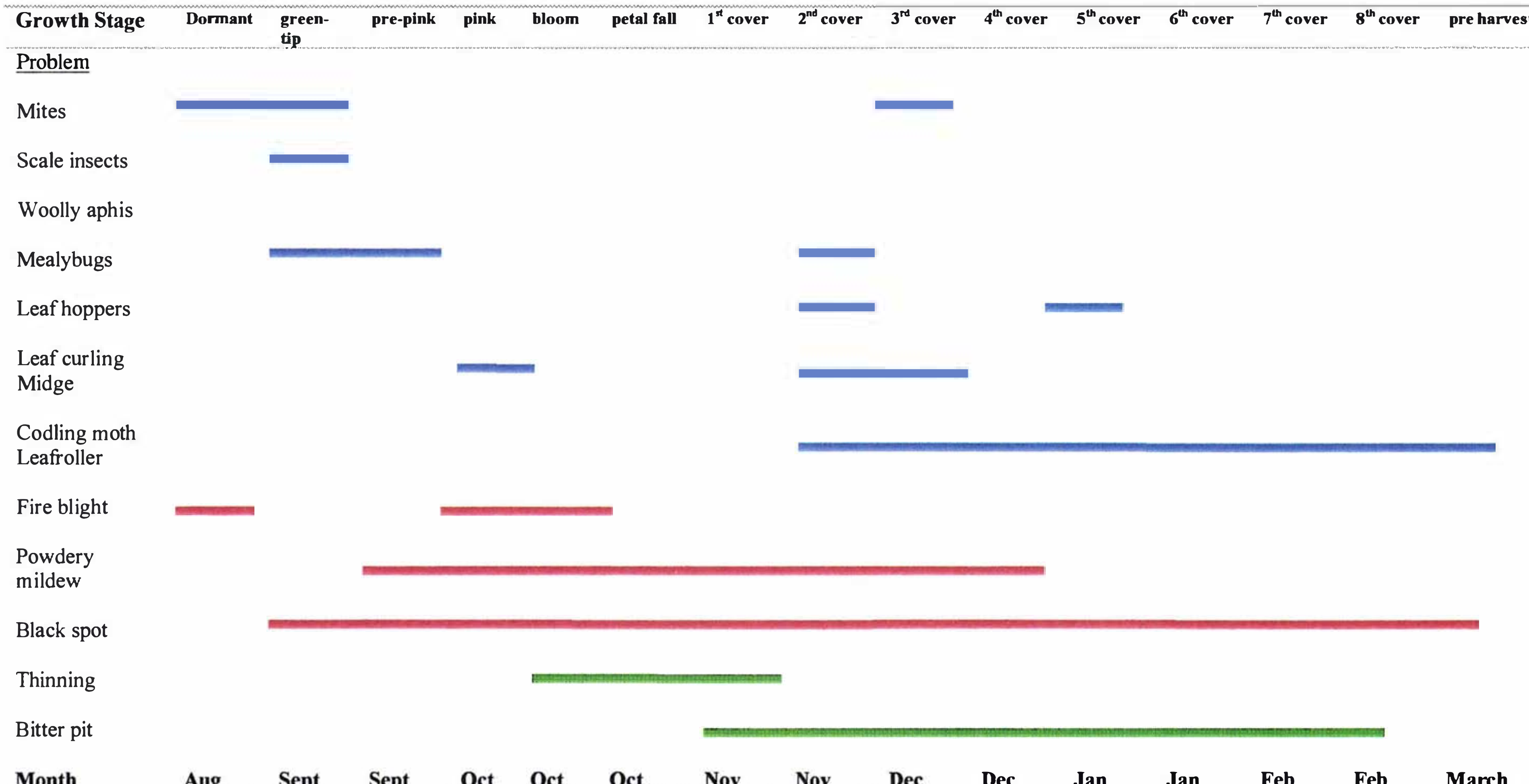
The examples above are subjective judgements. Another way to determine whether or not pesticide use is excessive, is to ask the question "In an average year, can growers produce export quality apples for similar profits, with less than the average number of standard rate pesticide applications they do now?" If the answer to this is "yes", then pesticide use, on the whole, is excessive. Even this definition can be argued, because the actual pesticide amounts can vary up to 100% between growers as shown by studies in Australia and New Zealand (Penrose, Thwaite and Bower, 1994). The author's own studies confirm this variation (see below). However, the problem must be looked at from an industry-wide perspective, and the average number of applications is the best way to do this.

5.2.2. Actual versus theoretical pesticide usage

To investigate this question, average application numbers were determined and the literature examined to see if it has been demonstrated that reductions can take place, using current technology.

One single disease and one single insect pest drive the spray program in New Zealand apple orchards (Walker *pers comm.*). In the early part of the program, black spot is the problem most growers time their sprays for, and from late November onwards, leafrollers are the target. Pesticides for other pests and diseases are often tank-mixed with pesticides for these two problems. The typical spray calendar in Figure 5.1 illustrates this.

Figure 5.1. Typical chemical application periods for common pests and diseases (+ thinning) in Hawkes Bay apple production



Spray diaries were obtained for the year 1994/1995 from 35 randomly selected Hawkes Bay growers. The results (variety Braeburn) are shown in Table 5.1.

Table 5.1. Pesticide applications for 1994/1995 in Hawkes Bay Apple Orchards (35 Growers)

Statistics	Black Spot	Leafroller	Total number of pesticides used (including thinning sprays)
Mean	18.3	9.1	40
Median	18.5	9.0	39
Minimum	12.0	2.0	22
Maximum	23.0	12.0	60

The figures reflect the number of active ingredients applied over a season. Many of these would have been tank-mixed. The number of actual applications (from the sprayer) averaged 20 over the season.

The numbers of black spot fungicides are higher than an earlier study of the spray diaries of the 50 growers who participated in the survey reported in chapter three. In the latter study, using data obtained over the1990/91 and 1991/92 seasons, an average of 14.1 black spot and 8.5 leafroller tank mixed applications were used (Brenton-Rule, 1993). What has lead to the apparent average increase in blackspot fungicides, from an average of 14.1 to 18.3 is uncertain, but recent seasons have been particularly bad for blackspot and this may have made growers more risk-adverse. What is interesting however, is not so much the average, but the range. Some growers were applying close to 23 blackspot fungicides and 12 leafroller insecticides per season.

Beresford *et al* (1994) showed that on average, blackspot sprays could be reduced by 34% if using a weather-based program, which took fungicide applications from an average of 20 in a strict calendar-based programme, to 13.2 using a weather-based programme. Leafroller sprays are more difficult to reduce for some markets. For example, the US market insists upon eight leafroller sprays with a mid-to-late variety like Braeburn in the Hawkes Bay, although this can be reduced if leafroller traps are used (ENZA, 1996). Applications can be further reduced, if the fruit is destined for a less "leafroller sensitive" market such as Europe. Clearly it is possible for sprays to be reduced, especially from the high end of the range, therefore "excessive spraying" is often taking place.

5.3 Problem tree

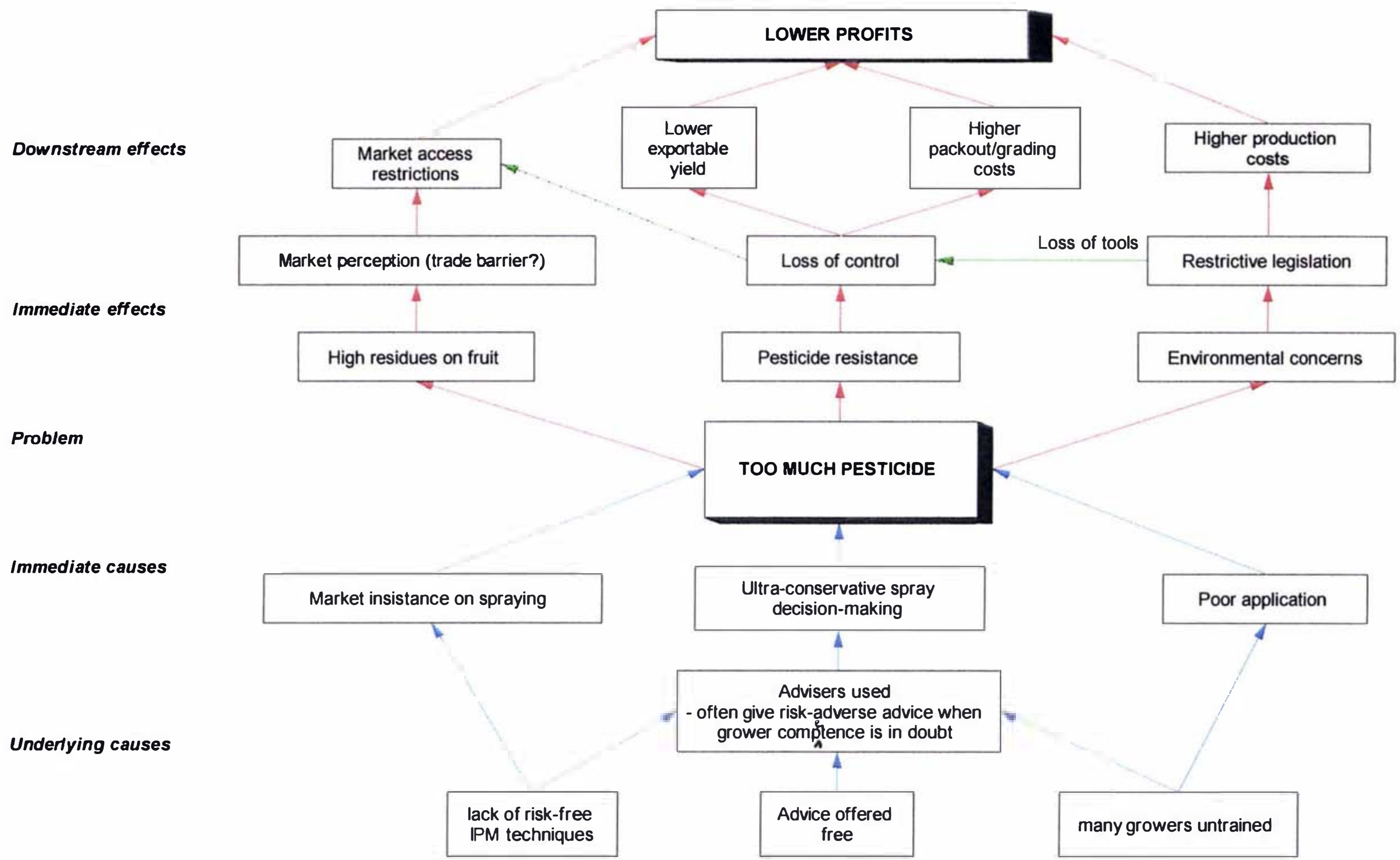
One way to focus on a problem, and hence set objectives for further action, is to use a problem tree (Norton and Mumford, 1993). Figure 5.2 shows such a problem tree for excess pesticide use in New Zealand apple orchards.

Having determined excessive pesticide use occurs, this becomes the problem under consideration. The problem tree itself is divided into branches and roots. The branches consist of the immediate effects of the problems and show the downstream implications of these. The roots show the immediate causes and, further down, the underlying causes which feed them. It is the latter which should be considered for action as it is those that feed into the main problem.

5.3.1 Effects of excessive pesticide use

There are three immediate results of excessive pesticide use in New Zealand apple growing. The first of these is environmental concerns, which can be national or international. In the Hawkes Bay region, the orchard industry is close to a major city, Hastings, and during the time of the two surveys, a number of articles appeared in the local press expressing concern about spray drift and groundwater contamination.

Figure 5.2. Problem tree for excessive pesticide use in apple growing.



These environmental concerns have lead to by-laws and national laws (e.g., the Resource Management Act, 1991) which has put extra demands on growers with regard to use of pesticides. Already, pesticide use is governed by five separate pieces of legislation, with more planned (see Appendix IV). More record keeping and care is required. While this is laudable and generally regarded as "a good thing", it does make the job of apple production more costly and demanding. If fewer pesticides were used in the industry, then compliance costs would be lower.

Overseas regulations can also have an impact. If a pesticide widely used in New Zealand orchards is banned, then the New Zealand growers lose one more tool in their arsenal of control options which, if it was a key material, could contribute to loss of control. At the moment, this event has not occurred but the possibility exists.

All of these compliance rules and regulations, both for the overseas markets and for national laws, add to the cost of production.

Pesticide resistance is an ever-present threat and the probability is increased by excessive pesticide applications. No control "disasters" have occurred in apple growing but resistance has been recorded in many pests and diseases, and control has been lost in individual orchards. This has lead to financial losses for growers, both through increased grading costs and fewer export fruit to sell. Another downstream effect of loss of control is that it can lead to market access restrictions if the importing country perceives the threat of a quarantine pest somehow contaminating shipments.

The third immediate result of excessive pesticide use is the risk of high residue levels on fruit. It is not so much the risk however (as fruit is closely monitored), as the perception of risk by overseas markets. The perception of overseas markets that New Zealand fruit requires many pesticide applications, can be detrimental to market access and may be used as a weapon by competing countries with lower pesticide regimes. It can also be used as a trade barrier to protect local growers, even those in the Northern Hemisphere given that fruit can now be stored for a long time and the seasonality between hemispheres is not quite the issue it was.

Reduced market access, lower exportable yield and higher production and packing costs, all mean a lower return for growers and to the industry as a whole.

5.3.2 Causes of excessive pesticide use

What leads to pesticide over-use? Figure 5.2 shows three main factors. First, paradoxically, excessive pesticide application can be caused by market insistence. The North American market for example, insists that growers use up to 10 insecticide treatments on their fruit (depending on variety and region) to control leafroller. New Zealand growers must comply with this if they wish to export fruit to this market. This is a major constraint, and one that is not easily overcome.

A second factor is the decision-making process, as discussed for the surveys conducted and outlined in the previous chapters. Decision-making in the main is conservative and in some cases, such as black spot monitoring, more information to growers has not reduced fungicide application; in fact it may have even increased it. One of the reasons for this is that many (but not all) growers leave their pest and disease decision-making to someone else, either their consultant or horticultural merchant field representative. With the latter, the advice is free. The growers that pass on this decision-making tend to be ones that are less knowledgeable or interested in hands-on management of the crop. Some simply want a season free of worry.

Another reason for conservative spray regimes is that many of the spray reducing techniques carry a certain amount of risk. Growers have a lot to lose if failure occurs and tend to err on the side of caution, even if they do understand the pests and diseases concerned and their control.

5.4 Some solutions

The problem tree points to two main areas that could be improved. Robust, reliable and easy to use IPM techniques are needed, and many growers may need to take a more active part in the pest and disease management of their own orchards. In the absence of the former, most horticultural field representatives and consultants acting on behalf of the latter will run a conservative regime. One of the ways that growers can take a more active role in pest management decisions is through better training, or having more easily digestible information pertinent to their orchards at hand, which they can discuss with their adviser. The adviser survey showed that if advisers had confidence in their clients' abilities and knowledge, they would recommend less conservative spray regimes.

Robust and reliable IPM techniques continue to be developed by research organisations. Technology transfer is now a priority of both Hort+Research™ and the APMB, which will aid the up-skilling of growers. Based on this analysis, it was decided to contribute to this up-skilling by developing a tool which enabled growers to analyse their previous blackspot spray program, and so have a basis by which to make a judgement as regards their performance when planning the next season with their advisers. In this way, it is a tailored educational aid, through which they can receive feedback on whether sprays may have been wasted or not. This model is described in detail in the chapter 6.

A further tool is also described in chapter 7. This tool, called DIAGNOSIS, is a training aid, mainly for consultants or managers, which offers them a "virtual experience" at interpreting and solving difficult plant health problems. Although more indirect, use of this tool will aid the reduction of pesticides by improving the skills of decision-makers, *albeit* more indirectly than the first one. The development of DIAGNOSIS did not come directly out of the orchard studies detailed here, but was developed as a general training aid. However, it is original work that has application to this PhD study, hence its inclusion in this thesis.

5.5 References

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CHAPTER 6

SPRAYCHECK - A MODEL FOR EVALUATING GROWER TIMING OF BLACK SPOT FUNGICIDES IN APPLE ORCHARDS

This chapter describes a secondary decision-tool which growers could use to evaluate their decision-making for black spot fungicide applications

6.1 Introduction

Black spot, caused by the fungus *V. inaequalis*, is a major disease of apples and in New Zealand the disease must be completely controlled in order to produce fruit of export quality. The cost of control is high, accounting for around half of the cost of pest and disease control and typically 5-15% of production costs (NZ $600-1000/ha/year), which represents about $NZ 12 million annually (Beresford and Spink, 1992, Manktelow, Beresford, Batchelor and Walker, 1996). Control in commercial orchards normally involves a series of protectant (cover) sprays during the ascospore release period from early September to mid December, combined with eradicant sprays applied soon after suspected infection periods. Black spot spraying usually continues into the second half of the season to prevent secondary conidial infections. However, the disease risks over this period are usually low if disease has not become established. Protectant fungicide spray intervals are usually extended in the second half of the season, when the spray program is driven largely by leafroller insecticides and calcium application requirements.

Whilst cover sprays on a 7-10 day schedule are common, Beresford and Manktelow (1994) found there appeared to be scope to reduce fungicide use by 25%, without reducing profitability or increasing risk of infection, by timing sprays using weather information (35% if extra grading costs were not considered). Whilst crop quality can be used as a measure of the rigour of a disease control regime, there is no indication as to whether or not spraying has been too intensive, or whether individual fungicide applications were optimally timed.

The two surveys into disease management practices in Hawkes Bay apple orchards, reported in previous chapters, found it was common for growers to discuss their black spot fungicide programme with their advisers at the start of the growing season. However, there appeared to be no way of assessing the performance of the spray programme. Total control does not always mean fungicides were used correctly as gross over-spraying could have occurred. The question is, "Were sprays used most effectively?"

To help address this problem, a series of computer models were developed and combined in a draft computer program called SRAYCHECK. The SPRAYCHECK models examine individual spray diaries to analyse black spot spray management in the first half of the season. From the analysis, the grower or consultant will be able to determine the following:

- Which infection events may have resulted in crop infections.
- Whether protectant fungicides were correctly timed, with incorrect timing highlighted where adequate cover existed or fungicide was applied when there was no risk of infection.
- Whether eradicant fungicides applications were actually required.
- Whether use of eradicant fungicides adhered to the existing fungicide resistance management strategies (Gaunt, Elmer, Manktelow, and Moore, 1996).
- A minimum spray program for the period in question and its cost.
- The cost of their own program.

This chapter describes the models and the envisaged output of a final SPRAYCHECK commercial program. It should be noted that SPRACYCHECK has been designed primarily to allow growers to obtain some quantitative measure of their past fungicide programme. It does not attempt to simulate black spot development nor is it designed as a decision-aid during the growing season. Its purpose is to review the appropriateness of past fungicide applications, and in this way assist with better decision-making through grower education. The use of simulation models for black spot control has been recently reviewed by MacHardy (1996).

6.2 Development of the models

Flowchart models were constructed after collecting data from literature and a number of experts. From these models, a prototype version of the SPRAYCHECK program (written in QBASIC - Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-6399, USA.) was developed with the purpose of testing the logic on data which simulated both typical and extreme spray regimes. These were run and the output studied.

The major models in SPRAYCHECK are listed below:

1. A model to determine the risk of infection based on;
    - 1a. Blackspot infection periods
    - 1b. A simple fungicide cover decay model
    - 1c. Time of year
2. A model to work out a "Minimum spray strategy".
3. A decision model which analyses each spray decision made.

It is envisaged that the final SPRAYCHECK program will obtain data directly from the New Zealand Orchard 2000 decision support system (DSS) databases (Laurenson, Buwalda and Walker, 1994), and is likely to form part of this system. This DSS is based around a network of electronic data loggers and includes programs to monitor black spot infection periods and a spray diary recording system. The SPRAYCHECK models described in this chapter utilise data extracted from the Orchard 2000 DSS databases.

6.2.1 Infection risk and fungicide cover

Ascospore infection period data were obtained from weather data held in the Orchard 2000 databases by way of a pre-existing model "Spot Check" (Laurenson *et al*, 1994), which uses modified Mills criteria to define marginal, light, moderate or severe infection periods. The SPRAYCHECK model uses the conservative assumption that ascospore inoculum will be present throughout the September-December spring period. However, peak ascospore discharge typically occurs over a three to four week period that can shift by up to a month from season to season (Beresford and Manktelow, 1995). In the absence of monitored discharge data, SPRAYCHECK assumes a default six-week period of high ascospore presence from the final week of September to the first week in November. To reflect the greater primary infection risk during this time, marginal infection events are deemed to be significant. At other points during the season, ascospore inoculum potential is considered to be too low for marginal infection events to matter.

During the initial part of the season, while ascospores are the major source of inoculum, only infection periods which result from rain during the day are considered to be of importance. However, once disease becomes established in a crop, nighttime wetting events can also lead to infection by conidia. The default SPRAYCHECK assumption is that ascospores represent the major source of inoculum until the start of December and that conidia become dominant from then on. For this reason the model only utilises ascospore infection period data (where wetting was initiated during the day) to the start of December, but utilises all infection period data after that time.

Fungicide residue decay has a large bearing on risk of infection. One of the most difficult decisions for growers and consultants to answer is "Was the existing spray cover adequate for the infection period just passed, or will it be adequate in the event of a future one?" In order to determine this, some indication of the protection provided by the existing residue is required. This is not as straightforward as it might seem because crop growth and redistribution, along with natural degradation, dilute fungicide residue.

Studies of fungicide residues on apples are sparse in the literature, and results show a high degree of variation. Research on captan degradation was carried out by Frank *et al* (1985), who found a mostly exponential relationship between captan residue decrease and rainfall in the orchard. The calculated half residue disappearance on grapes and pears was given by 21mm of rain where small amounts of rain (2mm) fell within 3 days of application. In another year, on grapes, apples and pears, where rainfall occurred (18mm) after day 4, a calculated half residue disappearance was given by 58 - 67 mm of rain. No correlation was found between rainfall and residue where no rain fell for the first 7 days after application. In another study on captan residues in cherry and peaches (Northover *et al*, 1986), a 50% reduction of captan was associated with 8.3 - 51.4mm of rain. New Zealand studies on persimmons and kiwifruit (Holland, Malcolm, Mowat, Rohitha and Gaskin, 1996) support an exponential decay curve over time, where average rainfall is assumed.

Smith and MacHardy (1984) studied the retention and redistribution of captan on apple foliage and fruit specifically. Laboratory experiments showed that the relationship between rain and residue was not linear but followed an exponential decay curve. However, in the orchard studies, the relationship was linear, due to re-distribution of the captan to new growth with rainfall. On mature leaves, in the absence of rain, a linear decay rate of 8.4 to 11.1% per day was recorded. Decay after 23 - 35 mm of rain had fallen previous to assessment was measured at 7.3% a day. For protection against black spot, a residue of between 1 and 2 μg a.i./cm^2 appeared adequate. A captan application of 1.2 g a.i./l gave a residue of 5 - 13 μg a.i./cm^2. so a crop could lose no less that 66 - 90% of cover and still be protected from infection. These studies showed however that, even without rain, residues could be reduced by as much as 59 - 78% over 7 days.

The relationship between residue, rainfall and time is complicated by many factors not least by leaf expansion, the emergence of new growth and possibly formulation of the fungicide. Initially, an exponential decay model incorporating a linear rainfall effect was trialed for use in SPRAYCHECK, but this appeared unnecessarily complex. For the SPRAYCHECK analysis it was only important to know whether the fungicide residue level was likely to be adequate to prevent blackspot infection. In light of this, the simple linear decay rates found in the orchard experiments in the Smith and MacHardy (1984) study were used for the cover model. Published data was available on captan only, but other fungicides used to provide protectant cover, such as metiram, mancozeb and dodine which have similar usage recommendations, were found to have comparable decay patterns (Manktelow unpublished data).

There was some variation in the persistence of captan residues in the work cited above, so the more conservative values were used for the SPRAYCHECK model. From New Zealand work (e.g. Holland *et al*, 1996) it has been found that typical spray applications will give deposits of 2μg /cm^2 of leaf or fruit tissue for each kilogram of active ingredient applied. This implies, for example, that captan at the standard New Zealand application rate of 2 kg/ha will give an initial deposit of 4 μg a.i./cm^2. In the absence of rain, protectant fungicide residue levels have been assumed to reduce at a rate of 10% of the initial cover per day. This would allow an effective cover of 10 to 30% of the initial dose (or 0.4 to 1.2 μg /cm^2) to exist for 7 to 9 days. The 10% reduction per day assumption used is greater than the captan reduction found by Smith and MacHardy (1984), but it was felt that the higher decay figure better represented current spray interval recommendations. During sensitivity analysis it was found that even small changes in this parameter resulted in a large variation in output (see later).

Rainfall is assumed to reduce the residue at the rate of 2.5% per 1mm rain as found by Smith and MacHardy (1984). Hence, even if 20 mm of rain falls within 48 hours, the effective residue should persist for 4 days. This rate was felt to reflect the current manufacturer recommendations for apple protectant fungicide scheduling in the spring, which was to apply on a 7 - 10 day schedule but to consider earlier spraying where heavy rain follows treatment.

6.2.2 Minimum spray strategy

Different approaches to spray management range from the very conservative, where protectants are applied on a regular basis regardless of environmental parameters, to one which involves using eradicants only, after measured infection periods. A good strategy, which is used in SPRAYCHECK, is to ensure a protective cover is in place where conducive conditions for infection are forecast (Tate, Beresford, Wood and Manktelow, 1996). If it is suspected that an infection may have been successful (due to an infection event occurring when there is little or no perceived cover) then the recommendation is to apply an eradicant together with a protectant. The application of a protectant with an eradicant is part of the current DMI fungicide resistance management strategy (Gaunt *et al*, 1996).

The SPRAYCHECK model queries actual rainfall 1 - 2 days after the spray decision date in order to make a decision. If there is no chance of rain or sufficient cover still exists from a previous application, then the protective fungicide application is delayed, and the situation is assessed the next day. Although the model uses actual rainfall, in a real situation of course, the grower would act on forecast rainfall. However, the model illustrates the theoretical minimum spray program given perfect forecast information. Occasionally, high winds and/or a period of rain may prevent the application of protectant fungicides at the correct time resulting in infections. If this happens, the next spray contains an eradicant. If this eradicant is a DMI fungicide then it is included with a protectant to satisfy the fungicide resistance management strategy requirements.

It is assumed in the model that a "spray window" is required for a successful spray application. A window exists when average windspeed is below 10 km/h, leafwetness is below 50% and no rain falls for a period of at least three daylight hours. In most New Zealand orchards, a three hour window would represent spraying 3 to 5 ha of orchard per sprayer.

Although the spray program is, for the most part, driven by black spot in the first half of the season, a grower may have other problems (e.g. thinning, insect pests) which could require a spray application at a specific time. The grower may take the opportunity to tank mix a black spot fungicide with the other sprays to reduce the cost of application. The minimum spray program does not take this possibility into account, so it is simply a guide to indicate how few black spot applications would have been needed over the period rather than a recommended spray program.

6.2.3 Decision analysis

Using the spray diary and weather data together with the fungicide decay model, this unit examines each decision the grower has made and comes up with a recommendation, which can then be compared with what the grower actually did. The spray strategy used to provide the recommendation is the same as that for the minimum spray strategy outlined above.

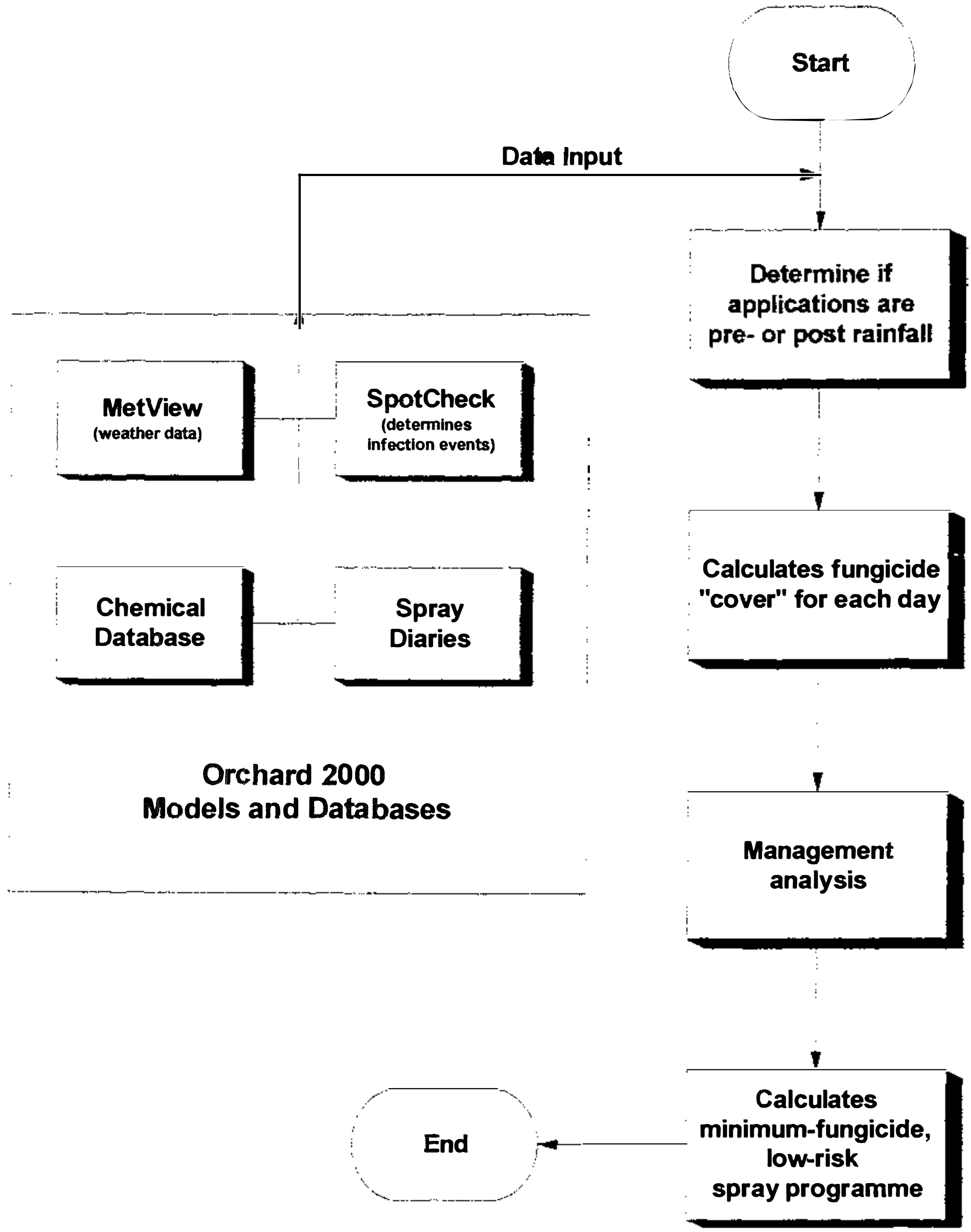
6.2.4 Other models

Other small models within SPRAYCHECK calculate the number of times an infection event may have occurred and works out an approximate cost of the minimum spray strategy. Costs are calculated using the price of the product/ha and typical application labour and machinery costs of at least $NZ 50/ha per application.

6.3 Description of the program

The program progresses through several sub-models (Fig 6.1). It starts by reading in data from a grower's spray diary for a particular block, from the beginning of the season, until either the present day or the end of the blackspot ascospore primary inoculum release period (beginning of December). Source data include black spot fungicides, hourly rainfall (mm), leafwetness (%), hourly wind run (km/hr) and infection events (calculated from the black spot infection model in Orchard 2000). It is assumed that SPRAYCHECK, in the Orchard 2000 system, will be linked to a fungicide database, which will include many facts about the product including cost, waiting periods, protectant life, etc. In the prototype test program, fungicide information was embedded as an array.

Figure 6.1. General outline of SPRAYCHECK showing submodels and data flow



6.3.1 Pre- or post-rain application model

The first sub-model determines whether a fungicide was sprayed before or after rain, where an application was made on a day when rainfall was recorded. This is not recorded in the spray diary but is necessary for determining the percentage fungicide cover at the end of the day in question. It is assumed that if no eradicant was included in the mix, then the grower sprayed before the rain. If an eradicant was included, then the grower may have incorporated it in response to a past infection period or rain, or rain earlier on that day. It is assumed that application took place prior to rainfall on the day of application, if it had rained within the kickback period of the eradicant. However, if no rain occurred within this kickback period and an eradicant was applied, it is assumed the grower was responding to rainfall on that day. The application is therefore determined by the model to have taken place after the rainfall.

6.3.2 Protectant cover model

The next step is to calculate percentage fungicide cover. The model is based on the work carried out by Smith and MacHardy (1984) described above. Percentage cover is calculated, day by day taking into account rainfall effects using the following equations, which are processed sequentially.

(1) $y_{(d)} = y_{(d-1)} - a$

(2) $y_{(d)} = y_{(d)} - (0.01 y_{(d)} w r_{(d)})$

Where y = % cover, d = day, a = % cover decay rate/day,
w= washoff rate in % cover/ mm rain /day and r = rainfall in mm.

Protectant fungicides (e.g. captan, mancozeb) are assumed to have an active protectant life of 10 days and eradicant fungicides a protectant life of two days. The exception to this is dodine, which has eradicant activity but also has a protectant life similar to captan and mancozeb.

Where two or more black spot fungicides are applied together, the model checks to see which should provide the longest period of protection and uses this for "cover". If a spray is applied whilst there is still cover present from a previous spray, then the model checks if the new cover is likely to last as long as the old cover. If the latter is going to be more durable, then this is the cover that is stored for use by other models.

6.3.3 Management analysis

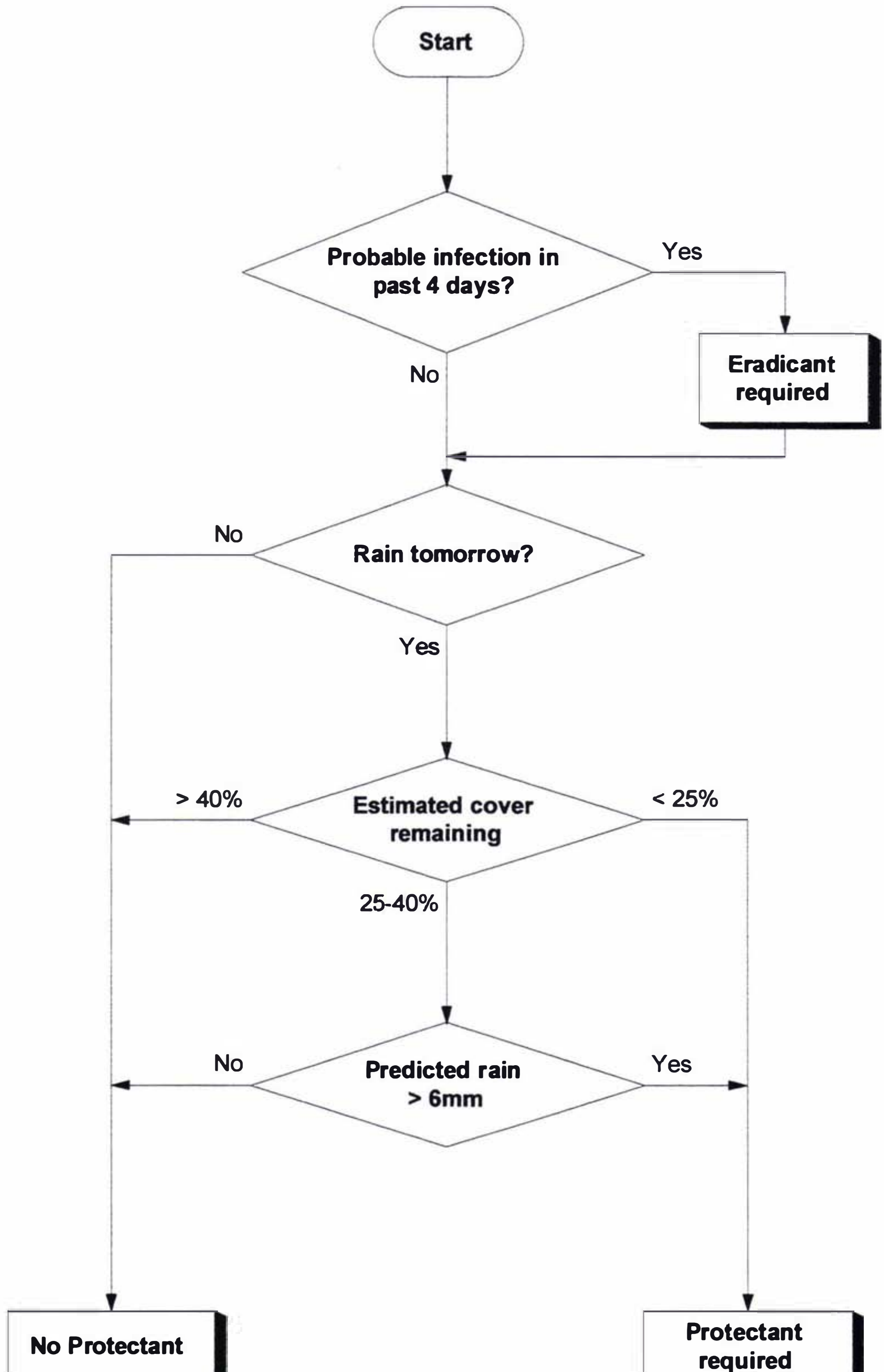
6.3.3.1 Decision model

After the cover is calculated, the program can then move to assessing the grower's spray strategy for the season. The first step in this is to examine each spray application and, given the information known at the time of the decision (rainfall, infection periods, fungicide cover, inoculum load), come up with a "best" recommendation (Fig 6.2).

The model starts, at the time of each spray decision by stepping backwards to a point within the reach of the longest kickback period of available sprays (typically four days). It then steps forward from this point to the current day, assessing if infection periods have occurred and whether or not they have been eradicated. If there are "uncured" infections then the model recommends appropriate fungicides, depending how close they are to the decision date under consideration. If the infection event was less then two days old, then dodine would be recommended as an eradicant. If the event was two to four days ago, then a DMI fungicide would be recommended.

The model then goes on to look for rainfall which occurred 1 - 2 days after the decision date. If rainfall has occurred, then it examines the present cover and comes up with a recommendation depending on the intensity and duration of that rainfall and how this may reduce cover. The model uses actual rainfall for the days ahead calculation and assumes this was forecast correctly. The same equations are used as in the protectant cover model and the number of days remaining before effective cover disappears is calculated. A protective fungicide is recommended if cover is calculated to be insufficient.

Figure 6.2. Simplified logic flow in the decision model



The fungicides recommended are of three types. A standard protectant, represented by captan, metiram, mancozeb or similar, a standard DMI eradicant e.g. fenarimol, mycobutinal or similar, and dodine. Dodine is considered separately as it is unique in being a non-DMI product which has a standard protectant life, together with a short kickback period.

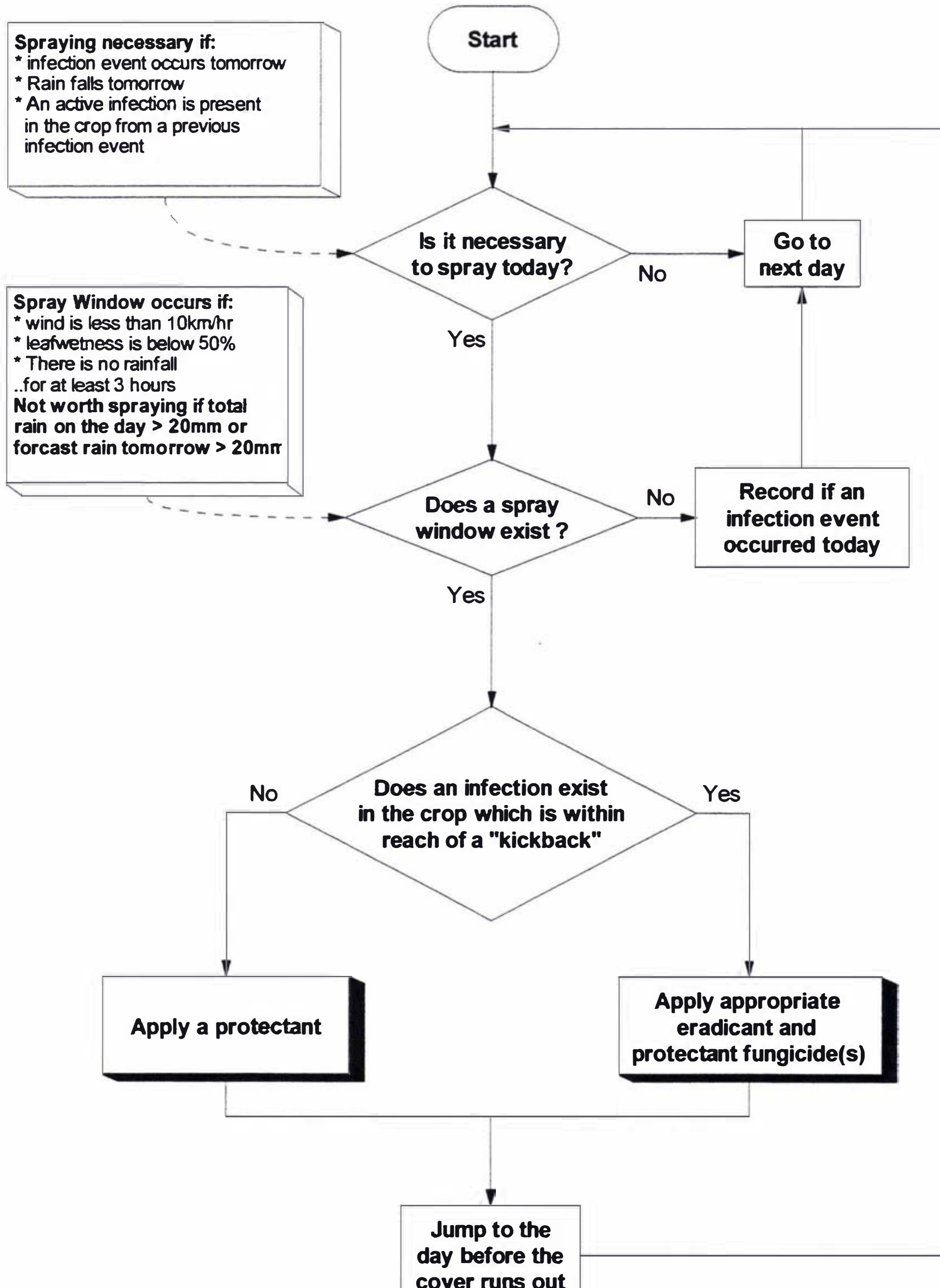
6.3.3.2 Exposure to risk, fungicide cost and resistant strategy information

Three small functions are processed after the decision model. The first of these determines whether or not the crop has been "at risk" from infection. That is, an infection period has occurred and the cover has been either absent or insufficient. The second model simply adds the cost of a grower's fungicide programme (application costs and chemicals) from the information in the spray diary and the prices in the fungicide price database. Finally, a grower's fungicide programme is assessed to determine if it exceeded the fungicide resistance strategy for the DMI compounds i.e. were more than four DMI applications made during the course of the season?

6.3.3.3 Minimum spray strategy model

This model takes the rainfall and infection period data, and plans a theoretical minimum fungicide programme to prevent black spot infection (Fig 6.3). After a protectant fungicide application, the programme works out how long the effective cover will last given the rainfall, and then jumps ahead to the day before the cover runs out. It then assesses the weather for rain in the next few days and makes a decision on whether to apply another protectant, or wait another day. If applications cannot be made because of rain on the day, then the program steps ahead a day. If an infection period occurs as a consequence of this, then the next application will include an eradicant if the kickback properties are sufficient to eradicate the infection.

Figure 6.3. Minimum spray strategy model showing logic flow, decision parameters and recommendations



6.4 Testing and validation

A commented version of the prototype program, used to test these models is listed in Appendix V.

The model was tested in three stages. First, a data set of hypothetical values for weather, infection periods and fungicide applications was used to verify that the logic in the program was correct. The second stage involved collecting meteorological data and associated infection periods (calculated from Orchard 2000) from five automatic weather stations in the Hawkes Bay area and 27 grower diaries. This real-life data was used as input to the model. These growers were a random subset of those surveyed in chapter 3. An example of weather, infection period and spray diary input files, and the resultant output file generated by the model, are attached in Appendices VI (a) to VI (d). The output was scrutinised in order to check that the analysis and recommendations were realistic. In the last stage, the models used for management analysis (which included the cover model) were subjected to a one-sample against high quality performance test, as described in Harrison (1991). Sensitivity analyses on several of the key parameters were also carried out.

6.4.1 High quality performance test - Method

Twenty-two grower spray diaries from four locations were selected for the test. This data set was a subset of those used above. The complete set was not used as, in the opinion of one expert, infection period data at one particular site did not seem to match up well with weather data indicating a possible fault with the infection period recorder. Hence only four of the five sites where data was available were used.

Five experts, consisting of two black spot scientists, two merchant field representatives and one private consultant were sent survey sheets containing the spray diary, weather and black spot monitor information (Appendix VII). They were asked to go through each sheet and consider questions relating to each day that the grower applied a fungicide. These considerations are the same as those that the model must make, when analysing the decision points. Each expert undertook the exercise independently and they were not shown the model's assessment using the same data. All participants had at least five years experience advising growers in the use of black spot fungicides.

For each decision point, the experts were asked to consider:

(i) Would the crop have become infected between the last application and this one?

(ii) If the crop had become infected, could the infection have been eradicated if a fungicide was applied today?

(iii) If eradication were possible, would it be better to use dodine or a DMI fungicide?

(iv) If there was no eradicatable infection present, would the grower need to spray today with a protectant (due to risk of further infection), or could they wait until the next day (and hence postpone fungicide application)?

The assessment from this independent "panel of experts" was then compared with the answers determined by the model using exactly the same information. Each spray decision-point assessment was a choice between two possibilities. If the experts agreed with the model at any single spray decision-point then this was recorded as a "pass". If they chose the alternative, then it was regarded as a "fail". Results were then reported as a proportion of passes to failures. An overall result of 1.0 for a particular decision-point assessment question in one grower data set would indicate complete agreement by all experts. These proportions were then averaged over the 22 grower sets. Refinement-weighted means were used, as the number of these questions answered per grower diary could vary depending on the number of applications, and also between experts as questions (ii), (iii) and (iv) were conditional.

Data was analysed by determining confidence intervals and t-values. Single factor ANOVAS and charts were also used to determine if significant differences in opinion occurred between the experts.

6.4.2 High quality performance test - Results and discussion

Table 6.1 shows the mean score from the pool of experts over 22 growers, for the four critical questions.

Table 6.1. Agreement between group of experts and SPRAYCHECK for the answers to the four questions required for management decision analysis

Question	*Had the crop become infected?*	*If so, could the infection be eradicated?*	*If an infection could be eradicated, what should be used, dodine or a DMI?*	*If there was no infection able to be eradicated, would the grower still need to apply a fungicide on this day?*
Means	0.9	0.92	0.72	0.82
C.I. (5%)	0.03	0.07	0.15	0.04

For both whether there had been an infection of the crop between sprays, and whether or not these could be eradicated, there was a high level of agreement with the model, being 90% and 92% respectively. The question relating to whether or not a protective fungicide would be required at that particular time was also in reasonable agreement with the model at 82%.

Where the model differed significantly from the experts was on the use of dodine versus DMI. There is some risk of russet with dodine on some varieties if used over the flowering period. The model did not take this into account, using simply the difference in the kickback period of the products. It seems in most experts' minds, the risk of russet outweighs the desirability of dodine as a short kick-back material, in place of a DMI. The final version of the model will be changed to reflect this. In fact, the average shown for the dodine versus DMI question in the table is higher than it should be. One expert's results agreed completely with the model, but commented on his script that, although technically the most appropriate material as regards a resistance strategy, he probably wouldn't recommend dodine at this time due to russet risk. The four other experts took russet into consideration when selecting the chemical. This explains the large confidence interval for this question in the analysis.

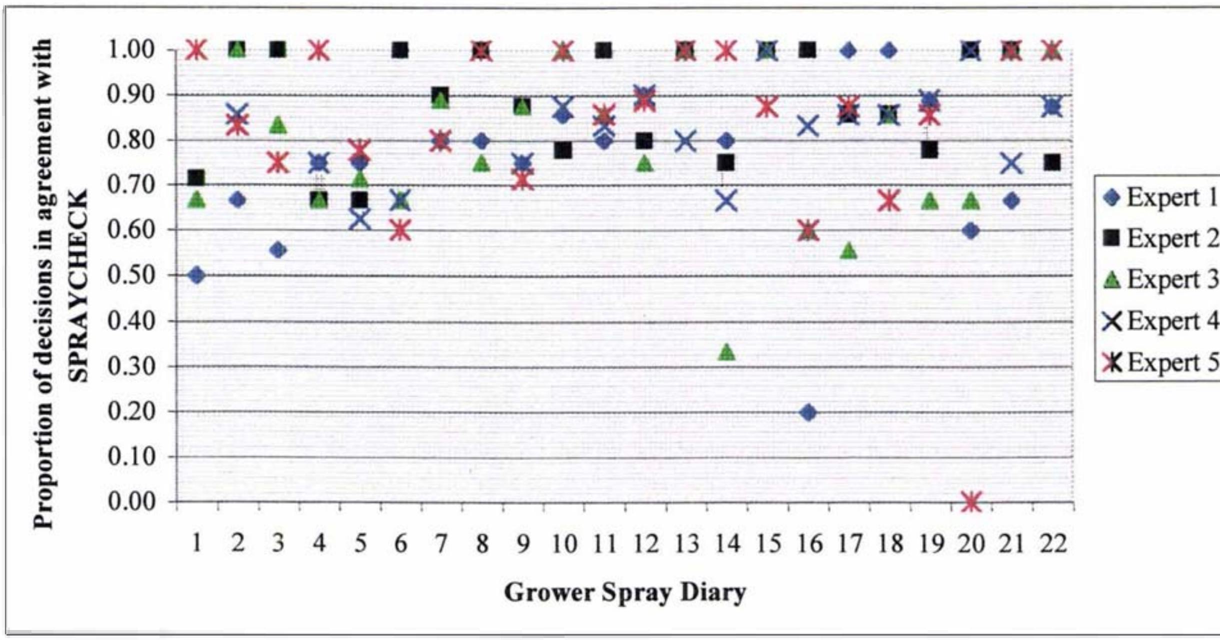
Although the validation appeared satisfactory, it was felt that the data might be misleading, in that some of the decisions were not very challenging. For example, with regard to applying a protectant fungicide (question iv), if there was no rainfall on the decision day and none the next day, then the decision analysis of both the experts and the model would invariably be the same i.e. do not spray. On the other hand, if there was rainfall on either of those days, the decision would then involve an assessment of the amount of fungicide cover left, and hence how well the crop would be protected from a potential infection. The decision would then involve comparing the cover model in SPRAYCHECK to "rules-of-thumb" by the experts. If these "difficult" decision points were too few in the data set, then the model may not be tested rigorously enough.

To investigate this, a subset of the data was examined, consisting of decision points relating to question (iv), where rainfall was indicated either today or tomorrow. This resulted in a lower mean of 0.74 with a confidence interval of 0.06. This indicates less agreement between the experts as a group and the model on these difficult decisions with regard to applying a protectant fungicide to prevent future infections. However, when experts were compared with one another in the full data set (Fig 6.4a) and the data sub-set (Fig 6.4b), large variations occurred for each decision point, particularly in the case of the latter. This is an indication of the difficulty of this particular decision and it appears that the recommendations SPRAYCHECK gave were as good as any. Means and confidence intervals for individual experts over the 22 data sets for question (iv) and its subset are shown in figures 6.5a and 6.5b

In summary, the model does seem to reflect the current heuristic rules experts use to analyse spray decisions. When compared to the expert group, it appeared weakest at analysing whether protectant cover from a previous application was adequate or not, when considering if a protectant fungicide was necessary before predicted conducive conditions. However, there was a wide difference of opinion between the experts on this matter also.

Figure 6.4. Expert validation of protectant fungicide recommendation. Proportion of decisions in agreement with SPRAYCHECK.

(a) Full data set



(b) Rainfall recorded on or after the decision day

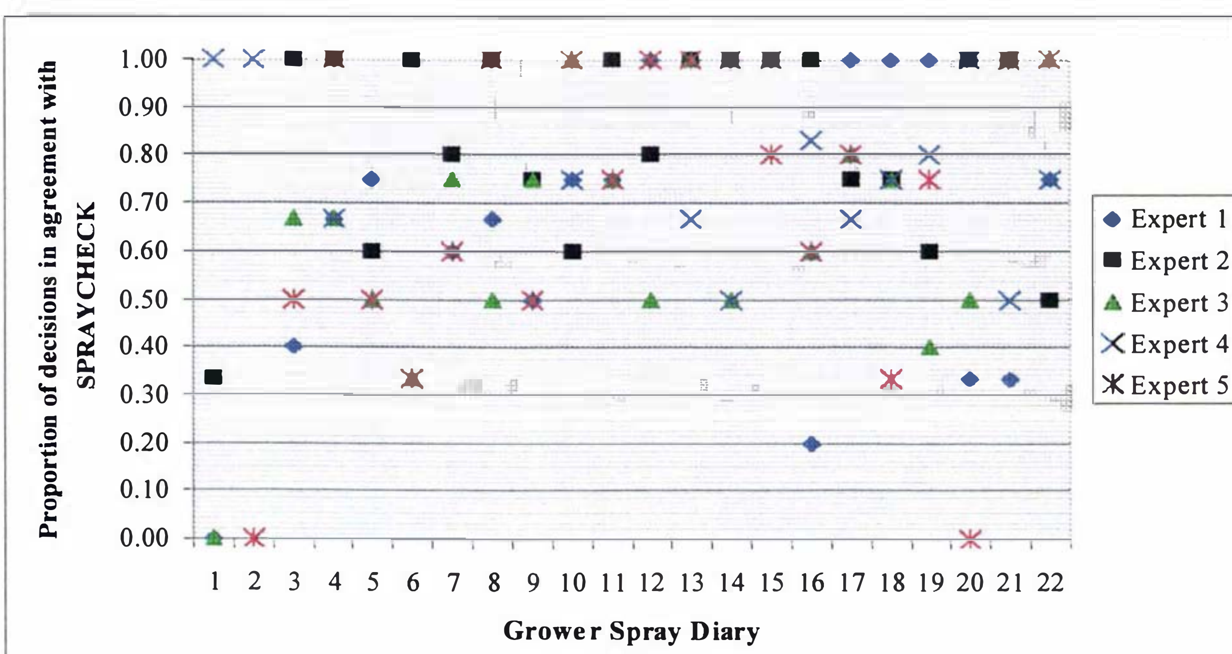
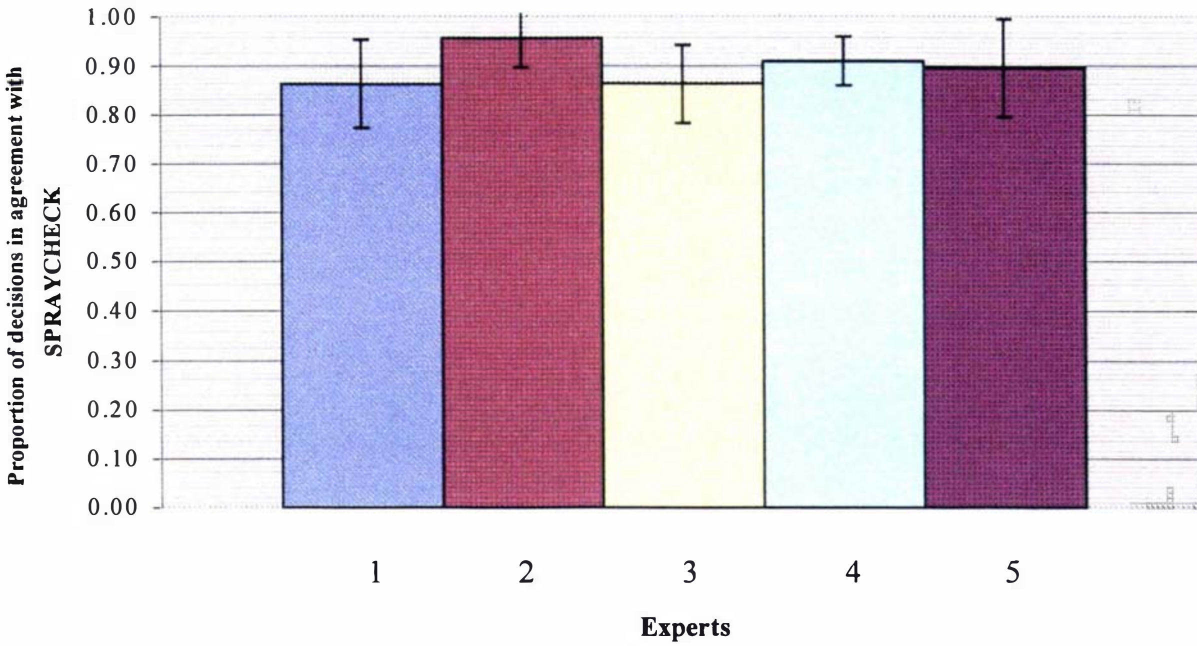
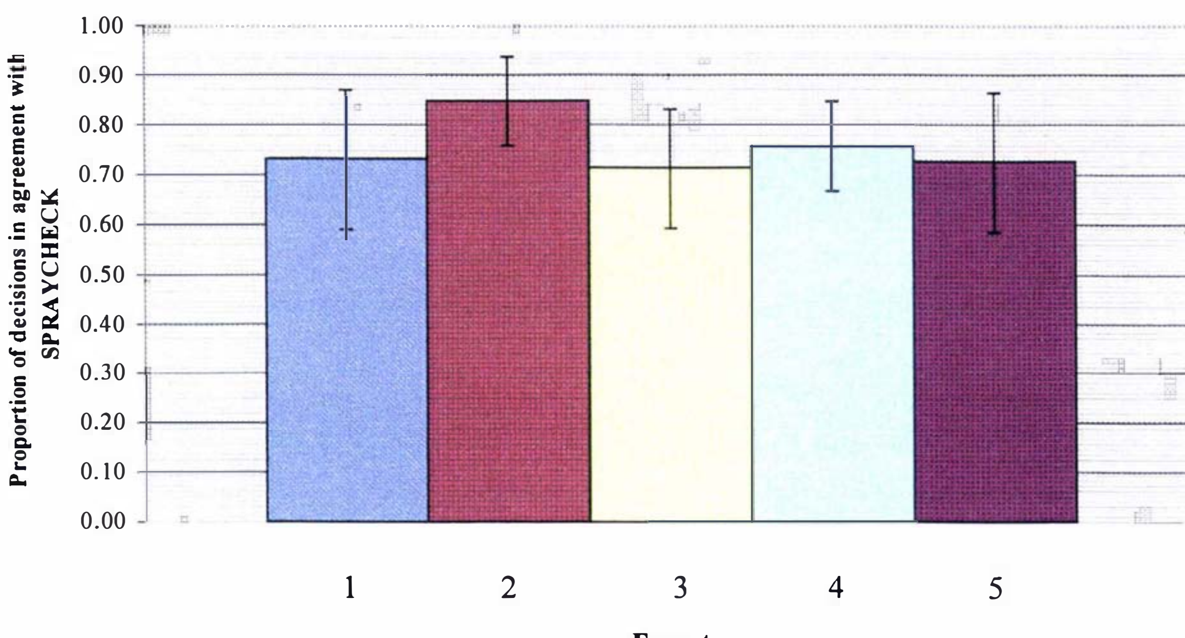


Figure 6.5 Expert validation of protectant fungicide recommendations - Differences between experts. Error bars represent confidence intervals.

(a) - Full data set



(b) - Rainfall recorded on or after the decision day.



6.4.3 Sensitivity analysis

During the construction of the model, a number of the parameter values used had to be based on "reasonable estimates" rather than precisely known values because the latter are not known. Given this situation, a sensitivity analysis on these parameters was conducted, to see what effect they had on the recommended minimum spray strategy. Parameters investigated were cover decay rate, wash-off rate due to rain, minimum number of hours for a spray "window" and percentage leafwetness (one parameter used in determining a spray window). Data from four weather stations for 1994/5 and 1995/6 were used for the analysis.

Of the parameters tested, variations in cover decay produced the largest change in the recommended number of sprays per season (Fig 6.6a). A doubling or halving of the decay rate resulted in an increase of 4.2 or a decrease of 3.5 sprays respectively.

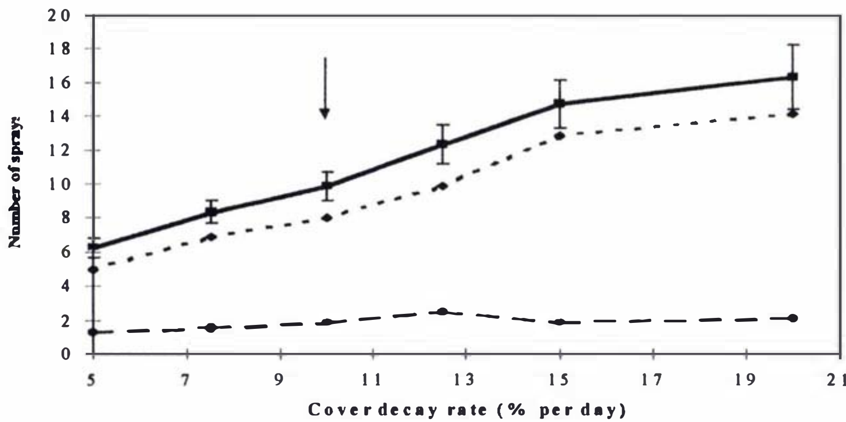
The number of spray windows determined by the model was relatively insensitive to changes in percentage leafwetness (Fig 6.6b). This can be explained by the fact that daylight leafwetness is mostly determined by rainfall, which is also used to determine the availability of a spray window.

With regard to the spray window, changing its length had a moderate effect on number of sprays (Fig 6.6c). Orchardists with large blocks could find it more difficult to manage the disease in windy or rainy seasons since they will require less frequent, longer spray windows (unless spray applications are spread over multiple days or windows, or they have multiple spray units).

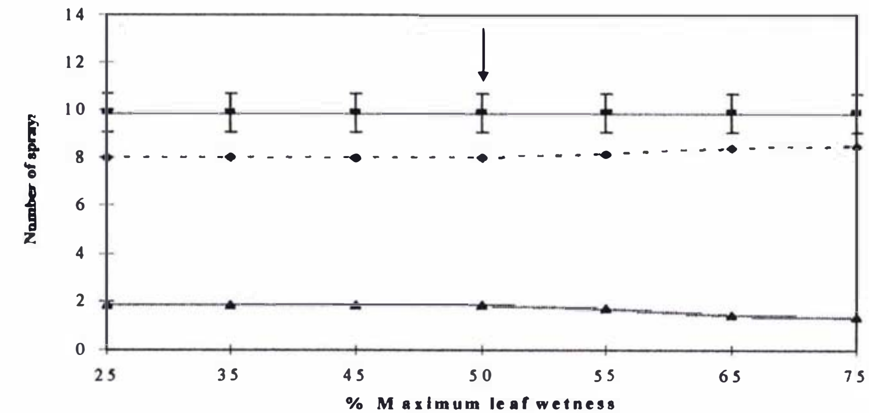
The model was relatively insensitive to a doubling or halving of the chosen wash-off rate (Fig 6.6d).

Figure 6.6. Sensitivity Analysis of cover decay rate, % leaf wettness, spray window and washoff rate.

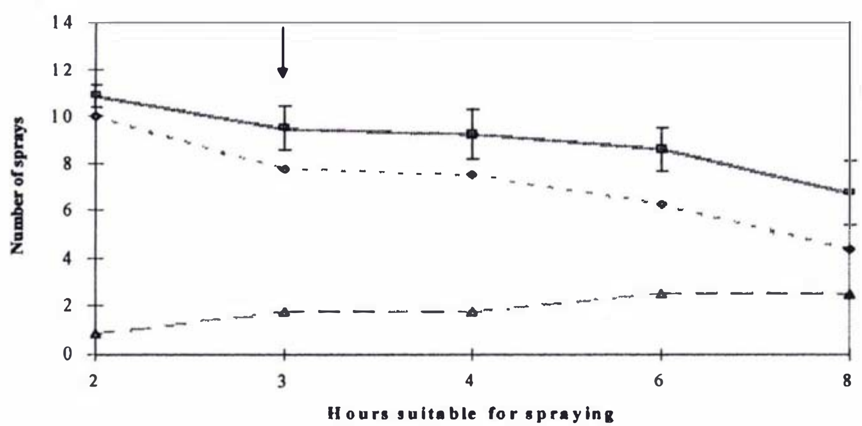
A. Cover decay rate



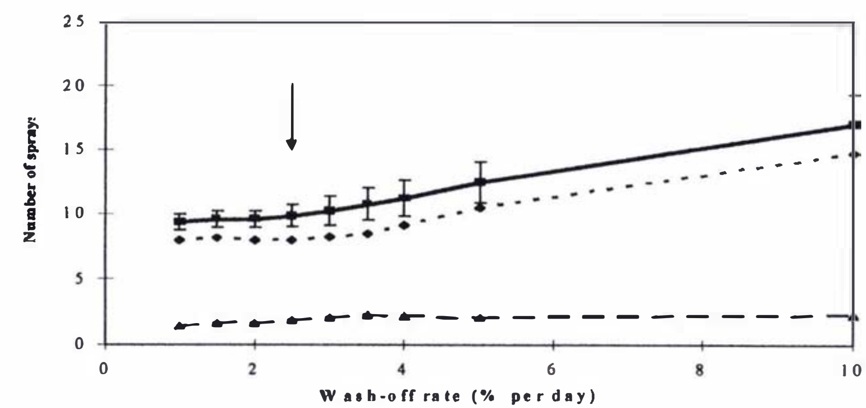
B. Percentage leaf wettness



C. Spray window



D. Washoff rate

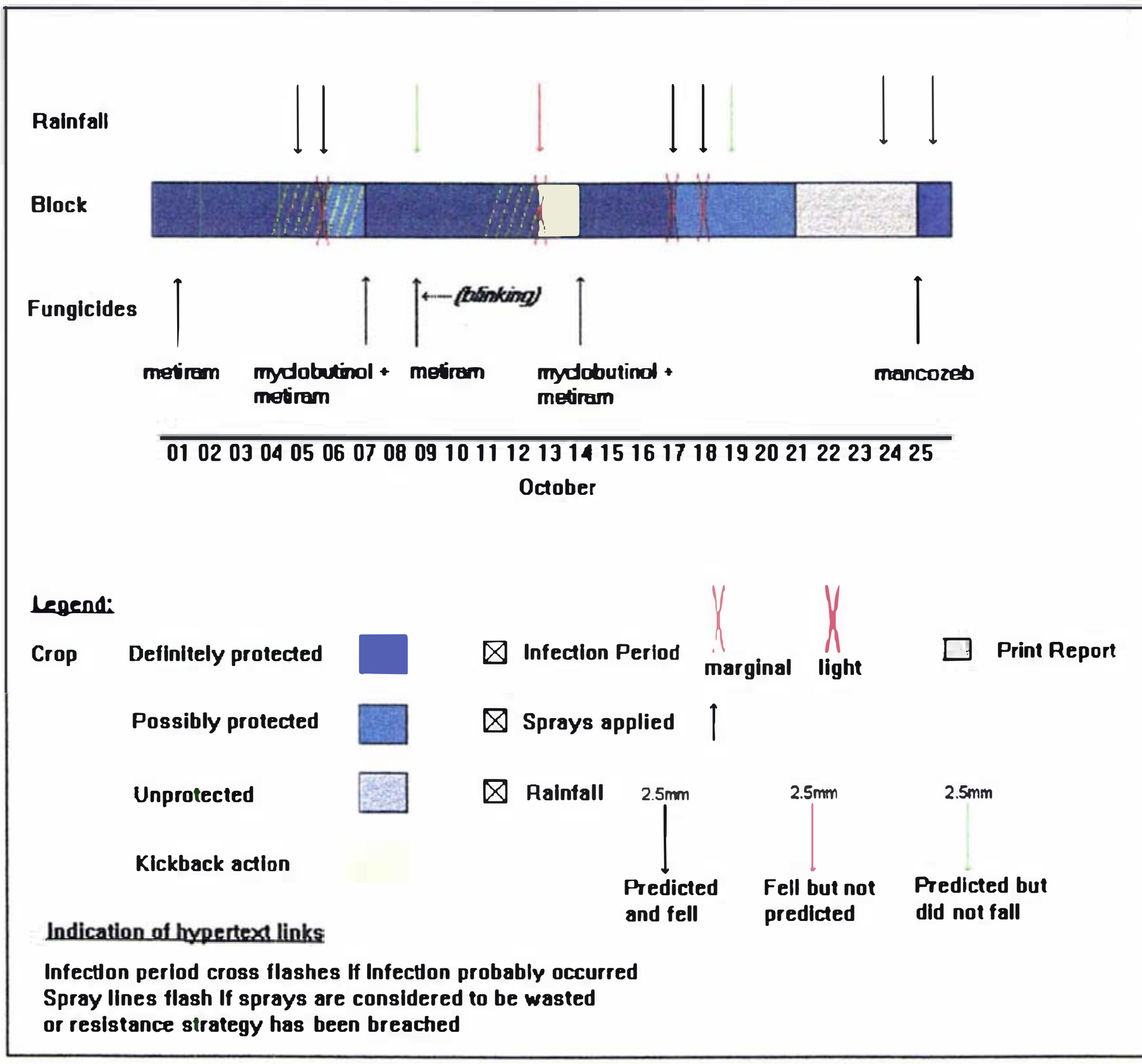


Key: —— = total, ●●●● = protectants, ---- = DMI's and dodine, → = default values in the program
Error bars show the S.E. over 8 data sets (4 weather stations in each of 2 years)

6. 5 Orchard 2000

When integrated into Orchard 2000, output will consist of a series of reports along with a graphical interface showing fungicide cover (Fig 6.5). The screen will have "hot spots" that the user can click on to see or print out the reports.

Figure 6.5. Proposed graphical interface for SPRAYCHECK



A scrolling display with a window of 28 days is envisaged. Cover is represented by a coloured bar: dark blue if the crop is protected and light grey if there is no effective cover. Infection periods will be represented by red crosses overlaid on this "cover bar". Rainfall is represented by coloured arrows at the top of the bar. Sprays are indicated at the bottom of the cover bar, and where eradicants have been used, yellow diagonal lines indicate their "kickback" period.

Blinking spray arrows and infection periods will be a feature of the display. Where sprays have been deemed to be unnecessary at the time (as determined by the decision model), or if they have exceeded the fungicide resistance strategy, then they will blink and the grower will be able to click on them and receive a report. The same applies to infection periods, which will blink if fungicide cover is deemed low enough to perhaps have resulted in an infection.

Growers will be able to click a report button which will give them a summary of the season, including calculated cover and the minimum spray strategy, and the difference in cost between the latter and their actual program.

6.6 Summary

A computer program, SPRAYCHECK, was developed to analyse grower black spot fungicide spray programs during the period of primary inoculum release. The program, consisting of a series of models, uses weather data, infection periods and information from growers' spray diaries to analyse grower black spot control decision-making. It also provides a recommended spray schedule for the season in question. Constructing the model revealed a lack of quantitative information regarding behaviour of fungicides and the levels required to fully protect against black spot on apple foliage in the field. An expert check showed the model's decision analysis to be comparable to experts, although a consideration of russet sensitivity needs to be incorporated. A sensitivity analysis revealed the rate of cover decay to be very important in determining the number of fungicides a grower would need to apply to fully protect their crop.

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CHAPTER 7

DIAGNOSIS - A TRAINING TOOL FOR PEST AND DISEASE PROBLEM-SOLVING IN APPLES AND OTHER CROPS

The chapter describes an educational software package, designed to assist with pesticide reduction through users aquiring better analytical and problem-solving skills

7.1 Introduction

Previous chapters have shown the need for better training in the apple industry. This training can take several forms, from formal degree or diploma qualifications, to informal workshops. This chapter describes a computer-based tool, which could be used in any of these training environments where computer equipment is available. Whilst the focus in this text is in relation to better training for the apple industry, it is generic software with a wide application for all crops. The bulk of this text is taken from the two papers on DIAGNOSIS which have already been published (Stewart, 1992; Stewart, Blackshaw, Duncan, Dale, Zalucki and Norton, 1995).

7.1.1 The role of computers in training

Computers have been used for teaching the principles of plant protection for a number of years. By running models, student understanding is aided by graphically illustrating changes in pest or pathogen populations over time in accordance with varying parameters. Hypertext-based applications assist students to better understand technical terms (Francl, 1993) and improving technology has led to the development of multimedia databases, where students can interactively access images of signs and symptoms from a videodisc for study (Rowe and Tainter, 1989).

Computer-based management games allow students to practice decision-making in plant protection as well as illustrating principles. In some, such as APPLESCAB (Blaise, Arneson and Gessler, 1987) and BEETGAME (Mumford, 1993), students are encouraged to apply integrated pest management (IPM) principles to a hypothetical "crop" and show a financial return on completion. Others, such as the sterile male insect release game CURACAO, (Sawyer *et al*, 1987) are designed to illustrate a specific concept.

Expert systems, which were initially designed to aid farmers or extension personnel with plant problem identification and/or management decision-making (Travis and Latin, 1991), also have a role to play as training aids (Mumford and Norton, 1989). Certain features of expert systems, particularly the transparency of the decision-making process and the ability to explain the system's reasoning, are useful for illustrating and explaining the various steps involved in the diagnosis or decision-making process. This is especially so when students themselves are required to construct the program (van Bruggen, Neher and Weicht, 1991).

7.1.2 How DIAGNOSIS differs from the rest

Whilst identifying an insect or a fungus may be a relatively straightforward process, diagnosing a real-life plant problem can be very difficult. Apples, for example, are afflicted by many pests, diseases and disorders. Some, like powdery mildew, are easy to recognise but others, such as nutritional deficiencies and pesticide damage, may not be. Furthermore, recognising the causal agent is only a part of solving the problem. The problem-solver must understand why the problem has developed and what to do about it.

To make a correct diagnosis and recommend an appropriate solution therefore, a practitioner needs a good working knowledge, not only of the plant protection disciplines, plant pathology, entomology, nematology and weed science, but also plant science, soil science and meteorology and how these relate to the growth of healthy plants (Grogan, 1981). Furthermore, the gathering and correct interpretation of observations is of the utmost importance. It is an holistic process and one where experience is a good teacher.

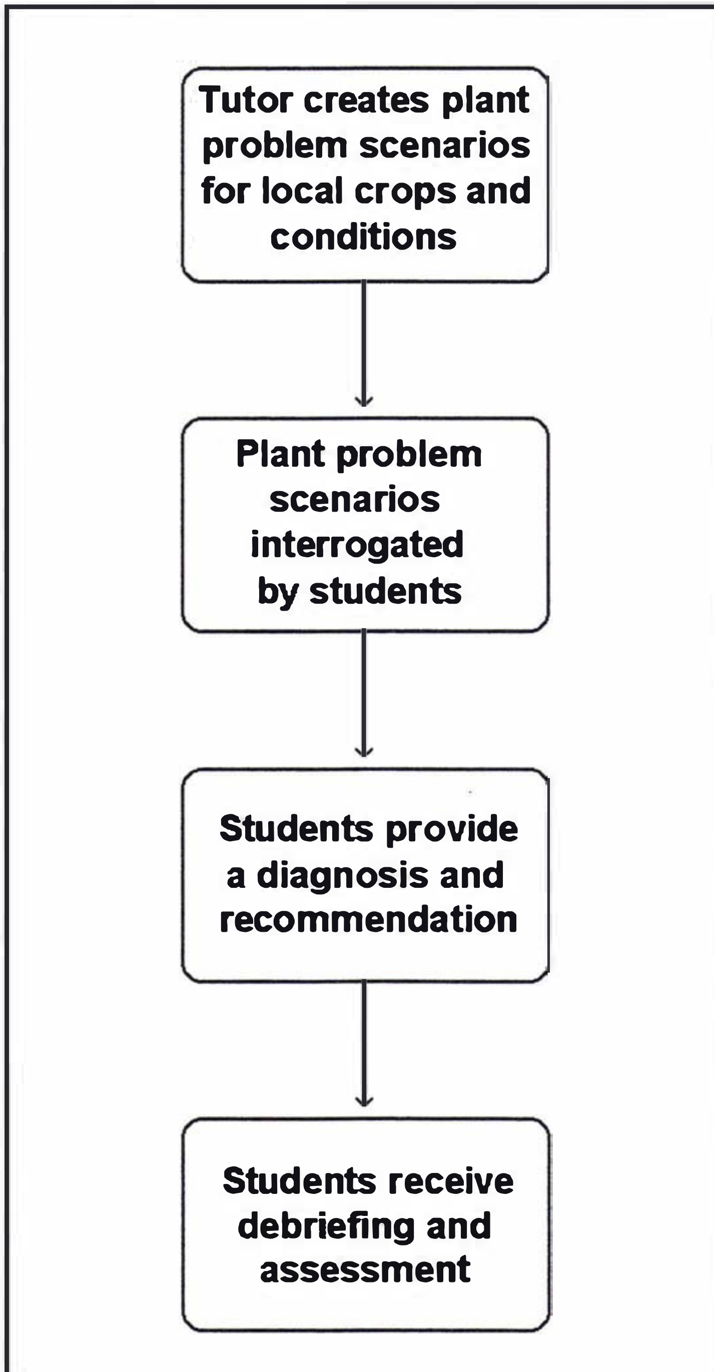
While an expert system approach can be helpful for teaching topics such as pest and disease diagnosis, it is still the program, using heuristics derived from an expert, which identifies the problem, rather than the student. The author has had some experience in expert systems, assisting in the development of one for diagnosing nutritional deficiencies in apple trees (Kemp, Stewart and Boorman, 1989).

DIAGNOSIS differs from the expert system approach by assuming the trainee is the expert. The DIAGNOSIS shell allows a tutor-defined plant problem scenario to be presented on which the trainees can practise their observational skills (Fig 7.1). By interrogating the computer model of the scenario, trainees can draw on their knowledge by way of lecture notes, books or practical classes to diagnosis the problem and provide answers to it. In this way, DIAGNOSIS is designed as a training tool to assist trainees to acquire the 'art' of disease diagnosis (Grogan, 1981).

7.2 The Program

The program described here is written in Borland C++ (Borland International, 4585 Scotts Valley Drive, Scotts Valley, CA 95066) for Windows 95, or Microsoft Windows 3.1 (Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-6399) under MS-DOS 5.0 or higher. Versions also exist for the Apple Macintosh and MS-DOS itself.

Figure 7.1 Major steps in DIAGNOSIS



7.3 Playing DIAGNOSIS

A DIAGNOSIS exercise takes the form of a simulated call-out to a grower's property including subsequent laboratory work if thought necessary, the object being to diagnose the problem and recommend solutions. It is assumed trainees have already been instructed on basic plant protection principles, including the theory and practice of pest and disease diagnosis. They now have an opportunity to apply what they have learned. Readers of this text can gain a fuller appreciation of DIAGNOSIS by running the demonstration program available on the world-wide-web at http://www.diagnosis.co.nz/, in conjunction with a scenario walk-through, pertaining to root rot of apples, the text of which can be found in Appendix VIII.

Once trainees have recorded their name and ID, they can then choose a supplied scenario from the File menu and the exercise commences. Trainees find themselves first in the field. After viewing a screen describing the initial situation (Fig 7.2), they have the option of undertaking a number of tasks by way of pull-down menus (Fig 7.3). Table 7.1 shows the options available in the field. Each time trainees make a selection, they are presented with a dialogue box similar to that in Figure 7.2. Trainees can click buttons on the dialogue boxes to show any available image, sound or video segment associated with the particular task they are undertaking at the time. Plant parts, any insects present, and soil can be collected at this stage for further study.

Figure 7.2. A typical introduction to a scenario

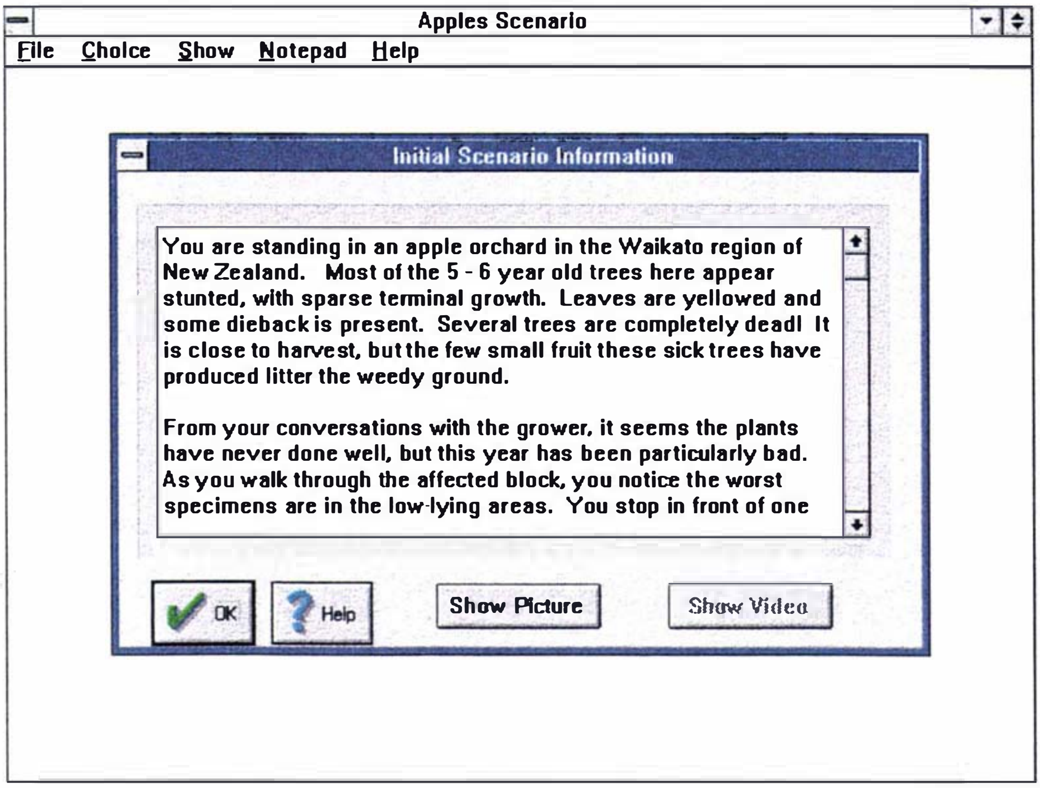


Figure 7.3. Some pull-down menus available in the field situation

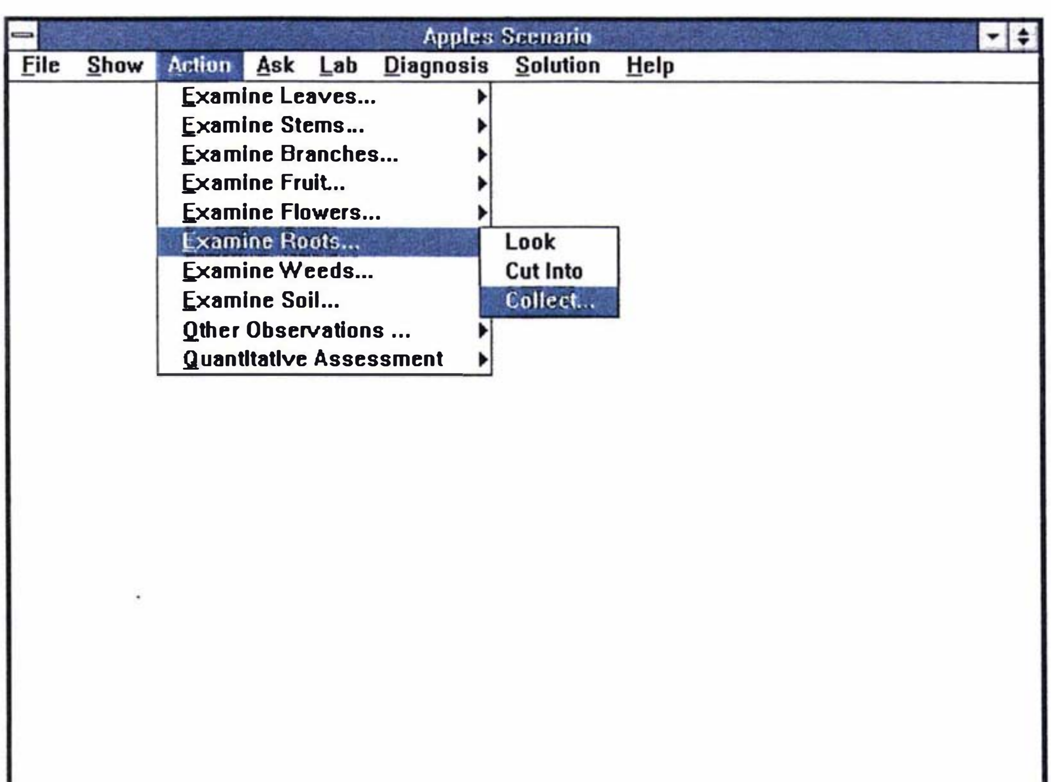


Table 7.1. Options available to players whilst in the field.

• Symptom distribution	• Question the grower on
• Examination of selected plant parts	- past weather
• Examination of soil	- weed management
• Examination of insects	- insect and disease management
• Check insect traps	- history of the problem
• Spray machinery check	- fertiliser
• Fertiliser machinery check	- drainage
• Quantitative assessment	- irrigation
- plant damage	- variety/cultivar/source
- weeds	- land use history
- nematodes	- neighbour's crops
• Question the neighbour	- their own diagnosis
	- changes in management

Trainees can save the exercise part way through and come back later to finish. This allows flexibility, where time-slots for equipment may be at a premium.

As the game proceeds, DIAGNOSIS automatically records which procedures were undertaken. After carrying out as many field observations as they feel are necessary, trainees would normally then proceed to the laboratory with any specimens they have collected. However before this, they are required to offer a preliminary diagnosis, justification and recommendation, which is recorded to disk for later assessment by the tutor. In the laboratory, as in the field, there are a number of processes that can be undertaken (Table 7.2).

Table 7.2. Options available to players whilst in the laboratory.

• Microscopic examination	• Pathogen isolation to agar
• Virus indexing	• Pathogenicity tests
• Bacterial indexing	• Humid chamber
• Residue analysis	• Pesticide resistance tests
• Weather research	• Nutrient analysis
• Nematode extraction	• Identification by expert
• Insect rearing	• Pathogen baiting from soil

Whilst building the scenario, the tutor can determine which procedures are crucial to the correct diagnosis and so write an appropriate response to appear at the de-briefing, depending on whether or not the trainees carried out the operation. The tutor can also attach a cost to these procedures if appropriate, in order to encourage the players to only carry out those which are essential for a conclusive diagnosis.

Finally, once they think they have identified the cause of the plant problem, trainees are asked to provide a full diagnosis, justification and recommendation, which is written to disk as before. The game then terminates.

As the program finishes, text prepared by the tutor during scenario construction is appended to the trainee's disk file. This text discusses the importance of crucial procedures and observations trainees undertook (or failed to undertake), and includes the correct diagnosis, recommended action and "shortest route". If the tutor wishes, the trainee can access this debriefing on the screen immediately upon finishing the game. This personalised feedback is an important part of DIAGNOSIS and one that contributes towards its value as a training tool.

The Macintosh version, whilst using the same approach, uses a different interface that fully exploits the 'drag and drop' features of Hypercard. In the field, players click on a tool and drag it over a plant part to carry out an action (Figure 7.4). Similarly in the laboratory, procedures are undertaken by dragging collected items over the appropriate equipment (Figure 7.5). At the time of writing this version is suitable principally for fungal and nematode problems. As Microsoft Windows™ is now the dominant operating system in the marketplace, no further upgrade is planned.

Figure 7.4. Field screen from Macintosh version of DIAGNOSIS showing stylised plant, tools available and items collected.

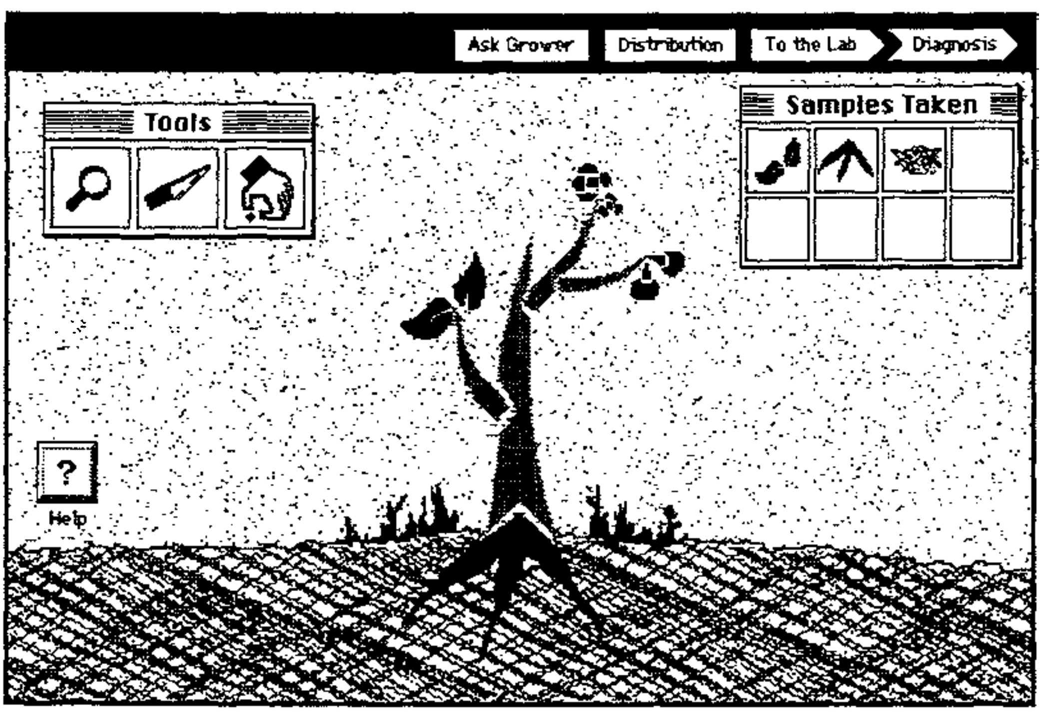
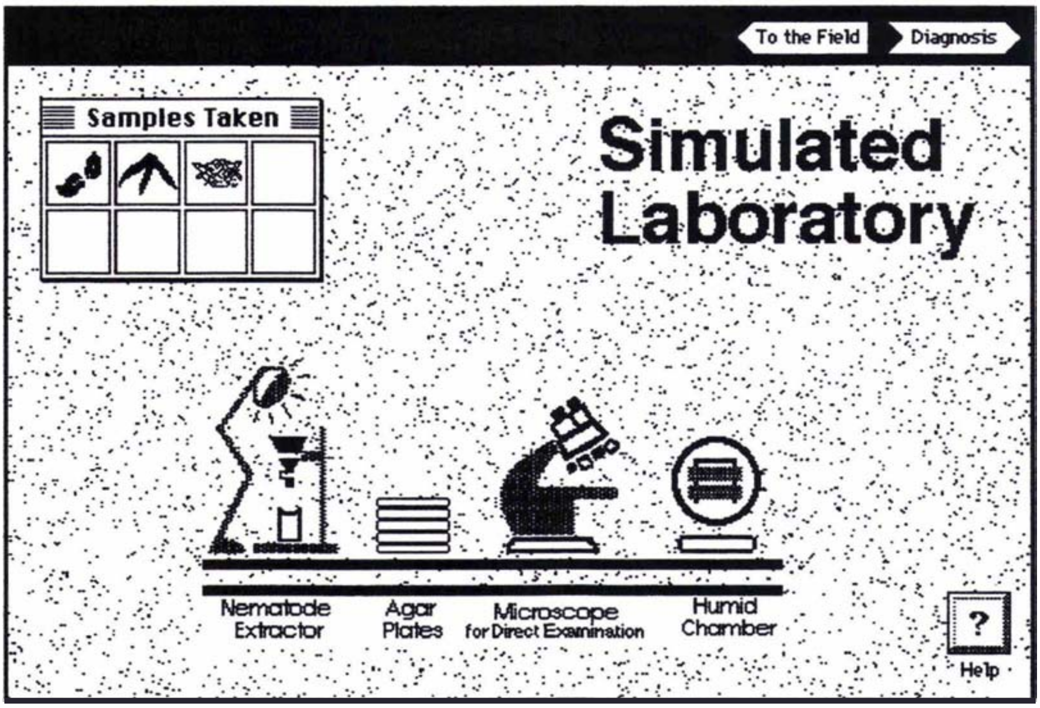


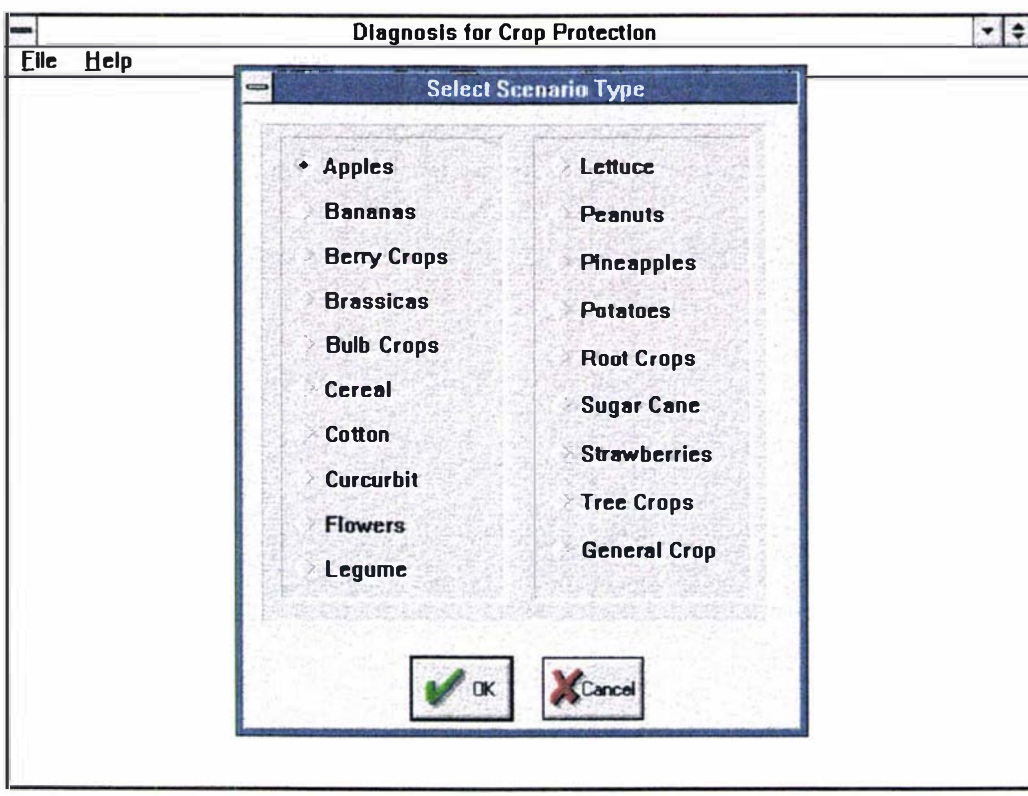
Figure 7.5. Laboratory screen from Macintosh version of DIAGNOSIS showing equipment available and items collected.



7. 4 Building scenarios

An important philosophy incorporated into DIAGNOSIS is the need to make the trainees' experiences as real as possible. This means scenarios should be crop and location specific. To provide for this, an associated 'scenario builder' program is an important component of DIAGNOSIS. This builder allows tutors to write their own 'local' scenarios for trainees to evaluate, or to modify existing ones. For each menu choice the tutor chooses to display in the scenario, all that is required in the builder is for text to be typed or pasted into an input box, and optional graphic and/or video files linked to them. A number of different crop types are currently supported (Fig 7.6).

Figure 7.6. A screen from the DIAGNOSIS builder showing available crop types



The quality of the scenarios is crucial to learning the art of pest and disease diagnosis. Care is essential in their preparation as they should reflect realistic crop problems together with the sort of misleading observations that occur in the real world. Consequently, the involvement of extension workers and crop consultants in scenario preparation is highly desirable.

At present DIAGNOSIS has only two apple scenarios, one on phytophthora root rot written by the author, the other on magnesium deficiency written by the Centre for Research on Tropical Pest Management, University of Queensland, Brisbane, Australia. More scenarios exist for other crops and these, along with a demonstration program, can be found on the DIAGNOSIS Internet website (Stewart, 1997). To become a comprehensive training tool for people working within the apple industry would require a whole series of apple associated scenarios, possibly linked with other multimedia tools which present straight information, such as LEARNPEST (Stewart and Davis, 1997). However, the present lack of a comprehensive suite of apple scenarios in no way discounts the problem-solving methodology assisted by the software. Once learned, the principles can be used on any pest or disease problem in apples.

7.5 Performance and discussion

DIAGNOSIS has been informally evaluated by many plant pathology and entomology experts, including those with expertise in apple crops. Comments from one of these is attached in Appendix IX. One hundred and seventy one copies have been sold worldwide since 1994. This figure is considered high for a specialist-training tool of this nature. In this way, Diagnosis has stood the "Face validity" and "Judgement of the Marketplace" test of validation as outlined in Harrison, (1991).

In addition, some survey work was carried out amongst students. In two surveys conducted in 1992 and 1993 respectively, third-year university degree plant protection trainees, after using both the older MS-DOS version (Stewart, 1992) and Macintosh version, were ask to rate the value of DIAGNOSIS as a learning exercise, using a scale of 1 to 5 where 1= no value and 5= excellent value. Out of a combined total of 23 trainees over the two years, 19 trainees gave the exercise a score of 5 and four trainees rated it a 4. Of the latter trainees, three awarded a 4 rather than a 5 due to the "user unfriendly" interface of the MS-DOS version, whilst one awarded the lower score due to the lack of procedures available. The Windows version, which was used for the first time in 1994, was also assessed in a survey similar to the one for MS-DOS. Fourteen trainees from a class of 15 awarded the DIAGNOSIS exercise using the Windows version a 5, whilst the other trainee rated it a 4.

Fig 7.7 shows a typical trainee de-briefing from a DIAGNOSIS exercise. The problem in this case is phytophthora crown rot in apples. In this run, the trainee has carried out most of the pertinent diagnostic procedures, the importance of which are reinforced in the debriefing text. However, the grower was not questioned regarding the variety of apple, nor the drainage on the property. Some varieties are more tolerant to *Phytophthora cactorum* than others and poor drainage can predispose trees to attack. The trainee should have elicited this information in order to make an informed recommendation, as the debriefing points out.

Figure 7.7. Contents of a disk file after a typical DIAGNOSIS exercise

Student Input

Fri Dec 17 12:44:04 1993

Name: John Smirth

Number: 93327852

Scenario Filename: JOHNS.APP

Number of actions: 13

Accumulated costs: $ 75

Preliminary Diagnosis: Some kind of root or crown rot?

Preliminary Justification:
There was a lesion at the crown of the tree, and the canopy was showing classic symptoms of a root problem.

Preliminary Recommendation:
If it is *Phytophthora spp.*, metalaxyl granules spread around the base of affected trees may help.

Final Diagnosis: The disease is crown rot of apples caused by *Phytophthora cactorum.*

Final Justification:
The leaves and twigs were smaller than normal, discoloured and wilted. A zonate lesion was observed at the base of the tree. This is typical of this disease. The trees most badly affected were in the low lying areas. This is typical of a soil-borne disease. Colonies matching the description of *Phytophthora cactorum* were isolated from samples of infected wood.

Final Recommendation:
The grower may wish to consider soil treatment with metalxyl granules although this is a very expensive treatment. However, the trees should be in full production, after years of establishment and with the current good returns for apples it may be economic. The alternative is to abandon the crop and grow something else which is not affected by this pathogen.

Figure 7.7. Contents of a disk file after a typical DIAGNOSIS exercise (cont.)

SOLUTION AND FEEDBACK

The Solution is:
Crown rot of apples caused by *Phytophthora cactorum*

Points to note:
A close examination of the above ground part of the tree provides clues as to the condition. Leaves on affected trees were small and highly coloured and in an advanced state of chlorosis or necrosis. Greener leaves appeared wilted and curled compared to healthy ones. In the absence of other things, these symptoms generally indicate a malfunctioning of the root system.

There was a dark, sour smelling lesion with a zonate margin at the base of affected trees. This is typical of *Phytophthora* crown rot.

Plating infected stem slivers to agar revealed sporangia and oogonia of *Phytophthora cactorum.*

Examining infected root material under the microscope would have revealed oospores

Plating infected root tissue to agar would have revealed sporangia and oogonia of *Phytophthora cactorum.*

Sometimes subtle clues can be present which gives an indication to the nature of the problem. For example, the weeds present were indicative of a wet soil.

"Tailored" debriefing

If you had asked the grower as to which variety had the problem, he would have told you it was coxs orange. This variety is very susceptible to Phytophthora root rot, and means any soil fungicide treatment would perhaps need to be done on a yearly basis, this adding to the cost.

If you had asked the grower about drainage, he would have told you that it was poor. Wet, waterlogged soils are very conducive to the disease. An improvement in drainage would have lead to a lessening of the disease.

Optimal Route
An examination of the leaves, together with the distribution of affected trees should have lead you to suspect a root or soil problem. Asking the grower the variety and about drainage would have offered good clues. From these observations, *Phytophthora cactorum* should have been on the shortlist.

Looking for a disease lesion on the stem would have been a good thing to do next. If found, cutting away the bark would reveal it more clearly.

Finally, if there was any remaining doubt, you could take a sample of the infected tissue to the lab and see if *P. cactorum* could be isolated from it.

Recommended Action
The best course of action for this grower would probably be to remove all of the Cox's Orange trees, improve drainage and then plant with a different crop or a more tolerant variety. A foliar application of a downwardly mobile fungicide such as ALIETTE (fosetyl- aluminium), or granular soil-broadcast fungicide such as metalaxyl (RIDOMIL), would help, although in this case it is unlikely it would have been economic. Too many trees were affected, and drainage would need to be improved eventually anyway, otherwise the disease would only have been temporarily checked.

7.6 Conclusion

DIAGNOSIS requires trainees to interpret observations on plant problems and suggest a plan of action. The tutor can easily assess performance and provide immediate feedback. Furthermore, the exercise is carried out using custom-built local problems. The multimedia capabilities of the software enables players to converse with the grower, and view high definition pictures of signs and symptoms. The latter is important, as the subtlety of symptom expression is sometimes difficult to capture in a textual description alone.

The use of DIAGNOSIS as a training aid for the apple industry, and indeed any other crop, will reduce pesticide use by helping provide better-trained advisers and managers, with the skills to holistically analyse problems and provide solutions.

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CHAPTER 8

GENERAL DISCUSSION

This chapter summarises the work outlined in this thesis, and how it met the objectives as defined in the research proposal. Suggestions for further work and improvements are also made.

8.0 Introduction

Since the awareness during the 1960's of problems associated with the exclusive use of chemicals as a control technique, agricultural industries have looked at ways to use them less frequently, and more effectively.

IPM, with its incorporation of other control techniques, is a methodology by which this can be achieved. However, for IPM techniques to be effective they must first be reliable, and second be easy to implement. To fulfil the former, research is required to demonstrate that the technique works effectively in nearly all cases, over a wide range of environmental and crop parameters. To fulfil the latter, an understanding of the grower's objectives, constraints, decision-making, and the industry's concerned economic and political infrastructure must be taken into account.

Decision support tools are part of the IPM process hence they need to be designed with these requirements in mind. This thesis deals with the development, construction and validation of two decision support tools, designed to be used to enhance grower awareness, analysis of a situation, and decision-making skills. In the process of defining such tools, research was conducted on how growers were using IPM methods, how much they were in control of the decision-making process and what factors may be leading to excessive pesticide applications.

To expand on this, Chapter 1 posed a problem being faced by the New Zealand apple industry; that of maintaining high quality and phytosanitary standard, whilst lowering chemical usage. The goal of this thesis was to construct examples of robust decision support tools, which may assist with alleviating this problem. Chapter 2 gave some background to the pest and disease problems facing the industry, and covered measures which had been undertaken over the years to find solutions. Chapters 3 and 4 detailed investigations into current practices in pest management and pest management decision-making, in order to gather data for determining decision-support tools. Chapter 5 used a decision-tools approach to define the problem of excess pesticide usage, outlining its causes and effects, pointing to areas where decision tools may assist. Chapter 6 and 7 described the constructing and testing of two such tools.

8.1 The grower and adviser surveys - snapshots at a time of change

This thesis has been compiled over five years, which is a relatively long time frame for a study of this nature. During this period significant changes have occurred in the New Zealand apple growing industry.

In 1992, at the time of the grower survey outlined in chapter 3, several features were evident. For the past five years, the industry had been very profitable and this had attracted many new, inexperienced growers. Many of these growers had come from non-orcharding backgrounds. Land prices were very high and many new orchardists were servicing large mortgages. The servicing sector was doing well and generally, there was a feeling of optimism.

Regarding pest management, ovicides were becoming very common, leading to less emphasis on mite counting and integrated mite control. Growers were experimenting with leafroller pheromone traps, as a way to reduce insecticide usage. The use of infection period data to time sprays was widespread, although perhaps more as a way to ensure quality than save on fungicides. Some pest problems were starting to become more important e.g. mealybug, and resistance to insecticides was suspected as a cause of this in Hawkes Bay.

The Apple and Pear Marketing Board, which had traditionally stayed away from production concerns, was moving towards providing advice on production matters. Decision support systems such as Orchard 2000, and information systems such as HortNet™, were only at the prototype stage, but leading growers were expressing much interest in their development.

Even in 1992, export markets were starting to diverge in their phytosanitary requirements, particularly over leafroller concerns. The USA seemed particularly sensitive in this regard, insisting on a minimum number of insecticide applications for this pest.

The following changes have occurred between the date of the first surveys in 1992 and 1997

- Apple leaf-curling midge is now a major pest
- The APMB has pulled out of "on orchard" advising, and is concentrating simply on servicing packhouses with advice, and funding technology-transfer by Hort+Research™.
- Hort+Research™ has increased its technology transfer activities, with numerous field days and training sessions now being held.
- The industry suffered hail damage in 1994 and 1996, leading to economic hardship for a significant number of growers.
- Wetter than usual spring weather in several seasons has seen significant black spot damage to crops.
- Orchard 2000, now well established and many growers are using the models contained within the system.
- Integrated fruit production (IFP) has been introduced, mostly to ensure continued access for the European market. The US market, on the other hand, insists on heavier insecticide use. Many growers are now deciding which market to grow for, and planning their pest and disease management accordingly.

- *Venturia inaequalis* ascospore levels are now monitored, and this information is available to consultants and other advisers, allowing more strategic spraying.

8.1.1 Apple growing today - the push for IFP

It is the active promotion of IFP which has been one of the more significant developments between 1992 and 1997. This is seen as necessary by the APMB to ensure access to European markets. The objective is to have a 100% uptake of IFP strategies by all growers by the year 2000. The publicity and promotion of this concept has led to significant awareness of the concept amongst growers (Walker *pers comm*).

Ironically, whilst IPF is necessary for the European market, the North American market insists on levels of insect control which could be beyond the abilities of IFP at present. Hence a dualism is appearing in apple growing, with mutually exclusive management regimes, depending on the market the fruit are destined for. Ideally those for Europe should be produced under a minimum pesticide IFP regime, whilst those for the USA are required to have high levels of insecticides to prevent leafroller contamination. This could have important implications for exporting as pest management decisions may preclude selling in certain markets, thus constraining the APMB in its response to market signals. The APMB is presently negotiating with USA officials in a bid to get acceptance for other non-chemical methods, such as fruit washing.

Much intellectual effort is now going into implementing IFP, with 77 growers nationwide (50 in Hawkes Bay) participating in trials. The major players and their roles are:

- APMB - determining the IFP standards for the marketplace
- Hort+Research™ - developing IFP manuals and providing technical support
- Consultants - IFP technology transfer and monitoring

- Growers - trained to identify pests, diseases and beneficial insects; accurately interpret disease forecasts and pest thresholds; and make the best pest and disease control decisions on the basis of information collected.

8.1.2 IFP implementation - the message from the surveys?

The two surveys revealed interesting facts about pest and disease management in apples, which were used in the problem definition (see 8.2), but also have relevance to today's IFP implementation activities. Growers recognised a need for pesticide reduction and were prepared to use IPM techniques where they were available and fail-safe. However, as a group they were relatively inexperienced and in many cases, the real pest and disease management decision-making was by someone else.

At present, monitoring for growers on the IFP program is being carried out by Hort+Reseach™ in collaboration with private consultants. It is expected that consultants and private firms or growers themselves will carry out this function, once these "free trials" have finished.

One of the major findings of the advisers' survey, detailed in Chapter 3, was the importance of horticultural merchant field representatives to the decision-making process. During this IFP implementation process, it is extremely important that the commercial firms feel they have a stake in the programme. The inclusion of private consultants is not enough. Many leading growers may use consultants, but others simply rely on the (free) advice of their merchant representative. From discussions with those involved in the implementation process, it seems more work needs to be done to include major merchant firms as some appear suspicious of, or feel excluded from, this process (Steffl *pers comm*).

8.2 The problem defined

The building of a problem tree was a useful application of a primary decision-tool (Norton and Mumford, 1993), in order to focus on the main problem concerned, it's underlying causes and where decision support may assist. There is no doubt that the strict quarantine requirements New Zealand growers must comply with, and the need for the highest quality to attract a premium price, is a major constraint to the reduction of pesticides. Nevertheless, there is still room for reduction under current technologies and grower training and education may facilitate this. The decision-support tools were designed with the latter in mind.

8.2.1 Grower training

Many of the tertiary institutions in New Zealand offer courses in fruit production, and pest and disease management. However, the need for more "on the job" industry training is evident.

The emergence of many newer growers, with backgrounds as diverse as law and waterfront labouring, means a real need exists for on-the-job training for mature people. Workshops, "orchard walk" days and grower meetings all contribute to this. As noted before, Hort+Research™ seems to be taking an active role in promoting technology transfer, enabling research results to get out to growers as soon as possible. Also, NZAET - the New Zealand Agricultural Chemical Education Trust (see Appendix 10), provides a mechanism by which people applying agricultural chemicals can gain a recognised qualification through the GROWSAFE™ program.

Without full knowledge of pests and diseases, IPM techniques can be misused. For example, when a black spot infection period occurs in a monitored area in Hawkes Bay, nearly all affected growers will know about it. However, evidence would suggest (Breton-Rule, 1993) that many growers (and presumably their advisers) take an infection period to mean they should apply a DMI fungicide, rather than questioning if the cover is already enough. In this case, more decision-making information may have led to more spraying, not less! If a grower knows there has definitely been an infection period, then the perception of risk is heightened. It is the old adage, “A little knowledge is a dangerous thing”.

8.2.2 The role of the adviser

During the term of this research project, there were many other industry-related activities undertaken which attempted to attack these basic problems, especially in the area of more reliable IPM techniques. However, in the author's opinion, not enough has yet been done to understand and exploit the relationship between growers and their advisers. A workshop, consisting of the major players and run along the lines described by Norton and Mumford (1993) would be a very valuable exercise. It is worth noting that the APMB have recently sponsored a social scientist postgraduate to study apple growers' attitudes and constraints to IFP, so the importance of these factors may at last be being realised.

8.3 SPRAYCHECK - education through decision-analysis

The problem tree revealed grower training as a way to reduce pesticides. The SPRAYCHECK model is essentially a training tool. It contributes to better decision-making by analysing past decisions and allowing growers (and/or their advisers) to reflect on what they have done.

The idea for SPRAYCHECK came out of the practices uncovered in the advisers survey. Every adviser met with their clients at the beginning of the season, but none had a way of assessing past spray programs for efficiencies. SPRAYCHECK seemed particularly useful for this purpose, providing a retrospective education tool allowing growers to see the relationship between black spot infection periods, spray cover and rainfall. Practical use of the model is aided by the fact that many grower spray diaries are now stored electronically.

8.3.1 Improvements and further research

The major weakness in the model is that it assumes infective ascospores are always present. When the model was being constructed, growers also had to make this assumption. In the last two years however, ascospore reports have become available giving growers a further tool with which to assess "risk".

As with most secondary decision tools, construction of the model revealed areas where knowledge was deficient. The "knowledge gaps" exposed have led to many areas for further research...some of these are:

- Studies to define the relationship between infection periods, spray residue, plant growth, rainfall and the different chemicals and surfactants used
- The minimum conditions of leafwetness, wind, and rainfall before another spray can be applied.

Although the model was designed primarily for education and decision-support, it can play a useful role as a research tool. Spray diaries can be analysed and correlated with other grower variables, such as the main adviser used. Future research work is planned in this area.

8.4 DIAGNOSIS - teaching problem-solving skills

Interpreting problems and making the correct diagnosis as to the cause, is a required skill for any grower, manager and adviser. The DIAGNOSIS program described in Chapter 7 is a novel way to acquire this skill. It is a chance to give trainees experience at problem solving, before they try it on a real crop.

Many expert systems are used for teaching. In these situations, the system diagnoses a problem and comes up with a justifiable solution. The student often learns by following the process and viewing the decisions. The relationship between the

computer program and the trainee is similar to that between a master and an apprentice, who observes the master and learns from what they do.
The unique aspect of DIAGNOSIS, is that rather than the computer mimicking an expert, the trainee is assumed to be the expert. In a way, it is the reverse of an expert system, presenting the observations and allowing the students (ie the experts) to do the interpretation themselves. Hence the students are at the centre of the problem-solving exercise. This is an important strength of this system.

8.4.1 Improvements and further development

As a training aid for the apple industry, DIAGNOSIS has two weaknesses. These are not fundamental, but they do require time and money to make the software more effective for this sector.

First, it requires more apple scenarios to be constructed. Second, DIAGNOSIS is not stand-alone; it must be used in conjunction with some information delivery process. This could be a textbook or manual, a teacher or lecture course. Enhancements are planned to make DIAGNOSIS more of a full multimedia course in its own right.

Problems can arise once task-specific models are expanded. Potential problems in the case of an expanded DIAGNOSIS program would be the large amounts of information required, how to present it effectively, and how to keep it updated.

8.5 Conclusion

The following is a synopsis of the work carried out, as it relates to the objectives as defined in chapter 1.

Objective 1

Based on the needs and observations of growers, specify one or more decision support systems.

Achievement

Growers were surveyed and their current pests and disease problems, IPM practices, receptiveness of growers to integrated decision support and the most appropriate delivery system ascertained. The survey found horticultural field representatives and consultants appeared to be major spray decision advisers and a follow-up survey of advisers themselves added weight to that. Problem-definition techniques were then used to identify the areas where decision support could assist in spray reduction.

Black spot spraying was ascertained to be an area of difficulty and grower education deemed important. A decision-support aid (SPRAYHECK) that analysed each decision point in previous black-spot spray programmes, and provided a theoretical minimum spray program was defined. It was envisaged this would be used as an educational and discussion tool for growers and their advisers, when planning the spray program.

Another education aid in draft form prior to this study - DIAGNOSIS, was re-defined according to this work and it's capabilities extended.

Objective 2

Design and construct examples of such systems.

Achievement

A full commercial version of DIAGNOSIS and a prototype of SPRAYCHECK that allowed validation of the models therein, were designed and constructed.

Objective 3

Validate the systems on historical data and test their credibility with experts.

Achievement

SPRAYCHECK was validated on artificial data and a real-life spray dairies, by face validity tests and comparing it's results with those of a number of experts supplied with the same input data. DIAGOSIS was validated through student surveys, face validity tests from other experts, and the "judgement of the marketplace.

Objective 4

Discuss their possible impact in the field.

Achievement

This was discussed in the thesis, and further developments and uses for the tools proposed

This study resulted in three publications in refereed international journals (Stewart, Blackshaw, Duncan, Dale, Zalucki and Norton, 1995; Stewart and Mumford, 1995; Stewart, Knight, Manktelow, and Mumford, 1997), one refereed conference proceeding (Stewart, Norton, Mumford and Fenemore, 1993), a chapter in a book (Stewart, 1997) and numerous other papers. A commercial software package (DIAGNOSIS) has been produced and one other package (SPRAYCHECK) is likely to be incorporated into an existing Decision Support System (Orchard 2000)

8.6 References

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THE END

APPENDIX I

APPLE GROWTH STAGES

Dormant

Budburst to greentip

Tight cluster

Pre-pink

Pink

Bloom

Petal fall

First cover

(Source of images: University of California. (1991). *Integrated pest management for apples and pears.* University of California statewide integrated pest management program. Publication 3340.

APPENDIX II

GROWER SURVEY FORM

Date: __________ **Name:** _______________

1. How many years have you been involved in growing apples?

   ____

2. (a) Are you a first-generation apple grower?

   Y / N

   (b) (if not) How many generations has your family been involved in growing apples?

   ____

3. (a) Which varieties do you have?

   (b) What is the total number of trees (or area) you manage?

   ____

4. Do you own or part-own the property yourself or are you managing it for someone else (circle)?

   Owner / Manager

5. (a) Here is a list of pests and diseases of apples:

Have any proved troublesome in the last 5 years despite your normal control program?

Pest/Disease (tick)	Last year	Prev year	Varieties	Details (frequency, extent, control)
leafrollers				
mites				
mealy bugs				
leafhoppers				
scale insects				
woolly apple aphid				
leaf-curling midge				
codling moth				
fireblight				
blackspot				
powdery mildew				
glomerella				
Phytophthora				
silverleaf				
re-plant disease				
Other...				

6. How do you see your current Pest and Disease practices changing in the next 5 years? (comments to be recorded here)

7. (a) To your knowledge, do you have predatory mites in your orchard?

Y / N

(b) (If yes), Do you consciously select fungicides, insecticides and miticides which are safe to predatory mites.

Y / N

8. Do you regularly monitor and pests or diseases in your apples?

Y / N

(b) (If yes) What form does this take?

ġeneral orchard walk

Assessment of specific pest or disease (specify)

Pest or disease	Quant.	Not Quant.

both

9. A recent survey identified the following pests and diseases (show list) as being difficult when it came to **deciding when to spray for them**.

(a) Do you have any trouble deciding when to control any of these? Is this the same for all varieties? Rank them in order of decision-making difficulty.

(b) Do you feel that this difficulty in decision-making (for this particular pest or disease) has led, in some cases, to a loss of control in your orchard.

Pest/disease	Y/N	Varietial differences	Rank	Loss of control?
leafrollers				
mites				
mealy bugs				
fireblight				
black spot				
powdery mildew				

10. (a) Do you (or your consultant) use any of the following decision-aids to help you with control of the pests and diseases in the "difficult" list shown in 8.? (Show grower the list below). If so, is it you or your consultant who does the monitoring and/or interpretation.

Y / N

For those selected, assign a value to the overall usefulness (1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = very good). Are they reliable, easy to interperate, practical and cost-efficient?.
For those you do not use it is probably because of one or more of the following reasons. Select the reasons and rank them in the order of importance.

1. *Don't know enough about them*
2. *Not readily available*
3. *Never felt I needed them*
4. *Not practical (elaborate)*
5. *Not reliable (elaborate)*
6. *Hard to interpret (elaborate)*
7. *Too expensive*
8. *Leave it all up to the consultant*

Decision-aid	Self Mon	Self Intrp	Consult Mon	Consult Intrp	Useful score	Not used rankings	Comments
Mills periods - DSIR warnings on radio etc.							
Mills period- own monitor							
fireblight infection periods							
leafroller pheromone traps							
codling moth pheromone traps							
DSIR mite hatch prediction							
Mite monitoring and spray on threshold (No predators)							
Mite monitoring and spray on thresholds (with predators)							

11. Here is a list of features for a hypothetical decision-aid designed for any of the "difficult" pests and diseases listed in 5. Rank them in order of importance as far as you are concerned.

Features include:

	Rank
Reliability	
Easy to interpret in order to make a decision (i.e. at a glance)	
Monitoring/counting automated	
Includes an optional educational aspect	
Gives control recommendations	

12. (a) Assume a service was present which automatically monitored pests and diseases in your orchard (or region) and communicated same-day control recommendations to you, along with other orchard-specific information which you might want. Would such a service appeal to you if it could be provided at a reasonable cost (circle)?

Y / N

(b) (If no) Why?

____

(c) (if yes) Approx how much per year would you be prepared to pay (circle)

$0
$1-$25
$26-$50
$101-$200
> $200

(d) What, in your opinion, would be the best way to deliver this service to growers, assuming they wanted it and already had the necessary equipment (circle)? How about yourself...(if yes for (a))

Fax machine
Into a computer via modem
Fast-Post mail
Telephone
Other______

(e) If the service was delivered by FAX, do you think this would encourage growers to buy a fax machine?

Y / N

(f) Do you own or have easy access to a fax machine yourself?

N / OWN/ ACCESS

(g) Do you own, or have easy access to a microcomputer?

N / OWN/ ACCESS

If so, what type is it?

PC/ Mac/ Other

(h) Do you feel comfortable using computers?

Y / N

13. In making decisions regarding when to spray for pests and diseases rank the following considerations in order of importance to you. Are there any specific pests or diseases for which you would rank these considerations differently?

	Rankings LR	MT	MB	FB	BS	PM
Availability/Non-availability of labour						
Qualitative assessment (gut feeling, intuition)						
Timing taken from spray chart						
Advice from someone else (rep, consultant)						
Monitored data (counts, result of decision-aid)						
Applied in a tank mix when spraying for something else.						
Predicted weather (next 2-3 days)						
Other...						

14. From the list I have <show list>, identify and rank the sources of advice you use in dealing with pests and diseases.

Source	Ranking	Comment
MAF consultants		
Apple and Pear Mktg board		
Private consultants		
Newspapers (specify)		
Journals (specify)		
Books		
Hort Merchants (specify)		
Faxlink		
Other growers		
Others....		

15. Which "consultant" (merchant rep, private consultant etc.) do you deal with most frequently?

____

16. Some people say that overseas buyers will insist on fewer and lower fungicide and insecticide residues on export apples in the next 10 years. Which of these choices represents your opinion on this statement.

strongly disagree
disagree
unsure
agree
strongly agree.

17. Some people say that resistance to fungicides or insecticides will become a major problem in the next 10 years. Which of these choices represents your opinion on this statement.

Strongly disagree
disagree
unsure
agree
strongly agree.

18. Which age grouping represents you?

<20
20-29
30-39
40-49
50-59
60+

19. Finally, have you received any formal training in apple growing. If so where and when?

APPENDIX III

ADVISERS SURVEY FORM

Name:

Age:

Experience in Apple consulting:

Any experience in Apple growing?: No. of clients:

A1. Do you give advice to growers on pest and disease related matters. If so, please give details?

Y/N

2. During the season, do you make regular visits to the orchard at particular times to offer pest and disease advice, or do you wait until the grower contacts you with a problem.

Y/N

Does the frequency of regular visits depend on the grower concerned. If so, what type of grower would you visit more or less of than others?

Y/N

On average, how often would you have contact with a client during the growing season?

3. For some orchards, do you feel that you are often the main "decision-maker" when it comes to the aspects of pest and disease control you advise on?. For what % of your clients do you feel you are the major "decision-maker"?

Do any of you clients expect you to know more about pests and disease levels in their orchards than they do themselves? What %?

4. In general terms, do you give growers a single recommendation, or do you more often give several options (of varying risks and costs) for growers to choose from.

5. Bearing in mind the nature of the job, are you more likely to be conservative in control recommendations than growers would be...in other words you would be more likely to recommend a program which may perhaps cost more but there is little risk of damage, as opposed to one which saves on sprays (therefore money for the grower)...but is a little more risky?

6. On a scale of 1 to 10, how would you rate the following growers on their pest and disease management skills where 1 = hopless and 10 = excellent

B. It's often said the best teacher is experience. Regarding pests and diseases, can you think of 2-3 important things that you've learned "on the job" that would be difficult to pick up from books or training courses.

C. Can you give me two or three examples of pest or disease problems where there just doesn't seem to be enough information readily available?

Is the information simply not known or is it hard to get?

Do you think there a need for more detailed, up-to-date, weather forecasts in HB?

D. If you were designing a training course for pests and disease management in apples, name the three most important things that should be included?

E. What do you find the most difficult aspect of your job?

F. Have you received any tertiary training in Horticulture?

APPENDIX IV

AGRICHEMICAL LEGISLATION

Most laws concerning the use of agrichemicals in the fruit industry, are currently covered by the Pesticides Act (1979) and the Toxic Substances Act (1979). The Animal Remedies Act (1967) covers aspects of agrichemical use in agriculture.

The Pesticides Act (1979)

This Act promotes the prudent, effective and safe use of agrichemicals. Agrichemicals cannot be distributed commercially in New Zealand without first being registered by the Pesticides Board. The Board can require specific application directions, declare directions to be mandatory, review or cancel registration in the light of new information and impound stocks. Other features of the Pesticides Act are to:

- establish the Pesticides Board to regulate the use of agrichemicals
- require all agrichemicals to be registered prior to import, manufacture or sale
- require all agrichemicals to be sold under a label acceptable to the Board

The Toxic Substances Act (1979)

This Act provides for the control of all toxic substances apart from medicines. It sets out schedules to which toxic substances are classified. The Toxic Substances Board advises the Minister and Department of Health on matters relating to toxic substances administration.

Hazardous Substances and New Organisms (HSNO) Bill

This Bill is currently before Parliament. It is designed to "tidy up" the control of hazardous substances, provide greater protection for the environment and control the introduction and release of new organisms. The HSNO legislation will require all hazardous substances (not just agrichemicals) to be subject to the same assessment criteria and controls. Apart from the border control provisions of the new Biosecurity Act, there was no law specifically for the control of new organisms. The HSNO legislation controls new organisms whether imported or genetically engineered in New Zealand.

An Environmental Risk Management Authority (ERMA) will be set up, with responsibility to:

- advise on the content of the regulations specifying national standards for and controls of
- licence and monitor disposal of
- promote public awareness of
- involve the public in decision making relating to hazardous substances and new organisms.

Once the HSNO Bill becomes law, there will be a time frame set within which manufacturers and importers will be required to notify ERMA of any potentially hazardous substances already in use, so that approval can be given for their continued use. The prime function of the HSNO legislation is to protect health and the environment. MAF Regulatory Authority will require additional assessment for compliance with the Agrichemical Compounds legislation (see below). Under the HSNO Bill, the Pesticides Act and the Toxic Substances Act will be repealed.

Agricultural Compounds (AC) Bill

Because the HSNO legislation covers only health and the environment, further legislation is required to control other aspects of agrichemical use. The Agricultural Compounds Bill is part of a wider programme 14 Acts into 4. It will cover those functions outside the HSNO legislation, including:

- management of risks to international market access
- provision of controls on use or label information for compliance with domestic residue standards
- management of risks to animal welfare
- management of pest and disease risks from agricultural compounds
- provision of information to consumers to enable informed decisions on purchase

It is planned that the HSNO and AC Bills will become law at the same time.

Resource Management Act (1991) (RMA)

The RMA adopts the philosophy that the environment can be used for the benefit of communities and the nation, but not in such a way that permanent damage will occur.

The stated aims of the RMA are to:

- promote the sustainable management of natural and physical resources
- safeguard the life-supporting capacity of air, water, soil and ecosystems
- avoid, remedy or mitigate any adverse effects of activities on the environment.

Regional and district councils have responsibility for the administration of the RMA. It is through the regional and district plans of these councils that the details for compliance are provided.

Health and Safety in Employment Act

There is general acceptance of the requirements of this legislation plus the financial advantage through a rebate in levies. Employers must take all practicable steps to ensure the safety of employees while at work. In particular, these obligations include:

- providing and maintaining a safe work environment
- providing and maintaining facilities for the safety and health of employees at work
- ensuring that all plant is designed, arranged, made and maintained so it is safe for employees
- ensuring that employees are not exposed to hazards
- developing procedures for dealing with emergencies that may arise while employees are at work.

Employment Contracts Act (1991)

There is wide acceptance of and agreement with this legislation. The aim of the Employment Contracts Act is to promote an efficient labour market, where:

- there is a move towards greater freedom for the parties in an employment relationship
- parties are able to negotiate the terms and conditions of their relationship with fewer legislative restraints and protection
- the first point of reference is the contract of employment

APPENDIX V

LISTING OF THE SPRAYCHECK PROGRAM

```
'SPRAYCHECK ASSESSOR (Prototype Version 1.0)
'22nd July 1996
'All output is for testing purposes only and will be in a
'different form in the final growers' progam.  This is just to show that the models
'work!!


'Dimension global arrays...

'SCREEN 12

period = 90                    ' sets the length of the period being
                               ' tested.  Would be the number of days
                               ' from the start of the season to the end
maxnumspraysonday = 5
numfungicides = 30

DIM fungicide$(numfungicides, 3)' dummy fungicide data array for testing
                               ' assumes choice of 30 Fungicides,
                               ' each one with a trade name, protectant life
                               ' and eradicant life.  These would
                               ' normally be read from the chemical
                               ' database
                               ' NB. Protectant and eradicant values not
                               ' yet in orch2000 database

DIM sprays$(period, maxnumspraysonday, 5)
                               ' Array to hold daily sprays.  Assumes no
                               ' more than 4 sprays at a time. Read from
                               ' spray diary and includes chemical, cost
                               ' whether it was a blackspot spray or not
                               ' rate and water applied / ha

DIM rainfall(period)           ' Array to hold daily rainfall in mm.  Read from
                               ' weather database. Calculated from 9am to
                               ' 9am next day

DIM hourlyweather(period, 3, 24)' Array to hold hourly rainfall figures

DIM diarydate$(period)         ' Date to correspond to days

DIM infect$(period)            ' Array to hold infection periods.  Calculated
                               ' from the Orchard 2000 model

DIM apptime$(period)           ' Array to hold boolean value (although a
                               ' string here for clarity).  Determined by
                               ' by model 1..Pre or Post-rain Model

DIM cover(period)              ' Array to hold cover calculated from
                               ' Model 2. Protectant cover Model

DIM decisioncover(period)      ' Array to hold calculated cover from previous
                               ' sprays on the day that a spray is applied
                               ' - filled in from model 2 but used by the
                               ' decision analysis model 3.1

DIM leafwet(period)            ' Array to hold average leafwetness

DIM wind(period)               ' "        "     "     windspeed


' Set global variables...

day = 1                        ' Start the spray diary at day 1
                               ' This variable is used throughout the
                               ' models as local variable

washoffrate = 2.47             ' 2.47 % of cover per 1mm of rain
                               ' calculated for captan...

minresidue = 15                ' 15% is the minimum "safe" residue
                               ' to prevent infection - 5% safety margin

' Start of data loading...

CLS

' fungicide data array.  This is dummy data used to test the model in lieu
' of a fungicide database to access.

fungicide$(1, 1) = "Baycor": fungicide$(1, 2) = "50": fungicide$(1, 3) = "4"
fungicide$(2, 1) = "Bavistin": fungicide$(2, 2) = "50": fungicide$(2, 3) = "1"
fungicide$(3, 1) = "Benlate": fungicide$(3, 2) = "50": fungicide$(3, 3) = "1"
fungicide$(4, 1) = "BLEND 79": fungicide$(4, 2) = "10": fungicide$(4, 3) = "0"
fungicide$(5, 1) = "CAPTAN 80 WP": fungicide$(5, 2) = "10": fungicide$(5, 3) = "0"
fungicide$(6, 1) = "Copper oxychloride": fungicide$(6, 2) = "10": fungicide$(6, 3) = "0"
fungicide$(7, 1) = "Cupric hydroxide": fungicide$(7, 2) = "10": fungicide$(7, 3) = "0"
fungicide$(8, 1) = "Delan": fungicide$(8, 2) = "10": fungicide$(8, 3) = "0"
fungicide$(9, 1) = "DITHANE M45": fungicide$(9, 2) = "10": fungicide$(9, 3) = "0"
fungicide$(10, 1) = "DODINE 400": fungicide$(10, 2) = "10": fungicide$(10, 3) = "2"
fungicide$(11, 1) = "Duo": fungicide$(11, 2) = "10": fungicide$(11, 3) = "0"
```

```
fungicide$(12, 1) = "MANZATE 200": fungicide$(12, 2) = "10": fungicide$(12, 3) = "0"
fungicide$(13, 1) = "Mizar": fungicide$(13, 2) = "10": fungicide$(13, 3) = "0"
fungicide$(14, 1) = "NUSTAR 20DF": fungicide$(14, 2) = "10": fungicide$(14, 3) = "4"
fungicide$(15, 1) = "ORTHOCIDE 48F": fungicide$(15, 2) = "10": fungicide$(15, 3) = "0"
fungicide$(16, 1) = "PALLINAL": fungicide$(16, 2) = "10": fungicide$(16, 3) = "0"
fungicide$(17, 1) = "POLYRAM DF": fungicide$(17, 2) = "10": fungicide$(17, 3) = "0"
fungicide$(18, 1) = "RUBIGAN FLO": fungicide$(18, 2) = "50": fungicide$(18, 3) = "4"
fungicide$(19, 1) = "Saprol": fungicide$(19, 2) = "10": fungicide$(19, 3) = "1"
fungicide$(20, 1) = "SYLLIT PLUS": fungicide$(20, 2) = "10": fungicide$(20, 3) = "2"
fungicide$(21, 1) = "SYSTHANE 40W": fungicide$(21, 2) = "50": fungicide$(21, 3) = "4"
fungicide$(22, 1) = "THIRAM 40F": fungicide$(22, 2) = "10": fungicide$(22, 3) = "0"
fungicide$(23, 1) = "TOPAS MZ62WP": fungicide$(23, 2) = "10": fungicide$(23, 3) = "4"
fungicide$(24, 1) = "Topsin": fungicide$(24, 2) = "50": fungicide$(24, 3) = "1"
fungicide$(25, 1) = "CAPTOR 480 FL": fungicide$(25, 2) = "10": fungicide$(25, 3) = "0"
fungicide$(26, 1) = "SYLLIT 40S": fungicide$(26, 2) = "10": fungicide$(26, 3) = "2"
fungicide$(27, 1) = "BLEND 88": fungicide$(27, 2) = "10": fungicide$(27, 3) = "0"
fungicide$(28, 1) = "RUBIGAN 12EC": fungicide$(28, 2) = "50": fungicide$(28, 3) = "4"
fungicide$(29, 1) = "ORTHOCIDE 80W": fungicide$(29, 2) = "10": fungicide$(29, 3) = "0"
fungicide$(30, 1) = "TOPAS 10 WP": fungicide$(30, 2) = "50": fungicide$(30, 3) = "4"

'First Data load.
'Load in weather data from an orchard2000 Metview output file...
'met file must commence at 6.00am on the first day of the spray log file
CLS
PRINT "Model working..."
filenm$ = "d:\datafi~1\research\phd\asessor\program\" + "met.txt"
OPEN filenm$ FOR INPUT AS 1
day = 1
DO
  FOR i = 1 TO 24                    ' Hourly data
    LINE INPUT #1, b$
    'PRINT b$
    length = LEN(b$)
    position = 1                     ' to avoid the first "
      DO                             ' Collect the date
        position = position + 1
        IF i = 1 THEN    ' Save the date of the first day
           diarydate$(day) = diarydate$(day) + MID$(b$, position, 1)
        END IF
      LOOP UNTIL MID$(b$, position + 1, 1) = CHR$(32) 'stop at the space
      DO                             ' miss out the time
        position = position + 1
      LOOP UNTIL MID$(b$, position, 1) = CHR$(9)
      FOR j = 1 TO 3
        DO                           ' Read data
          position = position + 1
          a$ = MID$(b$, position, 1)
          c$ = c$ + a$
        LOOP UNTIL (position = length) OR (ASC(a$) = 9) ' stop if all data read
                                                        ' or a tab stop reached
        hourlyweather(day, j, i) = VAL(c$)
        c$ = ""
        'PRINT hourlyweather(day, j, i)
      NEXT j
      b$ = ""

  NEXT i
                                        ' determines the start day and
                                        'the end day of the high risk
                                        ' period determined to be between
                                        ' last week in Sept and 1st week
                                        'in November
IF LEFT$(diarydate$(day), 5) = "21/09" THEN beginhighrisk = day
IF LEFT$(diarydate$(day), 4) = "7/11" THEN endhighrisk = day

day = day + 1
LOOP WHILE day <= period
CLOSE


'Calculates daily rainfall and av wind and leafwet...from 6am to 6am next day

FOR day = 1 TO period - 1
  FOR j = 7 TO 24
    leafwet(day) = leafwet(day) + hourlyweather(day, 1, j)
    wind(day) = wind(day) + hourlyweather(day, 2, j)
    rainfall(day) = rainfall(day) + hourlyweather(day, 3, j)
  NEXT j
  FOR j = 1 TO 6
    leafwet(day) = leafwet(day) + hourlyweather(day, 1, j)
    wind(day) = wind(day) + hourlyweather(day, 2, j)
    rainfall(day) = rainfall(day) + hourlyweather(day + 1, 3, j)
  NEXT j
wind(day) = wind(day) / 24                  ' Average to get daily figure
leafwet(day) = leafwet(day) / 24

NEXT day


'Loads in infection periods..
day = 1
filenm$ = "d:\datafi~1\research\phd\asessor\program\" + "infect.txt"
OPEN filenm$ FOR INPUT AS 1
  DO
    INPUT #1, checkday
    INPUT #1, infect$(day)
    IF day <> checkday THEN
      PRINT , "ERROR....days do not match!"
    END IF
    day = day + 1
  LOOP WHILE day <= period
CLOSE 1
```

```
'Loads in spray diary and weather data from file.  Assumes infection periods
' are recorded for a particular day between 6am and 6am the next day.
' Also assumes wind speed is in Km/hr (conversion routine needed to be
' included if in m/s)

day = 1
OPEN "d:\datafi~1\research\phd\asessor\program\" + "fungicid.txt" FOR INPUT AS 1
CLS
INPUT #1, b$                                  ' Read header line
Orchard$ = b$

  INPUT #1, b$                                ' First character
  i = 1
  DO WHILE ASC(MID$(b$, i, 1)) <> 9          ' read characters up to a tab
    data$ = data$ + MID$(b$, i, 1)
    i = i + 1
  LOOP

DO
  IF data$ = diarydate$(day) THEN
     arrayposition = day                      ' get the array position for the spray
  IF ASC(MID$(b$, i, 1)) <> 9 THEN            ' formatting check
      PRINT "Error...file not formatted correctly"
  ELSE
     i = i + 1                                ' get past the tab character
  END IF


  IF day = previousday THEN                   ' check to see if more than
                                              ' one chemical applied
     spraynum = spraynum + 1                   ' if so, skip date and call
     IF spraynum > maxnumspraysonday THEN
       PRINT "Error...too many chemicals applied"
       STOP
     END IF
  ELSE                                        ' it spray 2 or 3
     spraynum = 1                              ' If not, then it's spray 1
  END IF

  DO WHILE ASC(MID$(b$, i, 1)) <> 9          ' read it up to the next tab
     chem$ = chem$ + MID$(b$, i, 1)           ' save it
     i = i + 1
  LOOP

  i = i + 1
  DO WHILE ASC(MID$(b$, i, 1)) <> 9          ' read rate - characters up to a tab
     rate$ = rate$ + MID$(b$, i, 1)
     i = i + 1
  LOOP
  i = i + 1
  DO WHILE ASC(MID$(b$, i, 1)) <> 9            ' read water rate - characters up to a tab
     waterrate$ = waterrate$ + MID$(b$, i, 1)
     i = i + 1
  LOOP

  i = i + 1                                  ' get past the tab
  IF MID$(b$, i, 1) <> "$" THEN              ' check to see we are at the right place
     PRINT "error...should be an $ here"
     STOP
  END IF
  i = i + 1
  endline = LEN(b$) - i                     ' get the rest of the data
  chemcost$ = MID$(b$, i, endline)          ' which must be the price

  FOR i = 1 TO numfungicides                        ' and what it is used for
     IF chem$ = fungicide$(i, 1) THEN
        sprays$(day, spraynum, 3) = "Blackspot spray"
        EXIT FOR
     ELSE
        sprays$(day, spraynum, 3) = "Other spray"
     END IF
  NEXT i

  sprays$(day, spraynum, 1) = chem$           ' Load the array
  sprays$(day, spraynum, 2) = chemcost$
  sprays$(day, spraynum, 4) = rate$           ' Load the array
  sprays$(day, spraynum, 5) = waterrate$

  chem$ = ""                                  ' reset variables
  chemcost$ = ""
  rate$ = ""
  waterrate$ = ""

  previousday = day
  INPUT #1, b$                                ' First character
     i = 1
     data$ = ""
     DO WHILE ASC(MID$(b$, i, 1)) <> 9          ' read characters up to a tab
       data$ = data$ + MID$(b$, i, 1)
       ' PRINT "data$="; data$;
       i = i + 1
     LOOP
  IF data$ <> diarydate$(day) THEN       ' check to see if it's a different date
     day = day + 1                        'which means there is only one chem
  END IF
  ELSE
    day = day + 1
  END IF
LOOP UNTIL day = period
```

```
CLOSE 1

  FOR i = 1 TO period                   ' now sort sprays where more than one
    IF sprays$(i, 1, 1) <> "" THEN
      FOR j = 1 TO maxnumspraysonday ' so the one with the highest protectant
        IF sprays$(i, j, 3) = "Blackspot spray" THEN
          chem$ = sprays$(i, j, 1)          ' value goes in front.  Any non-black
          GOSUB selectchem                  ' -spot sprays go near the end.
          dc(j) = VAL(fungicide$(fungicide, 2))
          'PRINT "chem$="; chem$, dc(j)
        ELSE
          dc(j) = 100                       ' used to send non-blackspot sprays to
        END IF                              ' the end of the sort
      NEXT j

      IF dc(1) > dc(2) THEN
          tmp = dc(2)
          dc(2) = dc(1)
          dc(1) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 2, k)
          sprays$(i, 2, k) = sprays$(i, 1, k)
          sprays$(i, 1, k) = temp$
        NEXT k
      END IF
      IF dc(1) > dc(3) THEN
          tmp = dc(3)
          dc(3) = dc(2)
          dc(2) = dc(1)
          dc(1) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 3, k)
          sprays$(i, 3, k) = sprays$(i, 2, k)
          sprays$(i, 2, k) = sprays$(i, 1, k)
          sprays$(i, 1, k) = temp$
        NEXT k
      END IF

      IF dc(1) > dc(4) THEN
          tmp = dc(4)
          dc(4) = dc(3)
          dc(3) = dc(2)
          dc(2) = dc(1)
          dc(1) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 4, k)
          sprays$(i, 4, k) = sprays$(i, 3, k)
          sprays$(i, 3, k) = sprays$(i, 2, k)
          sprays$(i, 2, k) = sprays$(i, 1, k)
          sprays$(i, 1, k) = temp$
        NEXT k
      END IF

      IF dc(1) > dc(5) THEN
          tmp = dc(5)
          dc(5) = dc(4)
          dc(4) = dc(3)
          dc(3) = dc(2)
          dc(2) = dc(1)
          dc(1) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 5, k)
          sprays$(i, 5, k) = sprays$(i, 4, k)
          sprays$(i, 4, k) = sprays$(i, 3, k)
          sprays$(i, 3, k) = sprays$(i, 2, k)
          sprays$(i, 2, k) = sprays$(i, 1, k)
          sprays$(i, 1, k) = temp$
        NEXT k
      END IF


      IF dc(2) > dc(3) THEN
          tmp = dc(3)
          dc(3) = dc(2)
          dc(2) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 3, k)
          sprays$(i, 3, k) = sprays$(i, 2, k)
          sprays$(i, 2, k) = temp$
        NEXT k
        tmp = 0
      END IF

      IF dc(2) > dc(4) THEN
          tmp = dc(4)
          dc(4) = dc(3)
          dc(3) = dc(2)
          dc(2) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 4, k)
          sprays$(i, 4, k) = sprays$(i, 3, k)
          sprays$(i, 3, k) = sprays$(i, 2, k)
          sprays$(i, 2, k) = temp$
        NEXT k
        tmp = 0
      END IF

      IF dc(2) > dc(5) THEN
          tmp = dc(5)
```

```
          dc(5) = dc(4)
          dc(4) = dc(3)
          dc(3) = dc(2)
          dc(2) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 5, k)
          sprays$(i, 5, k) = sprays$(i, 4, k)
          sprays$(i, 4, k) = sprays$(i, 3, k)
          sprays$(i, 3, k) = sprays$(i, 2, k)
          sprays$(i, 2, k) = temp$
        NEXT k
        tmp = 0
      END IF

      IF dc(3) > dc(4) THEN
          tmp = dc(4)
          dc(4) = dc(3)
          dc(3) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 4, k)
          sprays$(i, 4, k) = sprays$(i, 3, k)
          sprays$(i, 3, k) = temp$
        NEXT k
        tmp = 0
      END IF


      IF dc(3) > dc(5) THEN
          tmp = dc(5)
          dc(5) = dc(4)
          dc(4) = dc(3)
          dc(3) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 5, k)
          sprays$(i, 5, k) = sprays$(i, 4, k)
          sprays$(i, 4, k) = sprays$(i, 3, k)
          sprays$(i, 3, k) = temp$
        NEXT k
        tmp = 0
      END IF

      IF dc(4) > dc(5) THEN
          tmp = dc(5)
          dc(5) = dc(4)
          dc(4) = tmp
        FOR k = 1 TO 5
          temp$ = sprays$(i, 5, k)
          sprays$(i, 5, k) = sprays$(i, 4, k)
          sprays$(i, 4, k) = temp$
        NEXT k
        tmp = 0
      END IF


    END IF
  NEXT i
  chem$ = ""

'----------------------------------------------------------------------------

' Model 1 - PRE or POST-RAIN APPLICATION MODEL
'

day = 0                               ' day counter set back to zero

DO                                    ' start of loop through the spray diary
  day = day + 1                       ' set to 1st day of season

  IF sprays$(day, 1, 1) <> "" AND rainfall(day) > 0 THEN   ' check for sprays
       FOR i = 1 TO maxnumspraysonday                       '
         chem$ = sprays$(day, i, 1)
         GOSUB selectchem                 ' Identify the fungicides applied
         kickback = VAL(fungicide$(fungicide, 3))  ' get kickback life
         IF maxkickback < kickback THEN     ' get the longest kick back life
            maxkickback = kickback          ' from all 3 sprays
         END IF
       NEXT i
       IF maxkickback = 0 THEN            'Just a protectant therefore
         apptime$(day) = "Before Rain"    'applied before rain
       ELSE
         daysback = 0                     'must be an eradicant so count back
         DO
           daysback = daysback + 1        'checks for marginal or definite infection periods, or rainfall
previously
                                          'assumes growers would respond to a marginal infect period as well
                                          'as a definite one.
           IF infect$(day - daysback) = "y" OR infect$(day - daysback) = "m" OR rainfall(day - daysback) > 0 THEN
             apptime$(day) = "Before Rain" 'Applied to eliminate
             EXIT DO                      'an existing infection
           END IF
                                          'loop back only until either the
                                          'kickback period is exceeded or
                                          'a spray is applied the day before
                                          'as this should have dealt with
                                          'any infections on that day and
                                          'prior to it
           IF day - daysback <= 1 THEN    'So it doesn't look back past the
             EXIT DO                      'start of the file
           END IF
         LOOP WHILE ((daysback <= maxkickback) AND (sprays$(day - (daysback + 1), 1, 1) = "")) AND (day - daysback)
> 1
         IF apptime$(day) = "" THEN       'No infection periods or rain
```

```
          apptime$(day) = "After Rain"     'previously so eradicant must have
        END IF                             'been applied after the rain on the
      END IF                               'day
  ELSE
    apptime$(day) = "n/a"        'Either no spray or no rain
  END IF
LOOP WHILE day < period
'
' End of model 1.1
'
'-----------------------------------------------------------------------------
Residue:  ' label in case this routine needs to be called alone in testing
'
' Model 2 - RESIDUE COVER MODEL
'
'Set some local variables...
'
day = 0

DO
   day = day + 1
   IF cover(day - 1) > 0 THEN
     cover(day) = cover(day - 1) - decayrate
     IF rainfall(day) <> 0 THEN                  'add in the effect of rain
        cover(day) = cover(day) - (cover(day) * ((washoffrate * rainfall(day)) / 100))
     END IF
     IF cover(day) < 0 THEN cover(day) = 0
   ELSE
     cover(day) = 0
   END IF
   IF sprays$(day, 1, 1) <> "" THEN

     chem$ = sprays$(day, 1, 1)                    ' Identify the fungicide.
     GOSUB selectchem
     IF fungicide <> 0 THEN                        ' check if it's a blackspot one

       decisioncover(day) = cover(day)               ' save for a later model
       newdecayrate = VAL(fungicide$(fungicide, 2))
       IF apptime$(day) = "Before Rain" THEN       ' was some of the new cover
         tempcover = 100 - (2.47 * rainfall(day))  ' washed off by rain?
       ELSE
         tempcover = 100                           ' new cover is 100%
       END IF
       newrdc = tempcover / newdecayrate           ' How many days is that?
       IF cover(day) <= 0 THEN
          oldrdc = 0
       ELSE
          oldrdc = CINT(cover(day) / decayrate)    ' How many days has the old
       END IF                                      ' cover got to run...
       IF oldrdc < newrdc THEN                     ' If less than the new cover
          cover(day) = tempcover                   ' then the new cover becomes
          decayrate = newdecayrate                 ' the cover.
       END IF
     END IF
   END IF
LOOP WHILE day < period

' End of Model 2
'
'-----------------------------------------------------------------------------
manage:  ' label in case this routine needs to be called alone in testing
'
' Model 3 - MANAGEMENT ANALYIS MODEL

' some new and reset variables

day = 0                                  ' reset day to 1
fungicide = 0
maximumkickback = 4
maxkickback = 0

DIM eradtype(period)        ' flag to determine which eradication recommendation to put up
DIM risk(period)            ' flag to determine which protectant recommendation to put up
DIM protanalysis$(11)


eradanalysis$(1) = "There were no infection events to be dealt with"
eradanalysis$(2) = "There is an infection event which requires eradication.  It is less than 2 days old so dodine
would be best."
eradanalysis$(3) = "There is an infection event which requires eradication.  It is over 2 days old so a DMI
fungicide (plus protectant) would be best."
eradanalysis$(4) = "There was an infection event but it was eradicated by a previous spray."
eradanalysis$(5) = "There was an infection event but adequate cover existed so further action was not required."

protanalysis$(1) = "Regarding cover, no protectant fungicide would have been required as there was no threat of
rain or infection periods today or tomorrow."
protanalysis$(2) = "Regarding cover, no protectant fungicide would have been required as, although there was threat
of rain today or tomorrow, the estimated cover was greater than 4 days."
protanalysis$(3) = "Regarding cover, no protectant fungicide would have been required, as although the cover was
estimated to last 2-4 days and rain was predicted, it was less than 5mm and only fell for a day."
protanalysis$(4) = "Regarding cover, a protectant fungicide was advisable as cover was less than 2 days and
rainfall was expected today or tomorrow."
protanalysis$(5) = "Regarding cover, a protectant fungicide was advisable as, although cover was likely to last
another 2-4 days, predicted rainfall was greater than 1 day which may have reduced cover enough for an infection."
protanalysis$(6) = "Regarding cover, a protectant fungicide was advisable as, although cover was likely to last
another 2-4 days and predicted rainfall was short, it was heavy and may have reduced cover enough for an
infection."

protanalysis$(7) = "A protectant fungicide was advisable as cover was less than 2 days and rainfall was predicted
today or tomorrow.  However, the dodine suggested as an eradicant, would have given the crop the necessary
protection."
protanalysis$(8) = _
```

```
"A protectant fungicide was advisable as although cover was likely to last another 2-4 days, rainfall was predicted
to be greater than 1 day which may have reduced cover enough for an infection.  However, the dodine suggested as an
eradicant would have given the crop the necessary protection." _

protanalysis$(9) = _
"A protectant fungicide was advisable as although cover was likely to last another 2-4 days and predicted rainfall
was short, it was heavy and so may have reduced cover enough for an infection.  However, the dodine suggested as an
eradicant would have given the crop the necessary protection." _


DO
  day = day + 1                            ' counter
  IF sprays$(day, 1, 1) <> "" THEN            ' check for sprays

                                           ' Step 1 - First, check for an
                                           ' infection period in the past
                                           ' which requires eradication

     FOR backcheck = day - maximumkickback TO day - 1  'go back a few days
       IF backcheck < 1 THEN backcheck = 1

                                                         ' check for infection periods
                                                         ' including marginal ones in
                                                         ' the high risk periods
       IF infect$(backcheck) = "y" OR (day >= beginhighrisk AND day <= endhighrisk AND infect$(backcheck) = "m")
THEN
         infection = 1
       END IF

       IF cover(backcheck) >= minresidue THEN   '
         infection = 0
         eradtype(day) = 5                  ' type 5
       END IF


       IF sprays$(backcheck, 1, 1) <> "" THEN    ' check for sprays which may have
         FOR i = 1 TO maxnumspraysonday       'eradicated existing infections
           chem$ = sprays$(backcheck, i, 1)' Identify the fungicide.
           GOSUB selectchem
           kickback = VAL(fungicide$(fungicide, 3)) ' get kickback life
           IF maxkickback < kickback THEN     ' get the longest kick back life
              maxkickback = kickback          ' from all 3 sprays
           END IF
         NEXT i
         IF dayspassed > 0 AND maxkickback >= dayspassed THEN   ' dayspassed reflects the number
           dayspassed = 0                     ' of days passed since an infect.
           infection = 0
           eradtype(day) = 4                       ' period.  If the kickback reaches
         ELSE                                 ' beyond this, eliminate infection
           IF infection = 1 THEN
             dayspassed = dayspassed + 1      'otherwise if and infection has
           END IF                             'occurred in the past, increment
         END IF
         maxkickback = 0
       ELSE
         IF infection = 1 THEN                ' Similarly, if no sprays went
           dayspassed = dayspassed + 1        ' on increment day
         END IF
       END IF
     NEXT backcheck                           ' check the next day forward

                                             ' Step 2 - was there an infection
                                             ' today?

     IF ((infect$(day) = "y") OR (day >= beginhighrisk AND day <= endhighrisk AND infect$(day) = "m")) AND
(decisioncover(day) < minresidue) AND (apptime$(day) = "After Rain") THEN
         infection = 1                       '  infection period hours before
                                             '  spray decision
     END IF

                                             ' Step 3 - How long ago was the
     IF infection = 1 THEN                   ' infection period?
       SELECT CASE dayspassed
         CASE IS < 2
           eradtype(day) = 2
           dodineused = 1
         CASE IS >= 2
           eradtype(day) = 3
       END SELECT
     ELSE
       eradtype(day) = 1
     END IF

                                            ' Step 4 - Is there a risk of
                                            ' blackspot tomorrow??

     IF rainfall(day + 1) > 0 OR (rainfall(day) > 0 AND apptime$(day) = "Before Rain") THEN
       SELECT CASE decisioncover(day)       ' check on cover

                                            "

                                            'if less then 2 days cover then
                                            'do nothing if dodine used or
                                            'apply protectant if dodine has
                                            'not been used.


          CASE IS <= 25                     ' i.e < 25% (2 days) assuming a decay
            IF dodineused = 1 THEN          ' of 7.5%/day and 10% being risky
              risk(day) = 7                    ' sets the risk type for recommendation
            ELSE
```

```
            risk(day) = 4
          END IF

        CASE 25 TO 40                    '25% to 40% cover (2-4 days)
          IF rainfall(day) > 0 THEN        'if it rains today...
             IF rainfall(day + 1) = 0 THEN   'and does not rain tomorrow...
                IF rainfall(day) > 5 THEN    'and todays rain is heavy
                   IF dodineused = 1 THEN      ' heavy rain, if dodine used then
                      risk(day) = 9             ' ok..otherwise an extra spray needed
                   ELSE
                      risk(day) = 6          'protectant -heavy rain,no rain
                   END IF                    'and insufficient protectant
                ELSE                         'if rain today but light
                   risk(day) = 3             'then protectant adequate light rain,no rain
                END IF
             ELSE                            'if rain tomorrow... (and today remember)
                IF dodineused = 1 THEN       'except if dodine has been used as an eradicant
                   risk(day) = 8             'dodine does job of protectant
                ELSE
                   risk(day) = 5             'protectant -rain,rain
                END IF
             END IF
          ELSE                               'if no rain today....
             IF rainfall(day + 1) > 0 THEN   'but rain tomorrow...
               IF rainfall(day + 1) > 5 THEN 'and rain is heavy...
                 IF dodineused = 1 THEN      ' heavy rain, if dodine used then
                    risk(day) = 9            ' ok..otherwise an extra spray needed
                 ELSE
                    risk(day) = 6            'protectant - no rain,heavy rain
                 END IF
               ELSE                          'if light rain tomorrow...
                 IF rainfall(day + 2) > 0 THEN  'and rain the day after next...
                   IF dodineused = 1 THEN       'except if dodine has been used as an eradicant
                      risk(day) = 8
                   ELSE
                      risk(day) = 5          'protectant - no rain,light rain,rain
                   END IF
                 ELSE                        'if no rain day after tomorrow
                   risk(day) = 3             'no protectant - no rain,light rain,no rain
                 END IF
               END IF
             ELSE                            'no rainfall tomorrow
               risk(day) = 1
             END IF
          END IF
        CASE ELSE                        ' > 4 days cover - do nothing
          risk(day) = 2
      END SELECT
    ELSE                                 ' if there is no risk, do nothing
      risk(day) = 1
    END IF


    dayspassed = 0
    dodineused = 0
    infection = 0                         ' program will move forward to
                                          ' another day

  END IF                                  ' new spray
LOOP WHILE day < period - 1               ' to ensure the program doesn't
                                          ' try to look past the EOF

' finish Model 2.1 -------------------------------------------------
infect:

' Model 3.2 - Exposure to Risk Model
'
DIM exposed(period)                       ' boolean array to hold the days
                                          ' where infection probably occurred
day = 0                                   ' reset to start of season
maximumkickback = 4
fungicide = 0
maxkickback = 0
kickback = 0
infection = 0                             ' flag.  Set to 1 when infection
                                          ' occurs

DO
  day = day + 1                           ' day counter
  IF infect$(day) = "y" OR (day >= beginhighrisk AND day <= endhighrisk AND infect$(day) = "m") THEN '
was there an infection period?
    IF cover(day) < minresidue THEN       ' was cover gone?
      infection = 1                       ' there has been an infection
      IF (period - day) <= maximumkickback THEN
         maximumkickback = (period - day)
      END IF
      FOR i = 0 TO maximumkickback
        IF sprays$(day + i, 1, 1) <> "" THEN   ' check for sprays which may have
          FOR j = 1 TO maxnumspraysonday                  'eradicated infections
            chem$ = sprays$(day + i, j, 1) ' Identify the fungicide.
            GOSUB selectchem
            kickback = VAL(fungicide$(fungicide, 3)) ' get kickback life
            IF maxkickback < kickback THEN     ' get the longest kick back life
               maxkickback = kickback          ' from all 3 sprays
            END IF
          NEXT j
          IF maxkickback >= i THEN
            infection = 0
          END IF
        maxkickback = 0
        END IF
      NEXT i
```

```
      IF infection = 0 THEN
        exposed(day) = 2
      ELSE
        exposed(day) = 1
      END IF
    ELSE                      ' there was cover present
      exposed(day) = 3        ' no infection
    END IF
  END IF
LOOP UNTIL day = period

' End of Model 3.2
'
'-------------------------------------------------------------------------
cost:

'   Model 3.3 - Fungicide cost model

DIM cost(numfungicides)
applycost = 25                  ' cost of applying a spray.  From Beresford
totalapplycost = 0              ' and Manktelow 1984
totalcost = 0
day = 0

DO
  day = day + 1
  IF sprays$(day, 1, 1) <> "" THEN   ' check that there was a spray
                                     ' on that day
    FOR i = 1 TO maxnumspraysonday
      IF sprays$(day, i, 3) = "Blackspot spray" THEN
        chem$ = sprays$(day, i, 1) 'Identify the fungicide.
        GOSUB selectchem
        cost(fungicide) = cost(fungicide) + VAL(sprays$(day, i, 2))
      END IF
    NEXT i
    IF sprays$(day, 1, 3) = "Blackspot spray" THEN
      totalapplycost = totalapplycost + applycost
    END IF
  END IF
LOOP UNTIL day = period

FOR i = 1 TO numfungicides                       ' get the total cost of fungicides
  IF cost(i) <> 0 THEN
    totalcost = totalcost + cost(i)
  END IF
NEXT i

'-------------------------------------------------------------------------

resistance:

'   Model 3.4 - Resistance strategy Model

day = 0
DO
  day = day + 1
  IF (infect$(day) = "y" OR (day >= beginhighrisk AND day <= endhighrisk AND infect$(day) = "m")) AND cover(day) <=
minresidue THEN
    totalinfect = totalinfect + 1
  END IF

  IF sprays$(day, 1, 1) <> "" THEN
    FOR i = 1 TO maxnumspraysonday
      query$ = sprays$(day, i, 1)

      SELECT CASE query$
        CASE "Baycor", "NUSTAR 20DF", "TOPAS 10 WP", "RUBIGAN FLO", "RUBIGAN 12EC", "SYSTHANE 40W", "TOPAS MZ62WP",
"BAYLETON 5DF"' or any other of the DMI sprays
        totaldmi = totaldmi + 1
      CASE ELSE

       END SELECT
      query$ = ""
    NEXT i
  END IF

LOOP UNTIL day = period

' End of Model 3.4

'-------------------------------------------------------------------------

ideal:
'Model 3.5 - Minimum spray strategy model
'This program takes simulated spray diary and weather data, and plans out a
'"good practice" spray program....assuming full weather information is known
'beforehand...also assuming the decay rate model is accurate


DIM fung$(period)
DIM calcover(period)

eradlife = 4         ' eradicant life
day = 1
applyerad = 0
infection = 0
dodinenum = 0
protnum = 0
dminum = 0

decayrate = 10                 ' decay rate of captan
```

```
dodinecost = 34              ' cost of dodine/ha
protectantcost = 30          ' cost of typical protectants
eradicantcost = 50           ' cost of typical DMI's
applycost = 25               ' typical application costs


maxleafwetness = 50          ' can't spray if weather above these values
maxwind = 10                  ' wind run in km (/hr). From Novachem manual
minspraywindow = 3           ' need a 3 hour minimum suitable window.
rainthreshold = 20           ' not worth spraying if 20mm rain going to fall


DO UNTIL day = period        ' start of the period loop

' check if a spray needs applying today due to forcast rain or
' a previous infection period.  If not, go to the next day.

  IF ((infect$(day + 1) = "y" OR (day + 1 >= beginhighrisk AND day + 1 <= endhighrisk AND infect$(day + 1) = "m"))
OR rainfall(day + 1) > 0) OR (applyerad > 0) THEN


' If the answer is yes, then check if sprays CAN be applied.  It might be
' too wet!

    spraywindowexists = 0
    hours = 7               ' start at 7am
    spraywindow = 0
    DO
      IF (hourlyweather(day, 1, hours) < maxleafwetness) AND (hourlyweather(day, 2, hours) < maxwind) AND
hourlyweather(day, 3, hours) = 0 THEN
         spraywindow = spraywindow + 1
      ELSE
         spraywindow = 0
      END IF
      IF spraywindow = minspraywindow THEN
        spraywindowexists = 1              ' spraying can be done
        EXIT DO
      ELSE
      hours = hours + 1
      END IF
    LOOP UNTIL hours = 21

    rainonday = 0
    FOR i = hours TO 24                    ' How much rain occurred after the spray window?
      rainonday = rainonday + hourlyweather(day, 3, i)
    NEXT i
    FOR i = 1 TO 6                         ' until 6am the next day
      rainonday = rainonday + hourlyweather(day + 1, 3, i)
    NEXT i

    IF spraywindowexists = 0 OR rainfall(day + 1) > rainthreshold OR rainonday > rainthreshold THEN

' if there is no spray window, check for an unprotected infection period.  If this has
' occurred, then start the kickback counter..

       IF infection = 1 THEN
        applyerad = applyerad + 1
      ELSEIF ((infect$(day + 1) = "y" OR (day + 1 >= beginhighrisk AND day + 1 <= endhighrisk AND infect$(day + 1)
= "m")) AND calcover(day + 1) < minresidue) THEN
          infection = 1
          applyerad = applyerad + 1  'boolean operation to indicate that an eradicant must be appied..
      END IF
      GOTO nextday  ' Then go to the next day.


' ok....we can and should apply a spray today..

    ELSE

'put on an eradicant if we have to...

      IF (applyerad > 0) AND (applyerad <= 3) THEN
        fung$(day) = "dodine"
        dodinenum = dodinenum + 1
        applyerad = 0
        infection = 0
      ELSEIF (applyerad > 3) AND (applyerad <= 5) THEN
        fung$(day) = "DMI fungicide and protectant"
        applyerad = 0
        infection = 0
        dminum = dminum + 1
      ELSEIF applyerad > 5 THEN
        fung$(day) = "missed ip"
        applyerad = 0
        infection = 0
      END IF

  ' Work out the protectant life.
  ' If an eradicant is applied, a protectant should be applied too
  ' assume the standard protectant life of 7 days...

      IF fung$(day) = "" THEN
        fung$(day) = "protectant"
        protnum = protnum + 1              'add up the number of sprays applied
      END IF
      td = 0                               ' this day is today
      DO
        IF day + td > period THEN
          EXIT DO
        ELSEIF td = 0 THEN
          calcover(day) = 100 - (washoffrate * rainonday) ' takes into account the washoff from rain after the
spray window
```

```
        ELSE
          calcover(day + td) = calcover((day + td) - 1) - decayrate
          IF rainfall(day + td) <> 0 THEN
            calcover(day + td) = calcover(day + td) - (calcover(day + td) * ((washoffrate * rainfall(day + td)) /
100))
          END IF
          IF calcover(day + td) < 0 THEN
            calcover(day + td) = 0
          END IF
          IF calcover(day + td) < minresidue THEN
            EXIT DO
          END IF
        END IF
        td = td + 1
      LOOP

      IF td = 1 THEN                  ' jump the days ahead to after the cover period
        day = day + (td - 1)          ' if rain is enough to completely was off cover
      ELSE                            ' then go to the next day
        day = (day + (td - 2))        ' otherwise go to 2 days before the end of the
      END IF                          ' cover..day=day+1 will take us to the day
      td = 0                          ' before cover runs out...
    END IF
  END IF

nextday:  ' jump to here if no infection periods or rain the next day..

  day = day + 1
LOOP 'end of the period loop

' End of Model 3.5
'---------------------------------------------------------------------------
'Model 5 - Report Model
'
report:
'SCREEN 12
'WIDTH 80, 43
CLS
OPEN "d:\datafi~1\research\phd\asessor\program\output.rtf" FOR OUTPUT AS 1   ' open file to receive output
WIDTH #1, 130
PRINT " Printing...."
PRINT #1, "SPRAYCHECK......Report Sheet"
PRINT #1, "----------------------------"
PRINT #1,
PRINT #1, Orchard$; "  "; "Using Day infection events only until Nov 30th"
Orchard$ = ""
PRINT #1,
PRINT #1, TIME$, DATE$
PRINT #1,


seasonsummary:

day = 0
PRINT #1, "DAYS"; TAB(7); "DATE"; TAB(15); "SPRAYS (RATE/100L, WATER RATE/HA, PRICE)"; TAB(70); " RAIN"; TAB(78);
"I.P?"; TAB(85); "% COVER"; TAB(96); "Pre or Post Rain"
PRINT #1, "-----------------------------------------------------------------------  ----  --------  ---------
-------"
PRINT #1,

FOR day = 1 TO period
  PRINT #1, day; " "; diarydate$(day); " ";
  FOR i = 1 TO maxnumspraysonday
    IF sprays$(day, i, 1) = "" THEN
      PRINT #1, "  ";
    ELSE
      PRINT #1, sprays$(day, i, 1); " "; sprays$(day, i, 4); " "; sprays$(day, i, 5); " "; sprays$(day, i, 2); " ";
    END IF
  NEXT i

  PRINT #1, TAB(70); USING "##.#"; rainfall(day);
  PRINT #1, TAB(78); infect$(day);
  PRINT #1, TAB(86); CINT(cover(day));
  PRINT #1, TAB(96); apptime$(day)
NEXT day
PRINT #1,
PRINT #1,
PRINT #1, "The following sprays were used and their cost calculated..."
FOR i = 1 TO numfungicides
  IF cost(i) <> 0 THEN
    PRINT #1, fungicide$(i, 1), cost(i)
  END IF
NEXT i
PRINT #1, "Fungicide product cost for season thus far...$"; totalcost
PRINT #1, "Application costs = $"; totalapplycost
PRINT #1, "Approx total costs/ha = $"; totalcost + totalapplycost
PRINT #1,
PRINT #1, "total infection periods requiring eradication = "; totalinfect
PRINT #1, "total DMI sprays = "; totaldmi
PRINT #1,
IF totaldmi > 6 THEN
  PRINT #1, "Resistance strategy exceeded"
ELSE
  PRINT #1, "Resistance strategy not exceeded"
END IF
PRINT #1, CHR$(12);

sprayanalysis:
PRINT #1, "Spray Decision Analyis"
PRINT #1, "----------------------"
PRINT #1,
```

```
FOR day = 1 TO period                   ' only pick days where blackspot spray occurred
  IF (eradtype(day) > 0) AND (sprays$(day, 1, 3) = "Blackspot spray") THEN
    PRINT #1, "Analysis of the spray decision on day "; day
    PRINT #1, "The following fungicides were applied: ";
    PRINT #1,
    FOR i = 1 TO maxnumspraysonday
      IF sprays$(day, i, 1) > "" THEN
        chem$ = sprays$(day, i, 1)
        GOSUB selectchem
        IF fungicide > 0 THEN              'just prints fungicides
          PRINT #1, sprays$(day, i, 1);
          IF VAL(fungicide$(fungicide, 3)) = 0 THEN
            PRINT #1, "- a standard protectant."
          ELSEIF (VAL(fungicide$(fungicide, 3)) >= 4) AND (VAL(fungicide$(fungicide, 2)) >= 50) THEN
            PRINT #1, "- a DMI fungicide with a 4 day reachback period and little protectant value."
          ELSEIF (VAL(fungicide$(fungicide, 3)) = 2 OR VAL(fungicide$(fungicide, 3)) = 1) AND
VAL(fungicide$(fungicide, 2)) >= 7 THEN
            PRINT #1, "- a protectant with a short reach back period."
          ELSEIF (VAL(fungicide$(fungicide, 3)) <= 2) AND (VAL(fungicide$(fungicide, 2)) = 50) THEN
            PRINT #1, " - an eradicant with a short reach back period"
          ELSEIF (VAL(fungicide$(fungicide, 3)) >= 4) AND (VAL(fungicide$(fungicide, 2)) >= 7) THEN
            PRINT #1, " - a DMI fungicide with a 4 day reachback period and moderate protectant activity"
          ELSE
            PRINT #1, "Unable to classify fungicide"
          END IF
        END IF
      END IF
    NEXT i
    PRINT #1,
    PRINT #1, "Recommendation:"
    PRINT #1, eradanalysis$(eradtype(day))
  END IF

  IF risk(day) > 0 AND (sprays$(day, 1, 3) = "Blackspot spray") THEN
    PRINT #1, protanalysis$(risk(day))
  IF eradtype(day) = 3 THEN PRINT #1, "However, a protectant would have been added anyway, in order to adhere to
the fungicide resistance strategy."
    PRINT #1,
    PRINT #1,
END IF
NEXT day
PRINT #1, CHR$(12);

infectanalysis:
PRINT #1, "Infection Period Analysis"
PRINT #1, "-------------------------"
PRINT #1,
FOR day = 1 TO period
  SELECT CASE exposed(day)
    CASE 1
      PRINT #1, "There was an infection period on day "; day: PRINT #1, "The crop was not protected by fungicide
cover and the infection was not eradicated!  Disease may have resulted."
      PRINT #1,
    CASE 2
      PRINT #1, "There was an infection period on day "; day: PRINT #1, "Any infections are likely to have been
eradicated with a later systemic fungicide application."
      PRINT #1,
    CASE 3
      PRINT #1, "There was an infection period on day "; day: PRINT #1, "The crop was protected with fungicide
cover."
      PRINT #1,
    CASE ELSE
      null = 0
  END SELECT
NEXT day
PRINT #1, CHR$(12);

idealspray:
PRINT #1, "Minimum Spray Strategy"
PRINT #1, "----------------------"
PRINT #1,
PRINT #1, "Day", "Date", "Rainfall", "Leafwet", "Wind", "Inft. events", "Cover", "Fungicides to add"
PRINT #1, "---", "----", "--------", "-------", "----", "------------", "-----", "-----------------"
PRINT #1,
day = 1
DO UNTIL day > period
PRINT #1, day, diarydate$(day),
PRINT #1, USING "##.#"; rainfall(day); : PRINT #1, , ;
PRINT #1, USING "###.#"; leafwet(day); : PRINT #1, , ;
PRINT #1, USING "###.#"; wind(day); : PRINT #1, , ;
PRINT #1, infect$(day), CINT(calcover(day)), fung$(day)
day = day + 1
LOOP
PRINT #1,
PRINT #1, "Total number of protectant sprays applied = "; protnum
PRINT #1, "Total number of DMI eradicant sprays applied = "; dminum
PRINT #1, "Number of dodine sprays applied = "; dodinenum
PRINT #1, 'cost worked out assuming all eradicants are applied with protectants....
PRINT #1, "Total cost = $"; (protnum * (protectantcost + applycost)) + (dodinenum * (dodinecost + applycost)) +
(dminum * eradicantcost)
PRINT #1, CHR$(12)
GOTO finish
'
'
'Subroutines
'
selectchem:
  SELECT CASE chem$
    CASE "Baycor"
      fungicide = 1
    CASE "Bavistin"
      fungicide = 2
```

```
    CASE "Benlate"
      fungicide = 3
    CASE "BLEND 79"
      fungicide = 4
    CASE "CAPTAN 80 WP"
      fungicide = 5
    CASE "Copper oxychloride"
      fungicide = 6
    CASE "Cupric hydroxide"
      fungicide = 7
    CASE "Delan"
      fungicide = 8
    CASE "DITHANE M45"
      fungicide = 9
    CASE "DODINE 400"
      fungicide = 10
    CASE "Duo"
      fungicide = 11
    CASE "MANZATE 200"
      fungicide = 12
    CASE "Mizar"
      fungicide = 13
    CASE "NUSTAR 20DF"
      fungicide = 14
    CASE "ORTHOCIDE 48F"
      fungicide = 15
    CASE "PALLINAL"
      fungicide = 16
    CASE "POLYRAM DF"
      fungicide = 17
    CASE "RUBIGAN FLO"
      fungicide = 18
    CASE "Saprol"
      fungicide = 19
    CASE "SYLLIT PLUS"
      fungicide = 20
    CASE "SYSTHANE 40W"
      fungicide = 21
    CASE "THIRAM 40F"
      fungicide = 22
    CASE "TOPAS MZ62WP"
      fungicide = 23
    CASE "Topsin"
      fungicide = 24
    CASE "CAPTOR 480 FL"
      fungicide = 25
    CASE "SYLLIT 40S"
      fungicide = 26
    CASE "BLEND 88"
      fungicide = 27
    CASE "RUBIGAN 12EC"
      fungicide = 28
    CASE "ORTHOCIDE 80W"
      fungicide = 29
    CASE "TOPAS 10 WP"
      fungicide = 30

    CASE ELSE
      fungicide = 0
  END SELECT
RETURN

finish:
CLOSE all
END
'end of program
```

APPENDIX VI

EXAMPLE INPUT/OUTPUT FILES IN SPRAYCHECK

(a) SPRAY DIARY DATA AS INPUT TO SPRAYCHECK

This data was taken from a grower's electronic diary (held in a SPRAYVIEW database in Orchard 2000). Note the data only includes single applications or tank mixes that contain a pesticide specifically for black spot. All other applications were stripped out prior to being fed into the model.

Data for each pesticide includes date applied, trade name, rate, water rate and cost per hectare. Note the cost per hectare does not include application costs.

```
Grower 1, Region 1

17/09/94    SYLLIT PLUS             80    1900   $27.16
23/09/94    DIAZINON 50W            100   1900   $41.10
23/09/94    SYLLIT PLUS             80    1900   $27.16
3/10/94     SYLLIT PLUS             80    1900   $27.16
14/10/94    SYLLIT PLUS             80    1900   $27.16
28/10/94    NUSTAR 20DF             10    2200   $59.16
28/10/94    POLYRAM DF              100   2200   $25.81
3/11/94     AZINPHOS METHYL 50 W    100   2200   $87.36
3/11/94     POLYRAM DF              125   2200   $32.26
26/11/94    BASUDIN 50WP            100   2200   $39.51
26/11/94    NUSTAR 20DF             10    2200   $59.16
3/12/94     LORSBAN 50W             50    2200   $50.85
3/12/94     SYLLIT PLUS             80    2200   $31.45
30/12/94    AZINPHOS METHYL 50 W    75    2200   $65.52
30/12/94    BAYLETON 5DF            50    2200   $54.76
30/12/94    SYLLIT PLUS             80    2200   $31.45
13/01/95    AZINPHOS METHYL 50 W    75    2200   $65.52
13/01/95    SYLLIT 40S              80    2200   $32.54
29/01/95    AZINPHOS METHYL 50 W    75    2200   $65.52
29/01/95    SYLLIT 40S              80    2200   $32.54
14/02/95    AZINPHOS METHYL 50 W    75    2200   $65.52
14/02/95    SYLLIT 40S              80    2200   $32.54
24/02/95    AZINPHOS METHYL 50 W    75    2200   $65.52
24/02/95    SYLLIT 40S              40    2200   $16.27
```

APPENDIX VI (b)

METEOROLOGICAL DATA SUPPLIED FOR SPRAYCHECK EVALUATION

Data includes hourly values for leafwetness, windspeed and rainfall. This is a small segment of a complete season's file

Date	hour	Leafwet %	windsp km/hr	rainfall mm
"16/09/94	0100"	2.46	9.38	0.00
"16/09/94	0200"	2.46	5.80	0.00
"16/09/94	0300"	2.46	1.53	0.00
"16/09/94	0400"	20.41	1.53	0.00
"16/09/94	0500"	20.41	3.21	0.00
"16/09/94	0600"	30.91	6.16	0.00
"16/09/94	0700"	30.91	4.77	0.00
"16/09/94	0800"	51.81	6.36	0.00
"16/09/94	0900"	0.54	9.72	0.00
"16/09/94	1000"	0.54	12.37	0.00
"16/09/94	1100"	0.54	15.58	0.00
"16/09/94	1200"	0.54	15.58	0.00
"16/09/94	1300"	0.54	16.86	0.00
"16/09/94	1400"	0.54	18.70	0.00
"16/09/94	1500"	0.54	15.92	0.00
"16/09/94	1600"	0.54	15.92	0.00
"16/09/94	1700"	57.13	15.92	0.20
"16/09/94	1800"	97.20	15.92	0.10
"16/09/94	1900"	97.20	14.46	0.10
"16/09/94	2000"	97.20	14.46	0.00
"16/09/94	2100"	97.20	12.86	0.00
"16/09/94	2200"	97.20	8.81	0.00
"16/09/94	2300"	97.20	6.96	0.00
"16/09/94	2400"	76.70	9.45	0.00
"17/09/94	0100"	92.79	7.48	0.30
"17/09/94	0200"	92.79	1.83	0.00
"17/09/94	0300"	92.79	1.83	0.00
"17/09/94	0400"	92.79	0.22	0.10
"17/09/94	0500"	92.79	0.22	0.00
"17/09/94	0600"	92.79	0.22	0.00
"17/09/94	0700"	92.79	0.22	0.00
"17/09/94	0800"	92.79	4.33	0.00
"17/09/94	0900"	92.79	2.94	0.00
"17/09/94	1000"	0.02	2.94	0.00
"17/09/94	1100"	0.02	2.94	0.00
"17/09/94	1200"	0.02	7.08	0.00
"17/09/94	1300"	0.02	9.45	0.00
"17/09/94	1400"	0.02	12.23	0.00
"17/09/94	1500"	0.02	12.24	0.00
"17/09/94	1600"	0.02	9.45	0.00
"17/09/94	1700"	0.02	8.43	0.00
"17/09/94	1800"	0.02	5.26	0.00
"17/09/94	1900"	44.51	3.57	0.00
"17/09/94	2000"	95.50	0.09	0.00

APPENDIX VI (c)

EXAMPLE DAYTIME INFECTION PERIODS

A linear file consisting of day number followed by infection event value for that day where:

Y=definite infection event,
M= possible infection period
N=no infection event.

Data obtained manually from SPOTCHECK model in Orchard 2000, for the 1994 season, at the Havelock North monitoring station, Hastings.

Day	Infection event	Day	Infection event	Day	Infection event	Day	Infection event
1	Y	24	Y	47	Y	70	N
2	Y	25	Y	48	N	71	N
3	N	26	N	49	N	72	N
4	N	27	N	50	N	73	N
5	N	28	N	51	N	74	N
6	N	29	N	52	N	75	Y
7	N	30	N	53	M	76	Y
8	N	31	N	54	N	77	Y
9	N	32	N	55	N	78	M
10	N	33	N	56	N	79	N
11	N	34	N	57	N	80	N
12	N	35	N	58	N	81	N
13	Y	36	N	59	N	82	N
14	Y	37	N	60	N	83	N
15	N	38	N	61	N	84	N
16	N	39	N	62	N	85	Y
17	N	40	N	63	N	86	Y
18	N	41	N	64	N	87	N
19	Y	42	M	65	N	88	M
20	N	43	N	66	N	89	M
21	N	44	N	67	N	90	N
22	N	45	N	68	N		
23	N	46	Y	69	N		

APPENDIX VI (d)

SPRAYCHECK MODEL OUTPUT

Printed output from the draft program, which is used to check sub-model analysis. The report is divided into the following sections:

1. A daily summary, showing applications, rainfall (in mm), infection periods, % estimated cover and whether pesticide application on a day where rainfall occurred was post-, or pre- the rain.

2. Spray decision analysis, where each spray decision date was evaluated.

3. Infection period analysis, where the model assesses whether an infection event may have resulted in infection of the crop

4. Minimum spray strategy, where the model plans out a theoretical "minimum blackspot spray program" based on weather data.

SPRAYCHECK......Report Sheet

Grower 1 - Location 1   Using Day infection events only until Nov 30th

DAYS	DATE	SPRAYS (RATE/100L, WATER RATE/HA, PRICE)	RAIN	I.P?	% COVER	Pre or Post Rain
1	16/09/94		0.8	y	0	n/a
2	17/09/94	SYLLIT PLUS 80 1900 27.1	0.0	y	100	n/a
3	18/09/94		0.1	n	90	n/a
4	19/09/94		0.0	n	80	n/a
5	20/09/94		4.9	n	61	n/a
6	21/09/94		0.0	n	51	n/a
7	22/09/94		0.0	n	41	n/a
8	23/09/94	SYLLIT PLUS 80 1900 27.1 DIAZINON 50W 100 1900 41.	0.0	n	100	n/a
9	24/09/94		0.0	n	90	n/a
10	25/09/94		0.0	n	80	n/a
11	26/09/94		3.5	n	64	n/a
12	27/09/94		0.0	n	54	n/a
13	28/09/94		2.8	y	41	n/a
14	29/09/94		0.0	y	31	n/a
15	30/09/94		0.0	n	21	n/a
16	1/10/94		0.0	n	11	n/a
17	2/10/94		0.9	n	1	n/a
18	3/10/94	SYLLIT PLUS 80 1900 27.1	0.0	n	100	n/a
19	4/10/94		1.1	y	88	n/a
20	5/10/94		0.0	n	78	n/a
21	6/10/94		0.0	n	68	n/a
22	7/10/94		0.0	n	58	n/a
23	8/10/94		0.0	n	48	n/a
24	9/10/94		1.1	y	37	n/a
25	10/10/94		0.1	y	26	n/a
26	11/10/94		0.0	n	16	n/a
27	12/10/94		0.0	n	6	n/a
28	13/10/94		0.0	n	0	n/a
29	14/10/94	SYLLIT PLUS 80 1900 27.1	8.7	n	100	After Rain
30	15/10/94		2.3	n	85	n/a
31	16/10/94		0.0	n	75	n/a
32	17/10/94		0.0	n	65	n/a
33	18/10/94		0.0	n	55	n/a
34	19/10/94		0.0	n	45	n/a
35	20/10/94		0.0	n	35	n/a
36	21/10/94		0.0	n	25	n/a
37	22/10/94		0.0	n	15	n/a
38	23/10/94		0.0	n	5	n/a
39	24/10/94		0.0	n	0	n/a
40	25/10/94		1.0	n	0	n/a
41	26/10/94		1.1	n	0	n/a
42	27/10/94		0.1	m	0	n/a
43	28/10/94	NUSTAR 20DF 10 2200 59.1 POLYRAM DF 100 2200 25.8	0.0	n	100	n/a
44	29/10/94		0.0	n	90	n/a
45	30/10/94		0.0	n	80	n/a
46	31/10/94		6.3	y	59	n/a
47	1/11/94		1.7	y	47	n/a
48	2/11/94		0.0	n	37	n/a
49	3/11/94	POLYRAM DF 125 2200 32.2 AZINPHOS METHYL 50 W 100 2200 87.3	0.0	n	100	n/a
50	4/11/94		0.0	n	90	n/a
51	5/11/94		0.0	n	80	n/a
52	6/11/94		0.5	n	69	n/a
53	7/11/94		1.2	m	57	n/a
54	8/11/94		0.0	n	47	n/a
55	9/11/94		0.0	n	37	n/a
56	10/11/94		0.0	n	27	n/a
57	11/11/94		0.0	n	17	n/a
58	12/11/94		0.0	n	7	n/a
59	13/11/94		0.0	n	0	n/a
60	14/11/94		0.0	n	0	n/a
61	15/11/94		0.0	n	0	n/a
62	16/11/94		1.7	n	0	n/a
63	17/11/94		0.0	n	0	n/a
64	18/11/94		0.0	n	0	n/a
65	19/11/94		0.5	n	0	n/a
66	20/11/94		0.0	n	0	n/a
67	21/11/94		0.0	n	0	n/a
68	22/11/94		0.0	n	0	n/a
69	23/11/94		0.0	n	0	n/a
70	24/11/94		0.0	n	0	n/a
71	25/11/94		0.0	n	0	n/a
72	26/11/94	NUSTAR 20DF 10 2200 59.1 BASUDIN 50WP 100 2200 39	0.0	n	100	n/a
73	27/11/94		0.0	n	90	n/a
74	28/11/94		0.0	n	80	n/a
75	29/11/94		0.8	y	69	n/a
76	30/11/94		1.2	y	57	n/a
77	1/12/94		0.0	y	47	n/a
78	2/12/94		0.0	m	37	n/a
79	3/12/94	SYLLIT PLUS 80 2200 31.4 LORSBAN 50W 50 2200 50.8	0.0	n	100	n/a
80	4/12/94		1.8	n	86	n/a
81	5/12/94		0.0	n	76	n/a
82	6/12/94		0.0	n	66	n/a
83	7/12/94		0.0	n	56	n/a
84	8/12/94		0.0	n	46	n/a
85	9/12/94		0.0	y	36	n/a
86	10/12/94		0.5	y	26	n/a
87	11/12/94		0.0	n	16	n/a
88	12/12/94		0.0	m	6	n/a
89	13/12/94		0.0	m	0	n/a
90	14/12/94		0.0	n	0	n/a

The following sprays were used and their cost calculated...

```
NUSTAR 20DF    118.2
POLYRAM DF     58
SYLLIT PLUS    139.8
Fungicide product cost for season thus far...$ 316
Application costs = $ 200
Total costs/ha = $ 516

total infection periods requiring eradication =  2
total DMI sprays =  2

Resistance strategy not exceeded



Spray Decision Analyis
----------------------

Analysis of the spray decision on day  2
The following fungicides were applied:
SYLLIT PLUS- a protectant with a short reach back period.

Recommendation:
There is an infection event which requires eradication.  It is less than 2 days old so dodine would be best.
A protectant fungicide was advisable as cover was less than 2 days and rainfall was predicted today or tomorrow.
However, the dodine suggested as an eradicant, would have given the crop the necessary protection.


Analysis of the spray decision on day  8
The following fungicides were applied:
SYLLIT PLUS- a protectant with a short reach back period.

Recommendation:
There were no infection events to be dealt with
Regarding cover, no protectant fungicide would have been required as there was no threat of rain or infection
periods today or tomorrow.


Analysis of the spray decision on day  18
The following fungicides were applied:
SYLLIT PLUS- a protectant with a short reach back period.

Recommendation:
There were no infection events to be dealt with
Regarding cover, a protectant fungicide was advisable as cover was less than 2 days and rainfall was expected today
or tomorrow.


Analysis of the spray decision on day  29
The following fungicides were applied:
SYLLIT PLUS- a protectant with a short reach back period.

Recommendation:
There were no infection events to be dealt with
Regarding cover, a protectant fungicide was advisable as cover was less than 2 days and rainfall was expected today
or tomorrow.


Analysis of the spray decision on day  43
The following fungicides were applied:
NUSTAR 20DF - a DMI fungicide with a 4 day reachback period and moderate protectant activity
POLYRAM DF- a standard protectant.

Recommendation:
There is an infection event which requires eradication.  It is less than 2 days old so dodine would be best.
Regarding cover, no protectant fungicide would have been required as there was no threat of rain or infection
periods today or tomorrow.


Analysis of the spray decision on day  49
The following fungicides were applied:
POLYRAM DF- a standard protectant.

Recommendation:
There were no infection events to be dealt with
Regarding cover, no protectant fungicide would have been required as there was no threat of rain or infection
periods today or tomorrow.


Analysis of the spray decision on day  72
The following fungicides were applied:
NUSTAR 20DF - a DMI fungicide with a 4 day reachback period and moderate protectant activity

Recommendation:
There were no infection events to be dealt with
Regarding cover, no protectant fungicide would have been required as there was no threat of rain or infection
periods today or tomorrow.


Analysis of the spray decision on day  79
The following fungicides were applied:
SYLLIT PLUS- a protectant with a short reach back period.

Recommendation:
There were no infection events to be dealt with
Regarding cover, no protectant fungicide would have been required, as although the cover was estimated to last 2-4
days and rain was predicted, it was less than 5mm and only fell for a day.
```

Infection Period Analysis

There was an infection period on day 1
Any infections are likely to have been eradicated with a later systemic fungicide application.

There was an infection period on day 2
The crop was protected with fungicide cover.

There was an infection period on day 13
The crop was protected with fungicide cover.

There was an infection period on day 14
The crop was protected with fungicide cover.

There was an infection period on day 19
The crop was protected with fungicide cover.

There was an infection period on day 24
The crop was protected with fungicide cover.

There was an infection period on day 25
The crop was protected with fungicide cover.

There was an infection period on day 42
Any infections are likely to have been eradicated with a later systemic fungicide application.

There was an infection period on day 46
The crop was protected with fungicide cover.

There was an infection period on day 47
The crop was protected with fungicide cover.

There was an infection period on day 53
The crop was protected with fungicide cover.

There was an infection period on day 75
The crop was protected with fungicide cover.

There was an infection period on day 76
The crop was protected with fungicide cover.

There was an infection period on day 77
The crop was protected with fungicide cover.

There was an infection period on day 85
The crop was protected with fungicide cover.

There was an infection period on day 86
The crop was protected with fungicide cover.

Minimum Spray Strategy

Day	Date	Rainfall	Leafwet	Wind	Inft. events	Cover	Fungicides to add
1	16/09/94	0.8	36.8	10.8	y	0	
2	17/09/94	0.0	56.6	4.0	y	100	dodine
3	18/09/94	0.1	41.9	2.4	n	90	
4	19/09/94	0.0	38.8	2.8	n	80	
5	20/09/94	4.9	31.9	8.6	n	61	
6	21/09/94	0.0	26.3	7.4	n	51	
7	22/09/94	0.0	0.4	8.4	n	41	
8	23/09/94	0.0	2.3	11.3	n	31	
9	24/09/94	0.0	24.9	2.9	n	21	
10	25/09/94	0.0	32.3	7.1	n	11	
11	26/09/94	3.5	17.7	5.2	n	0	
12	27/09/94	0.0	39.4	2.6	n	100	protectant
13	28/09/94	2.8	58.0	6.6	y	84	
14	29/09/94	0.0	34.1	10.2	y	74	
15	30/09/94	0.0	0.4	13.3	n	64	
16	1/10/94	0.0	12.1	7.6	n	54	
17	2/10/94	0.9	64.6	7.8	n	43	
18	3/10/94	0.0	31.3	4.4	n	33	
19	4/10/94	1.1	70.4	7.4	y	22	
20	5/10/94	0.0	42.7	4.1	n	12	
21	6/10/94	0.0	43.9	4.9	n	0	
22	7/10/94	0.0	16.2	6.1	n	0	
23	8/10/94	0.0	40.4	4.1	n	100	protectant
24	9/10/94	1.1	42.7	6.4	y	88	
25	10/10/94	0.1	28.2	12.6	y	77	
26	11/10/94	0.0	16.8	9.7	n	67	
27	12/10/94	0.0	0.6	9.6	n	57	
28	13/10/94	0.0	9.3	5.9	n	47	
29	14/10/94	8.7	73.5	7.6	n	29	
30	15/10/94	2.3	14.7	9.9	n	18	
31	16/10/94	0.0	13.6	9.7	n	8	
32	17/10/94	0.0	41.4	4.3	n	0	
33	18/10/94	0.0	26.7	13.5	n	0	
34	19/10/94	0.0	3.9	8.1	n	0	
35	20/10/94	0.0	30.4	5.9	n	0	
36	21/10/94	0.0	42.9	8.2	n	0	
37	22/10/94	0.0	43.3	4.0	n	0	
38	23/10/94	0.0	48.4	4.6	n	0	
39	24/10/94	0.0	45.7	6.5	n	0	
40	25/10/94	1.0	56.1	7.3	n	0	
41	26/10/94	1.1	55.2	10.0	n	0	
42	27/10/94	0.1	65.1	5.5	m	100	dodine
43	28/10/94	0.0	33.0	3.3	n	90	
44	29/10/94	0.0	50.5	3.7	n	80	
45	30/10/94	0.0	46.1	2.9	n	70	
46	31/10/94	6.3	40.9	7.8	y	51	
47	1/11/94	1.7	68.8	10.3	y	39	
48	2/11/94	0.0	11.2	6.7	n	29	
49	3/11/94	0.0	38.3	3.8	n	19	
50	4/11/94	0.0	41.1	3.0	n	9	
51	5/11/94	0.0	35.9	7.3	n	0	
52	6/11/94	0.5	23.1	11.1	n	0	
53	7/11/94	1.2	31.7	11.6	m	100	dodine
54	8/11/94	0.0	0.4	16.4	n	90	
55	9/11/94	0.0	0.8	11.9	n	80	
56	10/11/94	0.0	1.0	9.7	n	70	
57	11/11/94	0.0	9.6	6.8	n	60	
58	12/11/94	0.0	29.2	9.5	n	50	
59	13/11/94	0.0	14.2	5.4	n	40	
60	14/11/94	0.0	-0.0	10.2	n	30	
61	15/11/94	0.0	-0.0	10.0	n	100	protectant
62	16/11/94	1.7	13.3	10.3	n	86	
63	17/11/94	0.0	27.5	6.4	n	76	
64	18/11/94	0.0	10.7	7.2	n	66	
65	19/11/94	0.5	15.6	10.5	n	56	
66	20/11/94	0.0	39.3	3.8	n	46	
67	21/11/94	0.0	12.7	9.3	n	36	
68	22/11/94	0.0	-0.0	14.5	n	26	
69	23/11/94	0.0	0.0	13.0	n	16	
70	24/11/94	0.0	3.1	9.7	n	6	
71	25/11/94	0.0	24.3	4.6	n	0	
72	26/11/94	0.0	30.1	4.2	n	0	
73	27/11/94	0.0	35.6	3.2	n	0	
74	28/11/94	0.0	40.8	2.5	n	100	protectant
75	29/11/94	0.8	49.5	4.5	y	88	
76	30/11/94	1.2	66.4	3.7	y	76	
77	1/12/94	0.0	35.9	5.0	y	66	
78	2/12/94	0.0	30.7	3.8	m	56	
79	3/12/94	0.0	5.4	4.2	n	46	
80	4/12/94	1.8	48.0	5.3	n	34	
81	5/12/94	0.0	29.7	2.6	n	24	
82	6/12/94	0.0	3.2	9.5	n	14	
83	7/12/94	0.0	24.7	3.4	n	0	
84	8/12/94	0.0	20.2	4.4	n	100	protectant
85	9/12/94	0.0	3.9	7.7	y	90	
86	10/12/94	0.5	56.9	1.7	y	79	
87	11/12/94	0.0	17.8	3.8	n	69	
88	12/12/94	0.0	23.6	3.1	m	59	
89	13/12/94	0.0	30.8	5.6	m	49	
90	14/12/94	0.0	0.0	0.0	n	39	

Total number of protectant sprays applied = 5
Total number of DMI eradicant sprays applied = 0
Number of dodine sprays applied = 3

Approximate total cost/ha = $ 452

APPENDIX VII

SPRAYCHECK EXPERT VALIDATION SHEET

The following two pages show an example of the validation sheets given to the experts in order to assess the SPRAYCHECK model. Experts were asked to consider each spray day at a time, and answer the questions posed.

The questions related to the timing of the spray, not that particular material used by the grower that day. However, the fungicide used on a particular day was a consideration when evaluating the following spray date.

SPRAYCHECK......Expert Assessment sheet

Grower 1 - Location 1 Using Day infection events only until Nov 30th

With regard to the spray date in bold, in your opinion:

(Answer 2 and 3 only if you answered "yes" to 1)

(Answer 4 only if you did not answered 3)

(n.b. I.P. = infection period. y=definite, m=marginal, n=none recorded)

GROWTH STAGE	DAYS DATE	SPRAYS (RATE/100L, WATER RATE/HA)	RAIN in mm	I.P.?	1. Would the crop have become infected between the last spray and this date ? (if yes answer 2, if no go to 4)	2. If yes, is eradication possible? (if yes answer 3, if no go to 4)	3. If eradication is possible, tick the best option (assume DMI is mixed with protectant)	4. Would a protectant fungicide application be needed today, or could it have been put off until at least tomorrow? (assume rainfall which occurred was forecast, but ignore future infection periods. Base the decision on rain over today and tomorrow and estimated cover)
bud break 10/9	16/09/94		0.8	y				
	17/09/94	SYLLIT PLUS 80 1900	0.0	y				
	18/09/94		0.1	n				
	19/09/94		0.0	n				
	20/09/94		4.9	n				
	21/09/94		0.0	n				
	22/09/94		0.0	n				
	23/09/94	SYLLIT PLUS 80	0.0	n	☐ Yes ☐ No	☐ Yes ☐ No	☐dodine ☐ DMI	☐ **must** spray today ☐ could wait until tomorrow
	24/09/94		0.0	n				
	25/09/94		0.0	n				
	26/09/94		3.5	n				
	27/09/94		0.0	n				
	28/09/94		2.8	y				
	29/09/94		0.0	y				
	30/09/94		0.0	n				
	1/10/94		0.0	n				
full	2/10/94		0.9	n				
bloom	**3/10/94**	SYLLIT PLUS 80 1900	0.0	n	☐ Yes ☐ No	☐ Yes ☐ No	☐dodine ☐ DMI	☐ **must** spray today ☐ could wait until tomorrow
	4/10/94		1.1	y				
	5/10/94		0.0	n				
	6/10/94		0.0	n				
	7/10/94		0.0	n				
	8/10/94		0.0	n				
	9/10/94		1.1	y				
	10/10/94		0.1	y				
	11/10/94		0.0	n				
	12/10/94		0.0	n				
	13/10/94		0.0	n				
	14/10/94	SYLLIT PLUS 80 1900	8.7	n	☐ Yes ☐ No	☐ Yes ☐ No	☐dodine ☐ DMI	☐ **must** spray today ☐ could wait until tomorrow
	15/10/94		2.3	n				
	16/10/94		0.0	n				
	17/10/94		0.0	n				
	18/10/94		0.0	n				
	19/10/94		0.0	n				
	20/10/94		0.0	n				
	21/10/94		0.0	n				
	22/10/94		0.0	n				
	23/10/94		0.0	n				
	24/10/94		0.0	n				
Petal	25/10/94		1.0	n				

fall	26/10/94		1.1	n				
	27/10/94		0.1	m				
	28/10/94	NUSTAR 20DF 10 2200 POLYRAM DF 100 2200	0.0	n	☐ Yes ☐ No	☐ Yes ☐ No	☐dodine ☐ DMI	☐ **must** spray today ☐ could wait until tomorrow
	29/10/94		0.0	n				
	30/10/94		0.0	n				
	31/10/94		6.3	y				
	1/11/94		1.7	y				
	2/11/94		0.0	n				
	3/11/94	POLYRAM DF 125 2200	**0.0**	**n**	☐ Yes ☐ No	☐ Yes ☐ No	☐dodine ☐ DMI	☐ **must** spray today ☐ could wait until tomorrow
	4/11/94		0.0	n				
	5/11/94		0.0	n				
	6/11/94		0.5	n				
	7/11/94		1.2	m				
	8/11/94		0.0	n				
	9/11/94		0.0	n				
	10/11/94		0.0	n				
	11/11/94		0.0	n				
	12/11/94		0.0	n				
	13/11/94		0.0	n				
	14/11/94		0.0	n				
	15/11/94		0.0	n				
	16/11/94		1.7	n				
	17/11/94		0.0	n				
	18/11/94		0.0	n				
	19/11/94		0.5	n				
	20/11/94		0.0	n				
	21/11/94		0.0	n				
	22/11/94		0.0	n				
	23/11/94		0.0	n				
	24/11/94		0.0	n				
	25/11/94		0.0	n				
	26/11/94	NUSTAR 20DF 10 2200	**0.0**	**n**	☐ Yes ☐ No	☐ Yes ☐ No	☐dodine ☐ DMI	☐ **must** spray today ☐ could wait until tomorrow
	27/11/94		0.0	n				
	28/11/94		0.0	n				
	29/11/94		0.8	y				
	30/11/94		1.2	y				
	1/12/94		0.0	y				
	2/12/94		0.0	m				
	3/12/94	SYLLIT PLUS 80 2200	**0.0**	**n**	☐ Yes ☐ No	☐ Yes ☐ No	☐dodine ☐ DMI	☐ **must** spray today ☐ could wait until tomorrow
	4/12/94		1.8	n				
	5/12/94		0.0	n				
	6/12/94		0.0	n				
	7/12/94		0.0	n				
	8/12/94		0.0	n				
	9/12/94		0.0	y				
	10/12/94		0.5	y				
	11/12/94		0.0	n				
	12/12/94		0.0	m				
	13/12/94		0.0	m				
	14/12/94		0.0	n				

APPENDIX VIII

A DIAGNOSIS WALK-THROUGH

This is a cook book example of how a tutor might show the workings of DIAGNOSIS to a group of trainees, prior to them undertaking the exercise themselves. The scenario is phytophthora root rot, which is on the demonstration program which can be found at http://www.diagnosis.co.nz/ . Taken from the *DIAGNOSIS for CROP PROTECTION User Manual, 1997.*

The walk-through...step by step.

1. Start up the program and type in a fictitious name and number. Select load scenario and a series of crop types will appear. Go to apples and load the file Doug's apple problem. Now you are ready to start.

2. Read the contents of the initial scenario box aloud to the trainees. Ask them at this point whether they can see any clues? Things to note are the symptoms on the trees...typical of a root problem, and the fact that the worst affected were in a low-lying area. The latter implies a relationship with soil water. Note also that the disease is progressive....getting steadily worse each year.

3. At this point, ask the trainees what they would do. They could:

- Examine the leaves. Leaf symptoms describe a typical below ground problem. The arthropods are predatory and pest mites, as can be seen if collected and examined in the laboratory later. These are common in orchards but they have nothing to do with the problem. Collect some leaves here, for analysis later in the laboratory.
- Examine the stem. This reveals cracks....this should make trainees suspicious that perhaps a canker lurks underneath.

If the trainees were going through the exercise themselves, at this stage they should be starting to put a short-list of possibilities together. At undergraduate level (which this scenario is aimed at) they should be consulting books of apple diseases, and looking for diseases which resemble the symptoms observed. Waterlogging, or some sort of root rot/stem canker pathogen should be high on the short-list. You will note that the scenario mentions the absence of any mushroom-type bodies or mycelial fans. This is so trainees can downgrade the possibility of *Armillaria* sp. infection.

- Cut into stem. If a canker exists under the bark, this action will reveal it, as it does. The picture and description are typical of phytophthora root/foot rot which should immediately jump to the top of the trainees' shortlist.

The possibility that the problem is phytophthora root rot is now a strong one and trainees should move from an investigatory mode, into a confirmatory one, although not eliminating other possibilities just yet. In other words, they should be asking themselves "what supporting evidence do I need to confirm this"? The presence of the pathogen in the infected tissue would be strong evidence, so at this stage they should collect some infected tissue for processing in the lab later.

- Examine roots. These are rotten. Again, taking some tissue back to the lab would be worthwhile.
- Examine soil. The soil has a fairly high moisture content, which is favourable to phytophthora root rot. The trainees could take this back to the lab to try an isolation if they wished, although in a real situation isolating the pathogen from the tissue is evidence enough. If the trainees' suspected nematodes, then collecting soil for extraction is a good idea.
- Examining the branches and fruit adds nothing to the evidence.

Other observations:

- Symptom distribution. This simply reinforces the relationship between the disease and ground water, mentioned in the initial scenario information. The distribution is typical for a soil-borne disease.

If a problem with the sprayer is suspected, this can be investigated, as can the fertiliser spreader, if this is thought to be malfunctioning (if plants showed suspected fertiliser burns for example). Insect traps would be viewed if an appropriate insect problem was suspected. Note that nematodes cannot be selected; this is because the scenario creator has not included this procedure. The same applies wherever a button or menu item is greyed.

Examining weeds reveals weed damage. Ask the trainees what they think of this. It has been added as a red-herring which might (mistakenly) lead trainees to believe herbicide damage is the cause of the problem. The lesions are caused by a paraquat/diquat knockdown spray applied a few days previously, a fact that the trainees can find out by questioning the grower. This herbicide is safe to use around trees of this age and has no relationship with, or influence on, the disease. Note the weeds are indicative of a poorly drained soil.

A quantitative assessment of either plant damage, weeds or nematodes involves considerable work. In this scenario it costs money to do these things, so the trainees must think carefully as to whether they want to do this or not. In this case the extra evidence gained is probably not worth the money, although an assessment of plant damage does show one variety in particular is most affected. This variety is Cox's orange, a fact given by the grower if he is asked that question later.

When diagnosing a plant problem, much can be discovered by asking the grower pertinent questions about his/her operation. Bear in mind however, the answers can be vague, or sometimes even inaccurate if the grower has something to hide, or feels embarrassed.

In this scenario talking to the grower can be quite revealing...

Ask the grower about...

- Past weather. Weather has a major influence on pests and pathogens so this is an important question. It has been wet. A good season for oomycete root rotting pathogens.
- Disease management. Asking about this will reveal what the grower is doing presently about expected diseases. Nothing unusual in this case.
- Weed management. This is a useful area to question if herbicide damage is suspected. Here, the grower mentions the weed spray, which accounts for the lesions on the weed foliage.
- Insect management. Like disease management, it is important to know what the grower is doing here. Insect management can inadvertently cause disease problems and vice-versa. Here he mentions the predatory mites, which trainees may have already noticed on the leaves.
- Fertiliser regime Nothing unusual there.
- Drainage and irrigation. Useful to know about if it is suspected to be a pre-disposing factor. Here the grower mentions the problems with drainage. Yet more evidence for an oomycete root rot.
- Variety. This is an important question in any diagnostic exercise. The grower tells you the main variety affected is Cox's orange. This variety is very susceptible to phytophthora root rot.
- Land use history. What has gone before can be important. For example, residual herbicides can remain in the soil for some time, and applications years ago could be causing a problem now. It is worth noting here that the orchard was out of dairy pasture. This would indicate a high rainfall area.
- Management patterns. These have not changed in this case, but they are worth asking about. Sometimes the start of a problem can be traced to a change in grower management practices.
- Neighbours' crops. Often this question is worth asking. In this case, the

neighbours' crops look OK because his varieties are not as susceptible to phytophthora root rot as our growers are.

- Getting the growers opinion on what he thinks is wrong is a good idea. Sometimes he might be right, and give a lead a trainee had not considered. In this case, he is completely wrong.
- History of problem. Problems can appear gradually, or they can be sudden. The latter usually indicates some trigger event (frost, hail, pesticide application) which should be looked for when diagnosing the problem. In this case, it has been a gradual decline of the trees over a number of years.

Ask neighbour. Checking out the neighbour can sometimes be useful. They may tell you things the grower has not, and put their own perspective on the problem. In this case, the neighbour has not got the answer, but he does make reference to varietal differences between the two properties.

After checking out everything in the field, it is time to head to the lab, armed with specimens. Before entering the lab, trainees will be asked to give a preliminary diagnosis. Waterlogging, root rots or root feeding nematodes are three plausible ones, which could go in here.

Entering the lab, the trainee is given a piece of introductory text. This can be a good place to customise the scenario. You could insert some names of local characters they will recognise for example.

Once past this initial screen, trainees will be shown a screen which relates to what they have collected. Clicking on each of these objects will reveal a set of procedures.

Let us assume we have with us some leaf and root tissue. Click on the leaves and ask the trainees to note all the procedures available. Those in grey have not been inserted by the scenario creator so it is assumed they are very inappropriate. Some trainees may think the problem is a leaf pathogen. Clicking on agar plates will cause the tissue to be plated to agar (appropriate surface sterilisation assumed) and incubated. The box that then appears shows one fungus has grown out, and gives some options as to what to do with it. Click examine fungus□in the demo scenario you will see there is a cost associated with this. It is expensive to rent lab space and a microscope in New Zealand! This can easily be switched off in the builder. Now examine the fungus. There is a textual description and a photo.

The fungus from the leaves is a red-herring. It is actually *Alternaria alternata*, a fungus often found as a common saprophyte on dead and dying tissue.

Click 'Plant nutrient analysis'. You will see a list of nutrients trainees can select for testing. Select 'test for all' then click, OK. A list of figures will be returned. If compared against common standards, it would be found that the levels of macronutrients and micronutrients were low, showing the leaves were not obtaining the proper nutrition. Whist this is supporting evidence, it was not really necessary to do this test to come to the correct diagnosis. Useful to show the trainees in the walkthrough though.

Click OK from the procedures menu to get back to our samples. Now click on 'roots' and select 'agar plates'. Examine the fungus which has grown out. The images show oogonia and sporangia typical of *Phytophthora cactorum*. Our tentative diagnosis was confirmed!

It is worth noting to the trainees as you walk through these lab menus, the other things that can be done. For example, they could research the weather, call the grower on the phone (in case something was forgotten), send plant parts away for virus and pesticide testing or undertake nematode extraction. Had they extracted nematodes from the soil in this scenario they would find plenty. However, the photo would show them to be harmless miscellaneous feeders (at least to those trainees who could identify them as such of course!).

Now that the pathogen has been isolated, it is time to exit the lab and go back to the main screen. Select 'diagnosis'. This is the box trainees will need to type their diagnosis, justification, and recommendation into. All contents will be saved to disk in a file the name for which they will specify at the end of the exercise. Just how detailed you want the justification and recommendation is up to you as the tutor.

To finish the walk through, press the 'Show solution' menu. This can be switched off during a real exercise, but for now you can use it to illustrate what is likely to appear on the screen or disk after a real exercise.

Note there are three parts. Solution and feedback, optimal route and recommendation. Point out to the trainees that the feedback is customised according to what they did or did not do. The optimal route shows the shortest number of steps required to get to a solution (this is what an experienced diagnostician would do) and the recommendation is self explanatory.

APPENDIX IX

Fax from Dr Bill MacHardy re: DIAGNOSIS

02/15/96 08:39 UNHPLBIO 001

UNIVERSITY OF NEW HAMPSHIRE

Department of Plant Biology
College of Life Sciences and Agriculture
Nesmith Hall
Durham, New Hampshire 03824-3597
FAX (603) 862-4757

DATE: 14 February 1996 TOTAL PAGES TO FOLLOW: 1

FAX NUMBER: (64) 6 350 5606

TO: Terry Stewart
Department of Plant Science
Massey University
New Zealand

FROM: William MacHardy

COMMENTS

Dear Terry,

It has recently been brought to my attention that many of my colleagues who share an interest in apple production and apple scab disease, particularly those outside the US, may not be aware that my book on apple scab (*Apple Scab Biology, Epidemiology, and Management*) was published by APS Press in December. I am sending this fax in the event that you are one of those persons.

For your information, the book is 545 pages with 260 figures and 80 tables. I'm not sure how many articles, theses, dissertations, etc. were cited, but well over 1000 were collected, read, and considered. An order form is included in the event that you (or others) are interested in ordering a copy.

On another matter, I prepared a booklet for class use describing your Diagnosis program, and the students in my Plant Pathology class, working in pairs, selected a crop and disease and prepared a scenario as a class project. They thoroughly enjoyed the assignment and the scenarios were all very well done, so I have decided to make this a permanent part of the course. Most of the students were horticulture (plant science) majors. If you should update the Mac version to include the Scenario Builder and the other features of the Windows version, I would appreciate it if you would please let me k ow.

Yours sincerely,

Bill MacHardy

APPENDIX X

New Zealand Agricultural Chemical Education Trust

The Trust (NZAET) was established by organisations representing the principle primary producer groups [including NZFF, NZAPMB, NZKMB, The Association of Crown Research Institutes, New Zealand Vice-Chancellors' Committee, New Zealand Vegetable and Potato Growers Federation and the Agricultural Chemical and Animal Remedies Manufacturers Association of New Zealand (AGCARM)]. Initial funding was provided by the Agricultural and Marketing Research and Development Trust (AGMARDT) and the Accident Compensation Corporation (ACC). The objectives of NZAET are to:

- educate farmers and growers in the safe, responsible and efficient use of agrichemicals.
- inform the public on the need for responsible agrichemical use in commercial, domestic, recreational and amenity situations.
- make sure that all agrichemical users safeguard the natural environment and physical health of New Zealanders.
- maintain access for New Zealand grown produce to both domestic and international markets.

To achieve these objectives, the NZAET has set up a comprehensive user awareness and education programme designed to promote the safe and responsible use of agrichemicals. Central to the campaign are the Growsafe™ training programmes. A comprehensive Agrichemical Users Code of Practice has been developed by the NZAET. It provides practical and specific guidance for the safe, responsible and efficient use of agrichemicals for the control of weeds, pests and plant diseases. The Code of Practice has now become a New Zealand Standard (NZS8409:1995), and is currently undergoing a comprehensive review.