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AN EVALUATION OF PEST AND DISEASE CONTROL PRACTICES IN FIELD PROCESS TOMATOES IN HAWKES BAY AND OPPORTUNITIES FOR IMPROVED PEST MANAGEMENT

A thesis in partial fulfilment
of the requirement for the degree of
Master of Horticultural Science
at Massey University

Susanne Bland
February 1992

ABSTRACT

The spray practices of seven process tomatoes growers in the Hawkes Bay were evaluated during the 1990/1991 season by analysis of spray diaries, field surveys, and weather data. In very few instances were calendar spray systems, weather or insect thresholds used to determine spray scheduling. Use of monitoring and forecasting systems already available will help decrease the number of sprays applied providing adequate research in done to adapt them to local conditions. It is concluded that there is potential for pest management and integrated pest management systems to be introduced into the process tomato crops.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

A noticeable factor determining the need for pest control in many vegetable crops is the consumer's demand for high quality produce. This has led to lower tolerance by growers of any insect pest or disease in their crops. Often, increased pesticide usage has been seen as the answer to this problem, but with increased pesticide usage a number of new problems have arisen:

- Arthropod (and more recently pathogen) resistance to pesticides.
- Secondary outbreaks of arthropods other than those against which control was originally directed.
- Rapid resurgence of treated species necessitating repeated insecticide application.
- Increased pesticide residues on produce.
- Hazards to insecticide handlers and to persons, livestock, and wild-life subjected to contamination by drift.
- Legal complications from suits and other actions pertaining to the above problems.

The development of methods that will decrease our dependence on pesticides is becoming increasingly important. Consumer concern about residue levels and knowledge of the effects of pesticides in the environment has brought about calls for reduced pesticide usage.

Reducing spray usage is important to New Zealand in both the short the long term with respect to pesticide residue constraints in our overseas markets.

The aim of this thesis was to determine the spray practices of process tomato growers in the Hawkes Bay, the factors that stimulate growers to spray, and to determine whether there is potential for improved pest management and integrated pest management in this crop.

CHAPTER 2

LITERATURE REVIEW

2.1 Pest Management

The term pest is used in the present context in a general manner to describe any insect or disease causing organism that routinely or occasionally causes damage resulting in reduced yield or quality of the marketable product (Watson *et al*, 1975).

Numerous definitions have been given for integrated pest management (Way 1980, Whalon and Penman 1991, Huffaker and Smith 1980, Wearing 1988, and Zalom and Flint 1990). Rabb, 1972 (cited Luckman and Metcalf, 1982) defined IPM as: Pest management is the intelligent selection and use of pest-control actions (tactics) that will ensure favourable economic, ecological, and sociological consequences. Whalon and Penman (1991) described IPM as an approach to pest control that employs the best set of strategies, tactics and tools to maintain pest populations below economically damaging levels with minimum adverse environmental, economic and social consequences. Zalom and Flint (1990) stated "IPM is an ecologically based pest control strategy that considers all available management options, including inaction. IPM combines cultural, chemical, and biological controls with ecology and systems science".

All the definitions given above are very similar i.e the "intelligent use of", or "the best set" of control tactics available in a way that considers the environment, economics, and social consequences. Though the definition given by Zalom and Flint (1990) includes one aspect that is not stated in the other two definitions, the management option of inaction. This is a tactic often forgotten when growers consider risk reduction.

In most cases where the term pest management has been used it has been used interchangeably with the term integrated pest management. However, there is an important difference between PM and IPM that must be recognised. IPM is an integration of a number of different techniques that work together to control the pest, whereas PM can utilise either a single control procedure or it can integrate several control methods (i.e. IPM techniques). Thus IPM can be considered as a sub-group of PM.

Resistance to implementation of PM programmes is great due to farmers / growers wishing to reduce risk where possible, but this often resulting in unnecessary pesticide usage. Turpin and York (1981) suggested that farmers' reluctance to change practices may be due to a false assessment of the need and benefit of insecticide usage.

Pesticides are frequently applied in an insurance fashion against perceived insect-related yield losses and in many instances are not needed. Growers need to realise that insecticides as beneficial production tools should only be used in situations where pest pressure exceeds economic damage levels. This idea is gaining greater public attention with environmental groups and the media speculating on the effects of pesticides in the environment. This was highlighted in California, U.S.A. with the proposed Environmental Protection Act of 1990. Had this act been passed, it would eventually have forced the cancellation of a significant number of pesticides included on the U.S. Environmental Protection Agency's list of chemicals evaluated for carcinogenic potential (Stimmann and Ferguson, 1990). This type of action could be both advantageous and detrimental. It would have helped California's agricultural community identify and adopt effective and acceptable alternative pest management techniques and also assisted the University of California make informed decisions on its research direction and extension resources (Stimmann and Ferguson, 1990). However, there are a number of pesticides for which there are at present, no alternatives and their cancellation would have had a great effect on produce quality and quantity.

There is a need to develop new control options, and to start changing growers' practices who persist with conventional spray schedules moving towards more "acceptable control methods" using less pesticide input. This is where PM/IPM systems are important, but before adoption can occur PM/IPM systems have to be developed. There are five essential components to the development of an effective PM system that need to be determined:

1. Understanding the factors that regulate pest numbers (pest population dynamics).
2. The determination of pest damage thresholds and of economic thresholds.
3. Monitoring of pests and their natural enemies.
4. A decision making framework to determine action to be taken.
5. Methods of selectively manipulating pest populations.

Once these factors have been determined an effective PM programme can be developed and the programme marketed to growers.

2.1.1 Factors that regulate pest numbers (pest population dynamics).

Knowledge of the pest's life system[1] and the ecological system in which it lives influences and aids decision making in pest management. It is necessary to have this information when setting up monitoring systems and developing control methods for that pest.

Natural populations are influenced by factors in the environment which either, tend to restrict or depress numbers, or favour them. These factors can fluctuate daily and seasonally. In general, pest populations fluctuate around a mean that over the long term tends to remain fairly constant. Thus insect populations tend to operate on a 'replacement only' basis.

Pest problems can be viewed as people and pests competing for the same resource, food. Problems have developed due to monoculture production changing the natural vegetative cover and environment. These problems include changing complex natural environments which can naturally balance

[1] That part of the ecosystem which determines the abundance and evolution of a particular species (Clark, 1970).

themselves, to an agricultural monoculture systems which consist of plants of the same species. Monoculture systems therefore favour pests that feed upon that crop but not other insects that act as parasites or predators. In relation to plant diseases, large numbers of plant of the same species in the same area results in easy movement of the pathogen to new food sources. This is why natural systems are more stable, as they incorporate many checks and balances so no one species is likely to explode (Southwood and Way, 1970).

Factors that regulate insect populations include; the reproduction potential of the insect, environmental factors, and the structure of the insect population. The reproductive potential of an insect needs to be considered to ascertain potential numbers that could develop given any change in factors that otherwise prevent the population increasing. The environmental factors that restrict population explosion from occurring include climate, living space, soil type (this is important with soil inhabiting insects), quality and quantity of food, predators and parasites, and diseases. Density dependent factors such as living space, quantity of food, predators and parasites, and disease all confer stability on a biological system as they exert greater pressure as numbers increase thus, returning the population to a lower level.

The structure of a pest population is important. An insect population generally has a high birth rate/ high death rate with a predominance of juvenile forms and progressively fewer individuals as development towards maturity occurs. An understanding of factors that cause mortality at each stage may help in finding alternative control measures.

All the agents in a life system affect the performance of that population, though a few factors have a greater effect than others. If appropriate data is obtained on the major agents and processes involved in their regulation, then there are reasonable prospects of producing a quantitative model to describe the functioning of a life system. These models for pest species will eventually have sufficient predictive and explanatory value to be used in computer exercises to examine the likely outcome of various procedures of pest management (Clark 1970).

TABLE 1. Factors influencing pest populations (Southwood and May, 1970).

Factors affecting crop invasion
Numbers of potential invaders
Distance of source of invaders
Conditions for invasion and settling
Attractiveness of crop
Factors affecting natality, mortality, development, and emigration
Food, quality and quantity
Climate
Pesticides
Animals of the same sort (intra-specific competition, sex ratios, and virility)
Organisms of other sorts (natural enemies, inter-specific competitors)

The features of insect population dynamics / life systems of particular importance to pest management are; endogenous/exogenous habit, seasonal life-cycle (e.g. does it have stages of dormancy), day degrees[2] for emergence of eggs or pupae, number of generations per year, mode of reproduction, numbers of eggs or offspring produced, growth and development time and effect of the environment on it, feeding behaviour of insects (range of host plants, mode of feeding, nutrition effects on growth rates and fecundity affected by food quality), and the effects of natural enemies (Fenemore, 1990 Pers. Comm.).

An attempt to understand conditions under which pest situations arise need to

[2] Accumulation of heat units above a threshold, normally expressed as degree days (Fenemore 1992, Pers.Comm.).

be undertaken, and solving any pest problem should include three closely linked phases of investigation which feed back upon each other (Table 2. Clark, 1970).

Table 2.: The study of a pest situation (Clark, 1970)

PHASE I -	Deals with the causation of injury and identification and description of the major biological and physical influences involved.
PHASE II -	Investigation of economics of injury and functioning of the relevant life system.
PHASE III -	Modification of life systems to achieve satisfactory management.

Phase I is basically the intensive and systematic study of life histories, the object of which is to identify and describe the relevant elements of the pest situation, including the major components of the life system of each population.

Phase II deals with quantities and quantitative relationships. It is concerned with the actual operation of injurious interactions and the ecological processes entailed. It includes damage assessment of the pest either through biological values i.e. biomass productivity etc, or expressed as reduction in monetary values. Decisions are then made as to the amount of injury or loss that can be tolerated, and how much effort should be devoted to quantitative ecological study.

Phase III completes the analysis of the pest situation by combining the findings of phases I & II. From these analyses decisions are made how the life systems could be modified or circumvented, so courses of action can be determined.

It is this type of knowledge that allows the development of effective pest management systems. The obvious problem is the accumulation of this type of information. Most of the information on pest species is gathered from research in simplified artificial simulated crop systems or in natural habitats rather than the agro-ecosystems we are interested in. But information gathered from artificial simulations is the first step in learning the likely effects of pests in cropping systems. The rest can be found out through trial and error in field cropping situations.

2.1.2 Pest damage thresholds and economic thresholds.

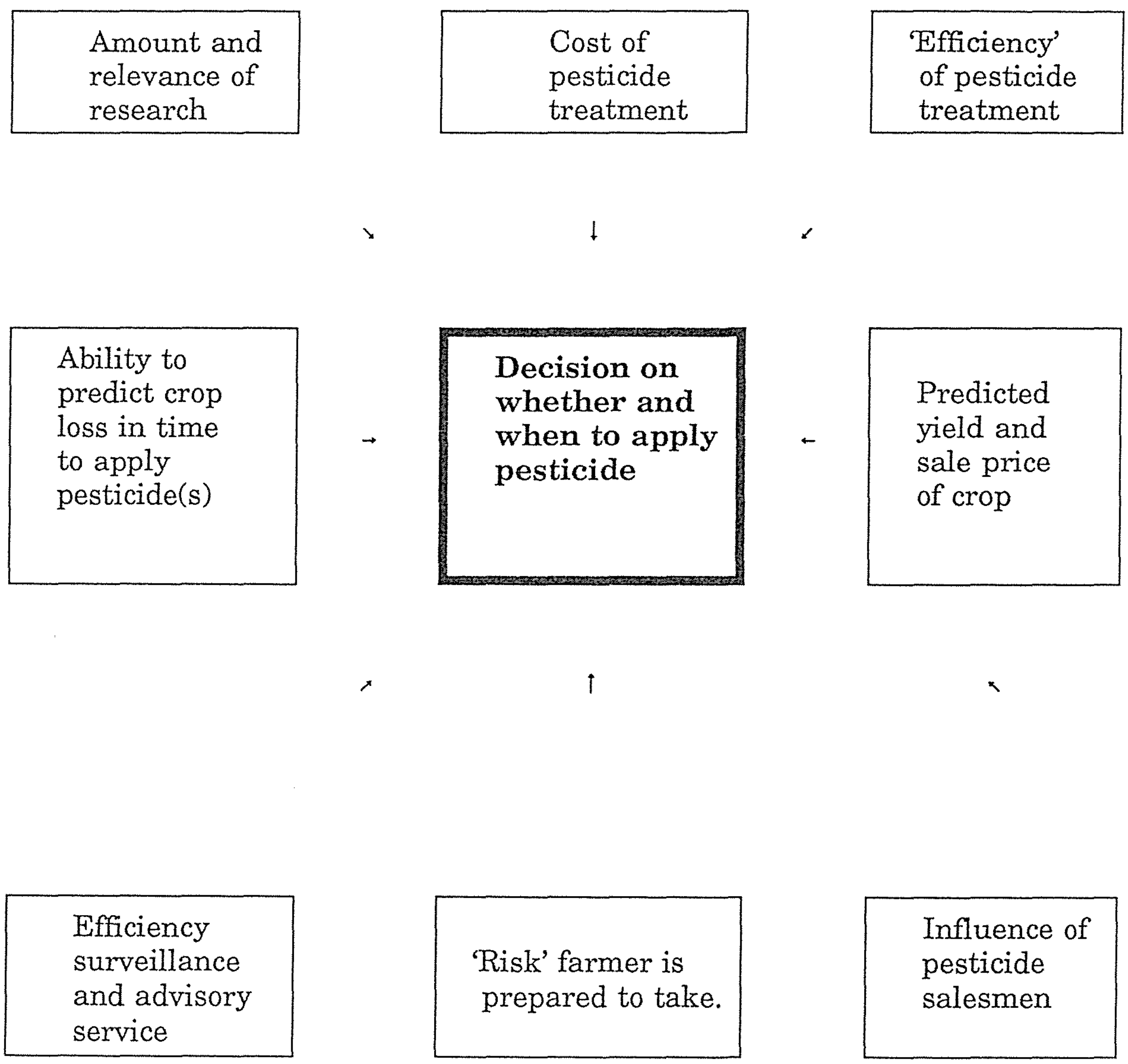
Pest management principles cannot be applied without economic thresholds to guide the deployment of management tactics. The development of economic thresholds requires biomathematical and economic expertise in the pest management research team. Though ultimately the use of thresholds depends on the grower's attitude to risk and his/her perception of the particular pest problem.

A number of definitions of economic thresholds are discussed by Szmedra *et al* (1990). The definition that will be used in this thesis is: The pest density at which a control tactic should be applied to prevent an increasing pest population from reaching the economic injury threshold (Stern *et al*, 1959 cited by Szmedra *et al*, 1990), economic injury threshold being the pest density at which incremental damage equals the cost of prevention, (Headley, 1972 cited Szmedra *et al*, 1990).

In the decision process of whether to apply a pesticide there are many factors that have to be considered (see figure 1). Of all the factors shown in fig.1 only one is readily quantifiable, that being the cost of pesticide treatment. Therefore in an attempt to establish an economic threshold such limitations impose considerable uncontrollable error. There are uncertainties in advanced knowledge of the yield and sale prices of crops, and whether it is possible to adequately predict pest infestation and crop losses by the time it is necessary to take preventative action. However, with crops grown under contract for a pre-determined price, the variability of return is limited, thus reducing variability in predictions.

Economic thresholds should first be determined for one or two key pests attacking a particular crop. (A key pest is one that is a perennial, persistent threat dominating chemical practices). In the absence of deliberate control by people, its population density often exceeds the economic threshold one or more times during the growing season (Stern 1973).

Figure 1.: Factors involved in the decision making process of whether to apply a pesticide (Way, 1980).



There are a number of problems associated with economic thresholds. Being able to distinguish between a pest's mere presence in the crop, as opposed to higher densities that cause a significant loss in quality and/or quantity of the harvested crop is important in economic threshold determination. To determine economic thresholds for most crops requires the ability to predict the probable consequences of continued increases in pest population in relation to subtleties of injury levels, if control measures are not implemented. The difficulties in gathering and analysing the complex factors in an ecosystem that regulate pest populations are a major problem. Useful tools to use include life tables[3], population studies, and damage assessments but difficulties with data collection and observation can occur in all the above.

In an ideal system the decision to apply a pesticide should be determined by the cost / potential benefit ratio (i.e. the cost of the control measure against the increased value of the crop that can be recovered or protected). This can be affected by market conditions, local grower economics, and investment in the crop, but not by personal values of the people concerned (Stern 1973).

Determination of economic thresholds in conjunction with agronomic variables will establish more precise treatments to avoid plant damage, yet this does not apply if viewed in the context of a geographical area rather than an individual grower. This is because the market price decreases and quality standards increase as total production increases, meaning that any potential insect injury no matter how severe, may not be of economic consideration.

As economic thresholds are "economic" they do not consider personal aspects such as the goals and behaviour of those making pest management decisions. They do not relate to situations where farmers are not able to monitor pests or respond quickly, or where the threshold is unmeasurably low, or where pest attack is constantly above the threshold (Mumford and Norton, 1984).

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[3] A summary statement on the life of a typical individual or cohort of individuals in a population showing the numerical changes in a population by describing the birth rate, the death rate, and the migration in that population (Price, 1975).

Useful thresholds are often developed from relatively simple data which are imprecise but which do have considerable practical value especially in situations where routine preventative treatments are extensively used.

With research and experience such initial economic thresholds can be adjusted to take into account other factors in the environment that may affect pest mortality e.g. natural enemies (see biological control, page 19.). All authors of papers relating to this topic realise that the thresholds are dynamic and differ for different areas, plant growth stage, weather conditions and other environmental factors (soils etc.) (Trumble 1990, Onstad 1987, and Call 1990).

In practice when no yield / pest density information is available the decision to spray is often based on advice from chemical company representatives, farm advisors, or extension entomologists. Such people depend heavily on past experience when there are no specific guidelines to follow. This often makes decision making difficult as often opinions can be biased even after many years of experience. The question then occurs of what does the grower base decisions on? Often the grower is often unable to predict the outcome of his decision, even in probabilistic terms. What is needed is more sophisticated knowledge of pest density and crop yield relationships leading to better decision making. This could optimise pesticide use and reduce the indiscriminant use of these substances.

Disease thresholds are similar in that most diseases like insects can be tolerated at low levels though numerical assessment is not easily achieved. However, a few diseases are not tolerated and require treatment before symptoms occur in the field. In such cases predictive systems have been developed with the economic threshold based on variables such as moisture conditions, temperature, spore production, and plant growth stage (Call, 1990).

2.1.3 Monitoring of pests and natural enemies.

The development of good, unbiased monitoring and sampling systems is a prerequisite to full utilisation of pest management. An approximation of disease and insect numbers present at any time is necessary in providing information upon which management decisions for spray application and timing can be made. The results of sampling and pre-determined economic injury levels must be considered together. One is of little value without the other. Both are necessary in order to make meaningful pest management decisions (Watson *et al*, 1975).

Monitoring systems do not have to rely on visual sighting of the damaging agent. Chelfant *et al* (1979) used the threshold of 1-2 holes per plant or the visual estimates of defoliation by cabbage looper (*Trichoplusia ni*), diamondback moth (*Plutella xylostella*), and cabbageworm (*Pieris rapae*) and a determination of the effect of this damage on the yield of marketable heads of cabbage.

Suitable sampling methods take into consideration the insect to be sampled and the crop with which it is associated. Sampling should be targeted at the insect stage causing damage to the crop. Though counts of eggs and adults may serve as indicators of expected larval numbers, these are not always reliable. Climatic conditions, beneficial insect numbers and other factors can greatly affect the development of an insect population, sometimes changing a potential problem into a harmless one.

The sampling method may need to change for the same insect species in different crops e.g. a sweep net is used to sample *Lygus* on cotton, but it is inadequate when sampling this pest in safflower because its main stem and branches are very woody when the plants begin to bloom and set seed. When this occurs the sweep net cannot be moved through the dense foliage (Stern, 1973). Four types of sampling are mentioned by Watson et al (1975) these are random, sequential, point and trap sampling.

Random sampling is the taking of samples at random, with good field coverage to determine insect numbers or damage per sample unit i.e. percentage infestation/ damage. e.g. counting the number of bollworm larvae per 100 randomly selected cotton terminals (cited Watson *et al*, 1975). This method is quick, inexpensive and simple to execute as well as providing an accurate evaluation of the field situation. In this method knowledge is needed on the distribution of the pest within the crop and on the plant, e.g. aphids usually colonise plants at the edge of fields earlier and in greater numbers than in the centre, and more plants are colonised in the lee of windbreaks (Cammell and Way, 1987). In these situations random sampling around the edges of the fields may be a very good indicator of potential problems the field may have in the future and the grower can act on that information. This depends on whether the insect is the only problem being monitored. If it is, then edge sampling may achieve the desired results. But if a range of insects and pests are being surveyed then that type of system may not achieve accurate results.

Sequential sampling requires continued sampling until a pre-established upper or lower infestation level is found. It is not commonly used. This method is used in California in the sampling of the tomato pest *Heliothis zea* (see page 23.).

Point sampling is a measure of the population density designed to relate the number of insects or their damage to the number of plants or plant parts per unit area. This has permitted the establishment of economic levels based on the numbers of insects or insect damage per unit area as related to stage of plant development, e.g. Watson *et al* 1975 cited a procedure for the monitoring of boll weevils: Examine the first fifty squares (fruiting buds) inch or larger in diameter, and measure the row feet required for the sample. Record the number of squares punctured or damaged by boll weevils, and repeat the procedure in at least three other locations. The number of damaged squares per foot of row is then related to the total squares converted to the number per acre.

Trap sampling is used primarily to determine the presence of a pest population in an area. Traps that can be used include, light, bait, impaction, sticky material traps and nets.

Temperature, relative humidity and moisture all have an affect on pest emergence and movement. With specific data on what levels affect specific pests it may be possible to develop an effective warning system. Remote sensing and aircraft reconnaissance are some of the more unusual monitoring methods that have been used, in instances when ground surveys to detect pest increase are time consuming and inaccurate. These are fast and effective techniques for certain types of pests e.g. desert locusts (*Schistocerca gregaria*). Use of aircraft and ground vehicles combined with better knowledge of the pest's biology and behaviour, meterological data to help detect air currents, possible breeding areas, and displacement and direction of movement have helped in combating this devastating pest (Stern, 1973).

More recently the use of infra-red photography to indicate stress in a crop has been used. This is effective as long as the photograph interpreter is experienced at detection of colour patterns or other changes on the film caused by stressed plants (Stern, 1973). Blazquez (1990) used this technique in the detection of late blight (*Phytophthora infestans*) in tomato crops.

When sampling, a number of practical considerations have to be taken into account. These include, the time of day the sample is taken, and frequency and recording of data. The time of day that samples are taken is important as it can affect the number of insects caught. Sampling records should be filled out by the field data collector and should include information on harmful and beneficial insects, identification of the paddock, date sampled and other pertinent comments.

The frequency of sampling is often weekly but may need to be more frequent when pest populations approach economic thresholds. In some crops with low economic thresholds frequent (i.e. twice weekly or every 2-3 days) sampling may be required.

The use of monitoring techniques and application of thresholds have resulted in reduced spraying without significant loss of quality in many crops (Shelton *et al* 1983, Morisak *et al* 1984,Theunissen and Den Ouden 1985, Cartwright *et al* 1987, Stewart and Sears 1988, Chalfant *et al* 1979, Workman *et al* 1980, Sears *et al* 1985, Kirby and Slosser 1984, and Hoffmann *et al* 1990).

2.1.4 A decision making framework to determine action to be taken.

As pest management is essentially flexible in nature, criteria for decision making are of crucial importance. Reliability in predicting the course of events is essential if pest management is to receive practical acceptance and for this reason some safety margin is usually built into economic thresholds. Such margins are necessary to cover site to site, and season to season variation that invariably occurs.

The decision maker must choose the sampling time , the life stage that is to be sampled, and the time for implementing control tactics. Contingency plans should be available for farmers who are unable to follow the best plan, especially with regards to sampling (Onstad, 1987).

2.1.5 Methods of selectively manipulating pest populations.

All integrated pest management programmes attempt to make maximum use of natural controls, particularly parasites and predators. Artificial measures should be applied to supplement them only when necessary, and thus achieve optimum timing of control measures.

There are a number of methods that can be used either alone or in combination to control pests and diseases. These include pesticides, biological control measures, plant resistance, and the use of pheromones.

2.1.5.1 Pesticides

Pesticides are still the most common way of protecting crops from damage from pests and diseases. Pesticides tend to be non-selective and can in some instances result in harmful residues in the environment. A number of selective pesticides are available that can target specific pests rather than give a broad spectrum insect kill.

Reducing spray application is one pest management technique available. One method of reducing spray applied to a crop is to make the application more efficient, either by directing the spray to the specific area of the crop that needs to be covered instead of an all over broadcast, or by reducing the volume of spray applied and using more efficient sprayers.

Finch (1987) has mentioned a number of alternative spray application methods. These include, spot application instead of band application, especially for soil-applied insecticides. Incorporation of insecticide into modules of media before planting has resulted in only 20-30% of insecticide being used. There have been attempts to improve foliar applied sprays by using new technology to reduce droplet size, and electro-charging of spray droplets. Unfortunately most of these methods have not proved as efficient as expected.

Controlled use of pesticides through correct monitoring and decision practices can reduce the numbers of pesticide sprays applied.

2.1.5.2. Biological control

Biological control utilises natural enemies in the natural habitat by increasing their numbers; for example by decreasing factors that cause mortality i.e pesticide.

A number of methods are used to increase numbers of natural enemies in an area. One method is to enhance the attraction of natural predators/parasites into the area e.g. planting nectar producing plants to attract parasite adults (Fenemore Pers. Comm, 1991). In some cases species of natural enemies are introduced into an area or country where they do not normally occur.

Two larval parasites *Apanteles kazak* and *Microplitis croceipes* have been introduced into New Zealand to control populations of *Heliocoverpa armigera* in tomato and lucerne crops. Results indicated 36-99% parasitism by *Apanteles kazak* in unsprayed tomato crops in Gisborne (Walker and Cameron, 1990).

Bacillus thuringiensis is a bacterial bioagent that is used against *Lepidoptera* larvae. It has been used against *H.zea* in tomatoes in the U.S.A. and against diamond back moth (*Plutella xylostella*), cabbage looper (*Trichoplusia ni*), and *Pieris rapae* in brassica crops (Hoffmann *et al* 1990, Sears *et al* 1983, Workman *et al* 1980 and Oatman *et al* 1983). *B. thuringiensis* has an advantage over conventional pesticides in that it does not affect natural enemies.

2.1.5.3. Plant resistance

In the past plants have developed a great diversity of methods to ward off or tolerate attack by plant feeding organisms through natural selection. People have sped up the natural selection process by selecting specific plant characteristics such as pest resistance and bred these into the plant. Plant breeding is now becoming an important force in the development of pest management programmes. However, plant resistance is not the only trait that has been selected for. Specific characteristics such as high yield and quality have been the important traits initially looked for. With selections initially based on these traits many genetic factors that confer resistance to pests in cultivated plants have been lost. It is only now with the need to decrease spray usage and a realisation that the environment has been affected through the over use of pesticides, that plant resistance to pests is again recognised as being very important.

Many examples of plant resistance can be found. Certain varieties of tomato (*Lycopersicon hirsutum* and *L. hirsutum* f. *glabratum*) have shown resistance to many insects including tomato fruit worm (*Heliothis zea*) , leaf miners (*Liriomyza* spp.) tomato pinworm (*Keiferia lycopersicella*), Hornworms (*Manduca* spp.), Colorado potato beetle (*Leptinotarsa decemlineata*), potato aphid (*Macrosiphum euphorbiae*), flea beetles, whiteflies, leafhoppers, spider mites and many others (Lange and Bronson 1981). An antibiotic factor in the leaves when extracted in ethanol was found to be lethal to tomato fruitworm when added to an artificial diet. When α tomatine and tomatidine were added to an oligidic diet at different concentrations and fed to *H. zea* and *Spodoptera exigua*, they depressed growth, development, and survival indicating that glycoalkaloids could be associated with the antibiotic factor (Lange and Weinburg cited Lange and Bronson 1981). α Tomatine has been found in stems, leaves and fruit of tomato and its biological activity demonstrated against many microorganisms (references cited Lange and Bronson 1981). It is this type of resistance that occurs naturally in plants that could be reintroduced into future varieties.

Resistance is not always due to chemicals produced within the plant. There may be some other feature that makes the plant less attractive or less suitable to the pest e.g. hairy leaves, colour, a nutritional factor, or hardness of tissue.

2.1.5.4 Pheromones

Pheromones are substances produced by insects for regulating behaviour such as mating, aggregation, movement etc. Pheromones are specific for each insect species, and are therefore a useful tool to use in IPM with other control techniques.

Sex pheromones have been used in a number of ways, as a tool used in monitoring, mating disruption and as a method to mass trap insects. In New Zealand pheromones combined with field scouting have been used to forecast potential egg and larval infestations of tomato fruit worm in Gisborne tomato and sweet corn crops (Walker and Cameron 1990). Mating pheromones have also been used to attract insects (generally the males) away from the crop and therefore disrupt mating with the female. This technique is used to mass trap the insect. Pheromones are also used in Israel successfully in controlling citrus flower moth (*Praye citri*), a key pest of lemons, using the mass trapping technique. It has been found that no insecticides are needed provided the traps are well maintained throughout the year and the dispensers replenished every four months (cited Sternlight, 1986). Mating disruption has been used commercially world wide against pink bollworm (*Pectinophora gossypiella*), and has resulted in 50% to 80% reduction in insecticide application (Sternlight, 1986).

2.2 Key pests and Diseases of field process tomatoes in the Hawkes Bay and potential monitoring systems that could be used.

2.2.1 Tomato Fruit Worm (*Helicoverpa armigera*)

Tomato fruit worm is a major pest of process tomato crops. It feeds on leaves and flowers initially, then moves to the fruit causing significant damage at low population levels. Monitoring can be used to reduce insecticide application, as up to 10% fruit damage can be tolerated on process tomato crops (Walker and Cameron, 1990).

Work has been done in the U.S.A. on *Heliothis zea* a very similar pest to *Helicoverpa armigera*. The monitoring system for *H. zea* (Anon 1985) involves monitoring eggs from the stage when there are significant numbers of green fruit of 2.5 cm in diameter on the plant until one week before harvest. Leaf samples (30 leaves for a paddock of up to 20 hectares in size) are taken from specific parts of randomly selected plants and eggs counted. The procedures and thresholds used are shown in Figure 2. Anon (1985) noted that with careful leaf sampling, it is possible to detect fruitworm before they enter the fruit.

Fruit sampling is another method that can be used but is of limited value due to damage occurring to the fruit before insecticide treatments can be applied. For this reason it is not discussed further.

Figure 2.: Procedure for sampling of *Heliothis zea* eggs in process tomato crops (Anon 1985).

Sampling Leaves for Tomato Fruitworm Eggs

From each sample plant, pick the leaf just below the highest open flower. Check both sides for tomato fruitworm eggs.

1. Pick one sample of 30 leaves. Tally the number of eggs here:____

   If the number is: 0 — don't treat; sample again next week.
   1 or 2 — don't treat; sample again in 3-4 days.
   3 or more — go to step 2.

2. Pick a second sample of 30 leaves, following a different route through the field. Tally the number of eggs here:____

   If the number is: 0 to 3 — don't treat: sample again in 2-4 days.
   4 or more — schedule a treatment for fruitworm. If eggs have not already begun hatching, check again in 2 days before applying insecticide.

Zalom *et al* (1990) gave the results of a demonstration project where 47 fields were monitored and pesticides applied when the number of eggs in the sample exceeded the action threshold (see figure 2.). The results showed that of 1,714 loads of tomatoes delivered to the canners, 1,289 had no damage, 374 were graded as trace damage, and 51 were graded at 0.5% damage. No load exceeded 0.5% damage. Comparative pesticide use on 35 fields not using the TFW egg monitoring program was 12% higher on mid-season fields, and 40% higher on late season fields. Economic evaluation of this demonstration found that use of the monitoring programme significantly reduced the risk of damage and had a net positive benefit of $7.10 US per acre or more depending on the growers degree of risk aversion. Despite the advantages, Zalom *et al* (1990) found that the monitoring programme was not always adopted, and further investigations showed that growers who owned their own land tended to adopt the system more readily than growers that leased land.

Pheromone trapping of adult male moths of tomato fruitworm is another method that could be employed to aid decision making. Hoffmann *et al* (1990) stated that pheromone traps could complement the IPM programm for process tomatoes by helping to determine when to begin sampling for fruitworm eggs. Their research showed that seasonal activity over an area was similar, and that regional trapping could be used to identify timing of flights. Similar work is discussed by Hoffmann *et al* (1991).

Information gathered by monitoring can have long term uses. On a regional scale it may help determine when and where infestations can occur, as well as the seasonal occurrence, movement, migration and spatial distribution of the insect (cited Hoffmann *et al*, 1991). This information could be of practical use in a pest management system.

Walker and Cameron (1990) discussed two monitoring methods trialed in Gisborne, New Zealand. The first was a field sampling or scouting method. The second was monitoring of adult male TFW using pheromone trapping. The first technique monitored egg and larval populations with the purpose of testing various spray decision thresholds. The second was used to determine when and if scouting was necessary, and therefore reduce the time entailed in continuous checking of individual crops. They found that increases in pheromone trap catches in tomatoes occurred in late-January, mid-February, and in March, which coincided with increases in egg counts. Therefore timing of monitoring can be targeted more accurately, and effective application of insecticides achieved.

2.2.2 Bacterial Speck (*Pseudomonas syringae)*

Bacterial Speck (*Pseudomonas syringae*) is a bacterial disease that affects a wide range of plants, causing a number of different diseases e.g. bacterial canker in stone fruits, blossom blight, die back in pear, black pit of citrus, leaf spot and shoot wilt plus many others (Hayward and Waterston, 1965). Considerable pathogenic variability exists, and no one isolate of *P.syringae* will infect all hosts recorded (Hayward and Waterston, 1965). Bacterial speck in tomato is specifically caused by *Pseudomonas syringae* pv. *tomato*, which is widespread in tomato growing areas (Watterson, 1985).

Bacterial speck is difficult to control as its causal organism can be carried as an epiphyte on seeds (McInnes *et al* 1988, Chambers, and Merriman cited Srisink and Sivasithamparam 1987, Bashan 1986). Plant debris, plant trash in the soil (Chambers, and Merriman cited Srisink and Sivasithamparam 1987, Bashan 1986), and non-host plants (Watterson 1985, Schneider and Grogan 1977) can be alternative hosts or carriers of bacterial speck. A study by Srisink and Sivasithamparam's (1987) found that *P.syringae* can occur in any well managed nursery with clean, well ventilated and illuminated glasshouses. Because *P.syringae* pv. *tomato* is so cosmopolitan it is difficult to control.

Distribution of this bacterium is generally wind-driven rain (Hayward and Waterston, 1965), via agents such as man, insects, birds, and on implements that are used in the field (Bashan, 1986). The factor important to transmission is moisture as the bacteria move in a film of water, even in cases where the bacteria is in an aerosol. In addition to passive landing on plants, rain may wash the bacteria from the air (McInnes *et al 1988*).

Basu (1966) reported that bacterial speck development was favoured by temperatures of 15-28°C and relative humidity of 75-97%. Research by Lindemann *et al* 1984, and Weller and Saetter 1980 (cited Jardine and Stephens, 1987) suggested that symptom development was associated with the attainment of some threshold population. Jardine and Stephens (1987) developed models to predict when epiphytic populations of *Pseudomonas* pv. *syringae tomato* reached population (threshold) levels at which symptom expression occurred. Basu (1966) defined an epiphytic threshold population of 1×10^6 colony forming units per millilitre of plant sample. They tested their model under field conditions modifying it so that it would predict when epiphytic populations developed to levels equal to, or greater than threshold level. Jardine and Stephen, (1987) used a threshold level of 1×10^6 as this allowed adequate time to make chemical control applications. It was suggested that the equation in table 3. may have application for use in commercial production areas where speck is a significant problem. But it was also stated that further testing with different cultivars, and in other locations would be needed to determine how it may be best used in a practical disease control program.

This type of model is ideal for a computerised forecasting system, that collects the environmental data for the model, and provides the forecast.

Table 3.: Equation predicting threshold populations of *Pseudomonas syringae* that may be applicable for commercial use in tomatoes (Jardine and Stephens, 1987).

$$BP = 0.98 + 0.72\,(R) - 0.11\,(T) + 0.01\,(H) + 0.51\,(P)$$

BP - the bacterial population predicted ($\log_{10}$).
R - the square root of (sum of the daily rainfall + 0.5 for the previous 7 days) (mm[4]).
T - The average temperature for the previous day (°C).
H - The arcsin square root of the average relative humidity for the previous day.
P - The population level ($\log_{10}$) at the previous sampling time.

2.2.3 Early Blight (*Alternaria solani*)

Early blight is caused by the fungal organism *Alternaria solani*. This organism is widespread in the tropics and in temperate zones. It is most commonly pathogenic to tomato, potato, and other solanaceous crops but has been recorded from a wide range of other species, notably *Brassica* spp. (cabbage, cauliflower) (Ellis and Gibson, 1975).

A foliar disease, early blight is characterised by irregular, brown dead spots up to 16 mm in diameter appearing on the older leaves first. These leaf spots

[4] Millimetres (mm) is assumed to be the units used for rainfall measurements in the equation as none are given in the paper by Jardine and Stephens (1987).

typically have concentric, black rings giving an oyster shell, or target-board appearance to the lesions (Watterson, 1985). These lesions are often surrounded by a yellow area. If there is a large number of lesions on the leaf it may turn completely yellow, dry up, and fall from the plant. In serious cases defoliation can become pronounced (Madden *et al*, 1978).

Pennsylvania State University developed a computerised forecasting system for tomato early blight. FAST (Forecaster of *Alternaria solani* on Tomato) was developed:

1. To identify periods when environmental conditions are favourable for early blight development.

2. To provide an efficient fungicide application guide (Madden *et al*, 1978).

The forecasting system incorporated two empirical models based on the following environmental parameters: maximum and minimum ambient air temperature, hours of leaf-wetness, maximum and minimum temperature during the wetness period, hours of relative humidity greater than 90%, and rainfall (Madden *et al*, 1978). The system indicates the appropriate time for fungicide application when all the factors are conducive to early blight infection. Madden *et al* (1978), Pennypacker *et al* (1983), and Williamson and Hilty (1988) all found this system reduced the number of fungicide sprays used per season with no significant difference in early blight infection compared with frequent spray schedules.

Pennypacker *et al* (1983) noted that FAST may work equally well in other geographical areas with similar weather patterns. They thought that commercial growers would consider using this forecast system only if it provided sufficient labour and financial savings, and if the forecast is reliable so their crop would not be jeopardised by an omitted spray. The likelihood of this occurring will depend on the risk aversion of the grower, and the importance he puts on reducing spray usage in his crop. Therefore it is difficult to predict the acceptance of such a system.

2.2.4 Late Blight (*Phytophthora infestans*)

Late blight is caused by the fungal organism *Phytophthora infestans*. This pathogen is distributed world-wide and has a wide host range including potato, tomato, and other *Solanaceae* plants (Stamps, 1985).

Watterson (1985) described the disease symptoms as: "The first symptoms of the disease are a bending down of leaf petiole. Lesions produced on the leaves and stems are large irregular, greenish, water-soaked patches. These patches enlarge, then turn brown and paper-like. During wet weather these lesions on the underside have a fine, white mould ring around them."

The threat of late blight and therefore, the need for fungicide depends heavily on weather and the supply of fungal inoculum. Late blight is favoured by moderate temperatures(12-20 °C)and abundant moisture (Fohner *et al*, 1984). Environmental conditions in relation to disease development have been used in the development of a number of forecasts for late blight (Hyre 1954, Wallin 1950 (cited MacHardy 1979), Krause *et al* 1975, and MacKenzie 1981).

"Blightcast" is the most commonly referred to forecast system for late blight. "Blightcast" is a combination of two previous forecasting systems; Hyre's system (Hyre 1945), and Wallin's system (Wallin, 1951). "Blightcast" is an integral linking and modification of late blight forecasting methods based on rainfall, relative humidity, and temperature (Krause *et al*, 1975). Fry (1977) found "blightcast" was more effective at controlling late blight than fungicide applications after 1.27cm of rain. However, Fohner (1984) found that in microclimates that favoured late blight, "Blightcast" required on average more sprays than weekly application. Thus it should be noted that simply having a forecasting system in place does not always mean less spray applications than would occur on a calendar spray basis MacKenzie (1984) suggested that the use of "Blightcast" eliminates early season sprays, and sprays where weather conditions are not conducive to the spread of focal infection. MacKenzie (1984) also suggested that as soon as blight symptoms are spotted the grower should change from the "Blightcast" system to a regular scheduled spray program.

If growers applied fungicides according to weather conditions instead of regular calendar sprays, they could reduce fungicide application without risking increased disease (Fohner *et al*, 1984).

CHAPTER 3

PROFILE: PROCESS TOMATO GROWING IN THE HAWKES BAY

3.1 Soils

The soils of the Hawkes Bay are generally a mix of the highly productive recent soils developed from alluvium deposits from the three major rivers that have built up the Heretaunga Plains. The recent soils are surrounded by yellow-grey soils that cover the rolling hilly land, and saline soils that occur on the land raised in the 1931 earthquake and in areas that where reclaimed by diversion of river silts on to its low lying marine marsh (Anon, 1954).

Generally the tomato growing areas are on very productive recent soils concentrated in a 10-15 km radius (as the crow flies) around the city of Hastings (not including crops grown in Waipawa).

3.2 Tomato varieties and areas grown:

In the 1990/1991 season approximately 556 ha of process tomatoes were grown in Hawkes Bay, on average producing 67 t/ha (Tate *et al*, 1991). Approximately ten tomato varieties were used (see table 4.), with Cannery Row being most prevalent. The qualities looked for in a process tomato include a firm skin, high soluble solids, a good brix level, good field storage capacity and good colour.

Table 4.: Tomato varieties grown in the 1990 / 1991 season (approx areas).

Variety*	Area(ha)*	% Area
Cannery Row	323.8	54.6
Alta	80.3	13.5
1204	99.5	16.8
6203	30.8	5.2
Apex	23.8	4.0
Brigade	12.6	2.1
UC82B	7.8	1.3
HM1204	6.4	1.1
Heinz	5.5	1.0
Nemma	2.2	0.4
TOTAL	592.8	100.00

* Variety names as given by J. Wattie Foods

3.3 Seasonal Calendar

3.3.1 Propagation

Tomato seed is imported direct into New Zealand either by Watties or by an importer. This ensures the varieties selected are the required ones for that growing season. These seed are grown on as transplants in cell trays in a local nursery until they are ready for planting.

3.3.2 Planting (end of October to early November):

Planting is generally done by a contractor employed by the growers. This contractor works in conjunction with the a Watties representative.
Planting is semi-mechanical, and plants are planted into preformed raised rows which are approximately 0.2 metres high and 1 metre in width at approximately 0.2-0.3 metre spacings. Before planting the rows are sprayed with a pre-emergence herbicide usually treflan^{R}.

3.3.3 Pest and Disease control

Pest and disease control is wholly the responsibility of the grower, there are no contractual agreements with the process company regulating spray type or usage that the grower has to abide by. Field officers are available to the growers if information is requested. Spray rates are generally carried out as per chemical company recommendations as given on spray labels, and withholding periods are abided by before harvest commences.

3.3.4 Irrigation

Irrigation is carried out with a moving overhead sprinkler system with water derived from artesian wells. With the process company monitoring the soil moisture levels, periods of stress can be determined and recommendations for irrigation given.

3.3.5 Harvest sample

Each truck entering the factory has a 20kg core sample taken from each trailer. This sample is sorted into dirt, greens and defects. Each of these groups is weighed. At the same time a brix reading on a sample of good fruit is taken and this plus the percentage of good fruit is used to determine the pay-out rate to the growers.

CHAPTER 4

METHODS

4.1 Grower survey

Seven major process tomato growers growing for J. Wattie Foods were surveyed. This survey was to enlist their co-operation in completing spray diaries during the 1990/1991 tomato season, and to ask questions pertaining to their spray practices. For this a survey sheet (table 5.) was developed.

The grower survey sheet was designed to ask simple questions that the grower could readily answer. As interviews were personally conducted more comprehensive answers could be elicited and any explanations given if required. Most growers were interviewed in their homes with only one interviewed by telephone. This meant interviewees where in a comfortable relaxed atmosphere which was more conducive to a thorough completion of the questionnaire. All growers except one completed the questionnaire.

4.2 Spray diaries

Growers were asked at the beginning of the 1990/1991 season to document all fungicide and insecticide spraying done on a paddock to paddock basis. Information requested included the date sprayed and the materials used. Table 6. is an example of a typical grower spray record sheet. The spray diaries were supplied at the start of the season, and collected at the end of the season by J. Wattie Foods (Hastings).

Information from these diaries was used to determine when growers sprayed, whether spraying was calendar based or whether other factors such as weather or insect presence had any influence.

The average number of fungicide and insecticide sprays applied per grower in the 1990/1991 season was calculated as a average over all growers.

Table 5.: Grower survey sheet used in interviews with Hawkes Bay process tomato growers.

GROWER SURVEY

OBJECTIVE :

The overall objective of my thesis is to assess the potential for pest management in field process tomatoes. Effective pest management may mean a decrease in spray usage and costs, and increased use of bio-control.

The information I am requesting from you will be used in conjunction with information on pest and disease problems that predominate in your crops throughout the season. From this information I hope to do cost/benefit studies of different systems that may reduce the number of sprays while retaining the necessary quality needed for processing.

INFORMATION REQUESTED :

A spray diary to be kept with information on :

- Dates of spray application
- Sprays used
- Rates of sprays used (rate / ha)
- Time taken per paddock (man hours)
- Time taken to fill tank with sprays (tractor idling during this time)

What do you as a grower perceive as the major pest and disease problems in your tomato crops?

For what pest and diseases do you spray on a regular schedule?

If thresholds are used what are they?

What proportion of total production costs are made up of pest and disease costs?

Table 6: Sample of spray diary sheet used by growers

SPRAY RECORD

GROWTH STAGE VARIETY **Block No.**

DATE	PRODUCT USED	RATE	PEST PROBLEM	WEATHER	COMMENTS
18/11/90	Champ	2 lit			
	Tamaron	2 lit			
25/11	Kocide 606	2 lit			
	Manzate DF.	2 Kg			
22/12	Kocide	2 lit			
	Hallmark	250 ml			
	Summisclex	2 lit.			
14/1	Kocide 606.	2 lit			
	Hallmark	250 ml			
	Summisclex.	2 lit			

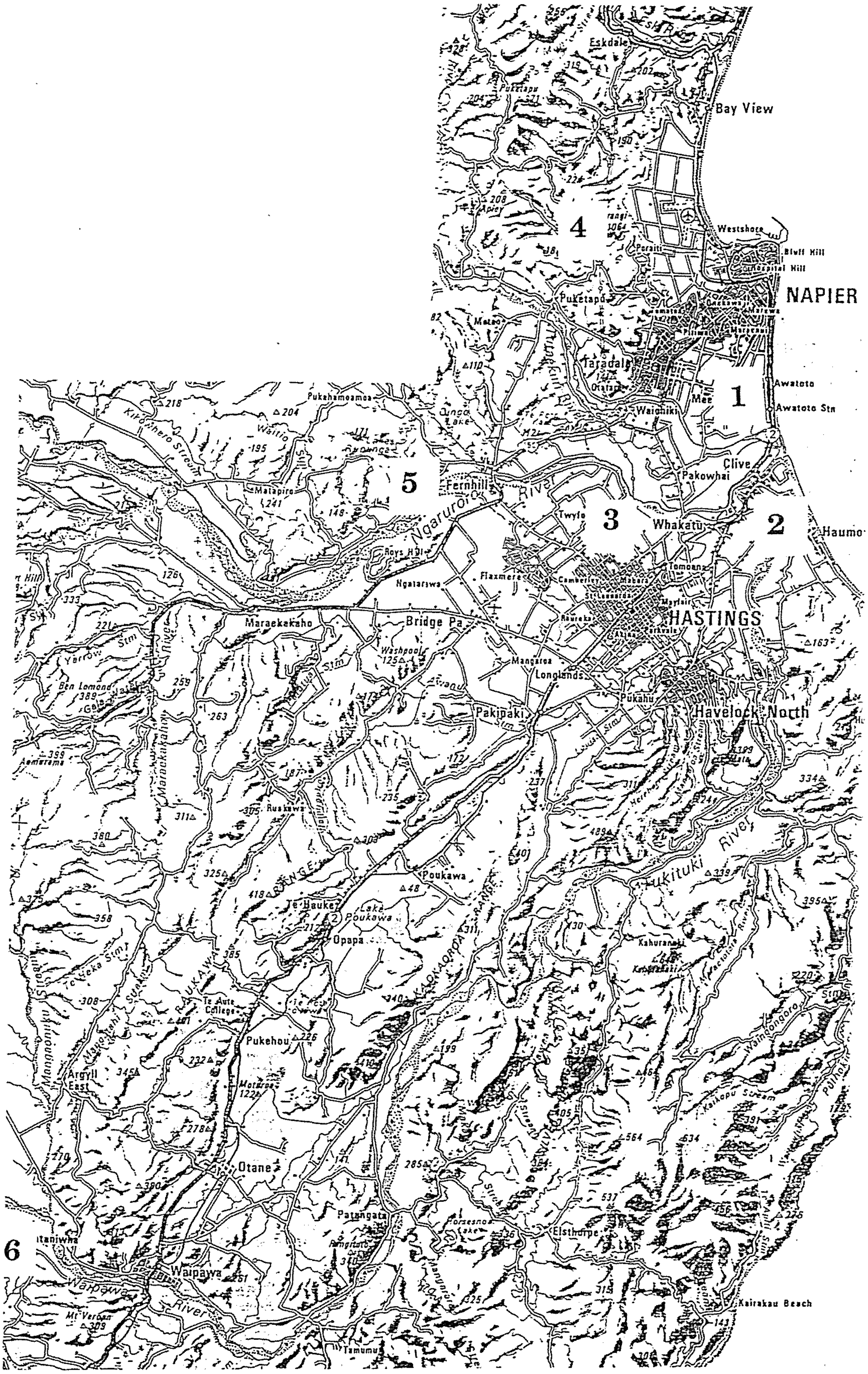
4.3 Paddock selection

For within season monitoring of pests and diseases a range of paddocks was selected. Paddock selection took into consideration a cross section of planting dates, travel time, and an attempt to view an area where a number of fields grown by different growers occurred (Farndon Road). Taking these criteria into consideration approximately 40 percent of fields were assessed from each of the major growers surveyed, though this may have been higher in some instances due to some fields having more than one variety. Some growers had less than 40 percent due to incomplete data received at the end of the season. Once paddocks were selected they were divided into six groupings which pertained to different geographical locations (see Table 7. and Figure 3.). This grouping was based on physical proximity of paddocks in an area, and the proximity to a weather data collection site.

Table 7. : Location classification of tomato growing areas.

LOCATIONAL GROUPING NUMBER	LOCATION (ROAD NAMES)
1	Farndon Rd, Riverbend Rd.
2	Tuki Tuki Rd,Parkhill Rd, Te Mata-Mangateretere Rd, Brookvale Rd, Lawn Rd.
3	Percival Rd, Ellwood Rd, Karamu Rd, Lynhurst Rd, Evenden Rd, York Rd.
4	Puketitiri Rd.
5	Ohiti Rd.
6	Onga Onga Rd, Waipawa.

Figure 3. : Map showing geographical location groupings of process tomato crops used as defined in Table 7.



4.4 Weather

Weather data (Anon, 1991) for Hastings, Napier, Havelock North, and Waipukarau were obtained from the daily newspaper 'The Hawkes Bay Herald Tribune'. The data included daily rainfall (mm), maximum and minimum temperature (°C), and frost readings (°C). The reading were for the previous 24 hours to 9am on the date of publication. There were days when data was not available such as week-ends and public holidays when the paper was not published.

4.5 Development of field monitoring sheet

A survey sheet was developed that could be used in field surveys to gather relevant information pertaining to specific fields.

The first sheet consisted of a single sided form to record data (see table 8.). This sheet was amended after the first survey, as a decision was made to count insect numbers on a per plant basis after the initial sheet had been printed. The amended form, as shown in table 9. had an area that allowed for insect numbers to be recorded on the back.

The pests and diseases included on the form are a duplicate of the pests and disease found on the 1989/1990 J. Wattie Foods tomato crop monitoring form (see table 10.). All other information such as date of collection, paddock number, and stage of growth was also included, so that all information pertaining to a specific field was recorded on one sheet.

Table 8.: Initial survey sheet used in the 1990/1991 field survey of process tomato crops in the Hawkes Bay.

TOMATO CROP MONITORING

DATE OF COLLECTION : ____________

PADDOCK NUMBER : ____________

STAGE OF PADDOCK (1-5) : ____________

Diseases	Nil	Low	Med	High	Define
Speck					
Sclerotinia					
Botrytis					
Late blight					
Early blight					
Fusarium crown					
Verticillium wilt					
Brown rot/Corky root					
Anthracnose					
Blossom end rot					
Spotted wilt					
Curly top					
CMV					
TMV					
Other					

Pests

Aphids					
Thrips					
Tomato fruit worm					
Looper					
Cutworm					
Wireworm					
White fringed weevil					
Slug damage					
Other					

Table 9.: Revised survey sheet (two sides of paper):

9 (a). Side one

TOMATO CROP MONITORING

DATE OF COLLECTION : ____________________

PADDOCK NUMBER : ____________________

STAGE OF PADDOCK (1-5) : ____________________

DISEASES	nil	low	med	high
Speck				
Sclerotinia				
Late blight				
Botrytis				
Early blight				
Fusarium crown				
Verticillium wilt				
Brown rot/ Corky root				
Antrahose				
Blossom end rot				
Spotted wilt				
Curly top				
CMV				
TMV				
OTHERS				

PESTS	nil	low	med	high	PESTS	N	L	M	H
Aphids					Thrips				
Tom fruit worm					Looper				
White frin weevil					Leaf-hopper				
Cutworm					Slug damage				
Wireworm					Other				

9 (b). Side two

INDIVIDUAL PLANT SAMPLE

No.s	APHIDS	THRIPS			
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
TOTAL					

Table 10.: Tomato Crop Monitoring form used by J. Wattie Foods.

TOMATO CROP MONITORING

DATA COLLECTION FORM 01

Date of Collection : ____/____/____

Paddock Number : ____________

Water Status (0.1m) : ____________

Water Status (0.3m) : ____________ Soil Temperature (°C) : ____________

DISEASES	NIL	LOW	MED	HIGH
Speck	☐	☐	☐	☐
Sclerotinia	☐	☐	☐	☐
Botrytis	☐	☐	☐	☐
Spotted Wilt	☐	☐	☐	☐
Late Blight	☐	☐	☐	☐
Early Blight	☐	☐	☐	☐
Curly Top	☐	☐	☐	☐
Fusarium Crown	☐	☐	☐	☐
Verticillum Wilt	☐	☐	☐	☐
Brown Rot/Corky Root	☐	☐	☐	☐
Anthranose	☐	☐	☐	☐
Blossom End Rot	☐	☐	☐	☐
Other ________	☐	☐	☐	☐

PESTS	NIL	LOW	MED	HIGH
Aphids	☐	☐	☐	☐
Thrip	☐	☐	☐	☐
Tomato Fruit Worm	☐	☐	☐	☐
Looper	☐	☐	☐	☐
Cutworm (@ est)	☐	☐	☐	☐
Wireworm (@ est)	☐	☐	☐	☐
White Fringe Weevil (@ est)	☐	☐	☐	☐
Slug Damage	☐	☐	☐	☐
Other ________	☐	☐	☐	☐

WEEDS

	NIL	LOW	MED	HIGH
General Condition	☐	☐	☐	☐

Presence of:	YES	NO		YES	NO
Night Shade	☐	☐	Nut Grass	☐	☐
Couch	☐	☐	Bindweed	☐	☐
Other Grasses	☐	☐			

Name Major Weed Species: ____________________

Flowering Status : 1st SET ☐ 2nd SET ☐ FULL ☐

Nitrogen Leaf Analysis (ppm Nitrates) : ____________

WORK DONE SINCE LAST VISIT (Observation Only)

	YES	NO		YES	NO
Irrigation	☐	☐	Thinning	☐	☐
Cultivation	☐	☐	Spraying	☐	☐
Handweeding	☐	☐			

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4.6 Insect and disease assessments

The majority of pest and disease incidence data used in this thesis was collected throughout the season by a J. Watties Foods Field Officer. As I was using this information it was necessary to compare the results from Watties field reports to the data that needed to be collected for this thesis.

4.6.1. Wattie J Foods Method:

Inspection of tomato fields was done weekly by a J. Wattie Foods representative. Inspection involved moving around each field in a random manner observing plants and shaking a number (generally more than ten plants per field) onto a sheet of white polythene. Visual estimates were made of disease incidence and insect infestation, each of which were classified arbitrarily into categories of high, medium, or low.

4.6.2. Author's method:

Selected paddocks were visited twice on the 10th and 11th of December 1990, and the 24th and 25th of January 1991. The plants were classified into one of 5 growth stages (see table 11, and figure 4 a,b,c,d,e). The five growth stages are a personal interpretation, and are based on the area a plant covers in the planted row.

The inspection method used was based on that of Watties, but more standardised. Fifteen plants were randomly selected from different areas in the field. These were given three firm shakes onto a 21cm x 29.7cm white waterproof cardboard sheet. The insect numbers were counted (insects/plant) and recorded, then classified as high medium or low according to an arbitrary system based on previous experience, as shown in tables 12a. and 12b.

Table 11.: Growth stages of tomato plants (personal view)

GROWTH STAGE	DESCRIPTION OF GROWTH STAGE
1	Newly planted, and plants just starting to grow. (Photo 1a).
2	Plants cover half the area between plants in the row. (Photo 1b.)
3	Plants touching each other within the row. (Photo 1c.)
4	Plants cover half the bed width. (Photo 1d.)
5	Full sized plants that cover the whole bed width. (Photo 1e.)

Figure 4 (a): Growth stage 1.

Figure 4 (b): **Growth stage 2.**

Figure 4 (c): **Growth stage 3.**

Figure 4 (d): Growth stage 4.

Figure 4 (e): Growth stage 5.

Table 12.: Arbitrary classification of insect density in relation to plant growth stages (mean number of insects on 15 plants). (a) Aphids and thrips; (b) Tomato fruit worm.

12 (a).: Aphids and thrips

Stage of growth	Low (insects/plant)	Medium (insects/plant)	High (insects/plant)
1	0.1 - 0.9	1.0 - 2.0	2.0+
2	0.1 - 0.9	1.0 - 2.0	2.0+
3	0.1 - 1.4	1.5 - 3.0	3.0+
4	0.1 - 3.9	4.0 - 6.0	6.0+
5	0.1 - 3.9	4.0 - 6.0	6.0+

12 (b).: Tomato fruit worm.

Stage of growth	Low (insects/plant)	Medium (insects/plant)	High (insects/plant)
1,2,3	NA	NA	NA
4	0.1 - 0.9	1.0 - 2.0	2.0+
5	0.1 - 0.9	1.0 - 2.0	2.0+

As tomato fruit worm is generally not found until the end of January in Hawkes Bay and Gisborne (Walker and Cameron, 1990), the plant growth stages 1, 2, and 3 are not applicable.

Determinations of disease levels were qualitative assessment based on personal experience of overall incidence made while moving around the paddock, taking into account the number of plants and the severity of symptoms.

4.7 Comparison of monitoring techniques:

The inspection results obtained by Wattie J Foods and that obtained by the author were compared.

Inspection results compiled by Wattie J Food on the weeks 11th to 16th December 1990, and 22th to 27th January 1991 for selected paddocks were compared to the data I collected on 10th and 11th of December 1990, and the 24th and 25th of January 1991 for the same paddocks.

Specific comparisons included, identification of the pests, diseases (including viruses) found in the field, and the levels at which they occurred.

4.8 Insect identification

Samples of commonly occurring insects were collected during the second field sampling, on the 24th and 25th of January 1991. Caterpillars were placed in a vial of EAA[5] for 24 hours then transferred into 75% ethanol until identification could be carried out. Aphids and thrips were placed directly into ethanol until identified.

Identification of the insect samples was undertaken by Dr. P.G. Fenemore on January the 28th 1991.

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[5] EAA is a 1:2:10 ratio of petroleum ether: 100% glacial acetic acid: 95% ethyl alcohol

4.9 Pre-harvest samples

A pre-harvest sample was taken from each paddock approximately one to two days before it was harvested. The sample consisted of three tomato plants that were selected arbitrarily from around the paddock and pulled out by the roots. All fruit, including rotten fruit under the plant were collected and placed in a box. All the fruit were then sorted into a number of categories according to defects and weighed (see table 13.).

Both the Watties field officer and the author inspected the same sample separately and results were noted separately on J. Wattie Foods Pre-Harvest Sampling Sheets (as seen in figure 3.). These were later compared visually to see if there were any appreciable differences between them. Only one comparison was possible due to the time of my visit, and the paddocks being sampled.

Table 13. Pre-harvest sample sheet.

TOMATO PRE-HARVEST SAMPLING

PADDOCK No:.......... DATE:........... (WEIGHT IN Kg)

Total Weight of Fruit = ...

Total no. of Fruit = ...

	GREEN	BREAKER	RED
TOTAL WEIGHT WITHIN COLOUR GROUP			
Deduction Categories 1) Blossom End Rot			
2) Split Fruit			
3) Black Mould			
4) Ground and Water Rot			
5) Anthracnose			
6) Virus Fruit			
7) Sunburnt Fruit			
8) Bacterial Speck			
9) Insect Damage			
10) Other Defects			

COMMENTS...

....

....

4.10 Spray application

4.10.1 Insecticide application:

A visual analysis was made comparing dates paddocks were sprayed with insecticide to the incidence of pests in the field, as documented in the weekly field report. This was undertaken with three growers who did not to use insecticides every time they sprayed. Information from growers' spray diaries was used to determine if pest incidence as reported in J.Wattie Food's (Hastings) weekly summary sheet may have been used as a basis for insecticide application.

4.10.2 Fungicide application:

Rainfall data was graphed for the 6 different areas as mm rainfall against date. Dates of fungicide application were indicated on the graphs to determine if there was any indication of spraying being done in relation to rainfall. An assumption was made that growers spraying within seven days after a period of rainfall do so due to the rainfall. This time takes into account the fact that growers cannot always get onto a field immediately after rain and that they have other tomato fields and crops to manage.

4.11 Intervals between sprays

For each paddock surveyed information from spray diaries was used to determine the time interval between each spray applied. This was done on a per paddock basis, but results graphed on a per grower basis[6]; then as a summary for all growers for the season. This graphed information was used to determine whether growers used a calendar based spraying system for pest and disease control.

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6 The number of paddocks per grower ranged from 3-12.

4.12 Relationship between spraying frequency and yield

A correlation analysis was carried out using spray diary data and yield data to determine if there was any relationship between spraying frequency and yield.

4.13 Rainfall

"Rainfall" as such can be difficult to determine due to its complexity. The problem in using rainfall as a threshold for spray recommendations is that rainfall is a complex process. A number of factors make up rainfall

* Amount (mm) and /or intensity
* Duration of each wet period
* Total duration (sum of wet periods)
* Number of wet periods

These factors make rainfall a difficult factor to use as a threshold. From the information available (daily rainfall in total mm) it is very difficult to assess the type of rainfall that occurred during the day. A description of rainfall intensity estimates is described by Neale (1985).

There is a further difficulty to consider i.e. assessing growers perceptions of levels of rainfall. They may recognise, or say that they spray after rainfall, but may not quantify amounts of rainfall in relation to spray application. Therefore a number of assumptions have been made to determine a threshold for the number of sprays that were needed in the 1990/1991 growing season.

The base threshold was determined by first identifying the growers with the highest and lowest number of sprays applied in the season. These both occurred in the Havelock North area (grower C,and F). After comparing data in relation to disease incidence and yield pertaining to these fields it was decided to use the grower who had the lowest number of sprays. An assumption was made that the grower concerned had a spray programme that suited the 1990/1991 season in terms of lower spray usage for acceptable yield and fruit quality. A horizonal line was placed on the rainfall graph for that area, then moved to a position on the graph where the five highest levels of rainfall were above or near the line. The rainfall level of this line was then used as the rainfall threshold at which fungicide spraying would be required. This threshold was then applied to rainfall graphs of other areas, to determine the hypothetical number of sprays that should have been applied in that area that season if the growers had been using the threshold.

4.14 Comparison of survey results with investigated data

The weather data, interval between sprays, Watties data sheets on pest and disease incidence and dates of fungicide and insecticide application were analysed to determine if the thresholds as stated by growers were in fact taken into account.

CHAPTER 5

RESULTS

5.1 Grower's perceptions of pest and disease problems

Table 14. summarises the pests and diseases that growers perceive as major problems in their process tomato crops, and those that they spray for on a regular basis.

5.2 Spray Costs

Most growers (4 out of 6) estimated that 13-16% of their total production costs were made up of pest and disease control costs (see table 15). Several growers stated that their proportion of costs would be the same as another grower they specifically named. Yet when comparing the number of sprays applied between growers there were differences in the average sprays for the season.

Of the six growers surveyed only two had worked out the pest and disease control costs and could readily give an answer to this question (see table 15). Most growers do not have a clear idea of their proportion of pest and diseases costs in relation to total production costs.

5.3 Comparison of pest and disease assessments

The surveys done on 11-16 th of December 1990, and the 22-27 th of January 1991 when compared to the corresponding weekly paddock reports compiled by J.Wattie Foods (Hastings) showed that levels of pest incidence (high, medium, and low) were similar though differences were found in some of the actual pests and diseases reported. This could be expected with low incidence and patchy distribution of pests and diseases during the season.

Table 14.: Pests and diseases that process tomato growers perceive as major problems and those they spray for regardless of incidence.

Grower	Insect	Disease	Pests or Diseases sprayed for on a regular basis
B	Aphid # Thrips # TFW *	Bacterial Speck	Bacterial Speck Late blight
C	Aphid # TFW *	Bacterial Speck	Aphid # TFW * Bacterial Speck
D	Aphid # Thrips # TFW *	Late Blight Sclerotinia Botrytis	Aphid # Thrips # TFW * Late Blight Sclerotinia
E	Aphid # Thrips # TFW *	Late Blight Early blight Sclerotinia Bacterial speck	Aphid # Thrips # TFW * Late Blight Early Blight
F	TFW *	Bacterial Speck Late Blight	Aphid # Thrips # TFW * Late Blight Bacterial Speck
G	Aphid # Thrips # TFW *	Early blight Bacterial Speck Sclerotinia + Botrytis +	Aphid # Thrips # TFW * Early Blight Late Blight Bacterial Speck Sclerotinia +

Early season problem, * Tomato fruit worm, + Seen as problem after fruit set.

Table 15.: Summary of spray costs as a percentage of total production costs, as given by process tomato growers.

Grower	Proportion of total production costs made up of spray costs (%)	Calculated (✓) or guessed (x) estimate of costs
200	13.5	x
300	15-16	x
400	NI*	x
500	10-15	x
600	13.6	✓
700	31.3	✓

* Grower had no idea of proportion of costs.

5.4 Insect counts

Insect counts from surveys conducted by the author and classified according to the arbitrary method are summarised in table 16 a,b,c,d,e.
Data from J.Wattie Foods indicated that only low numbers of any insect species were found in all paddocks over the 1990/1991 tomato season.

Table 16.: Insect infestation levels in process tomato paddocks at five crop growth stages in 1990/1991 season (a). growth stage 1.; (b). growth stage 2.; (c). growth stage 3.; (d). growth stage 4.; (e). growth stage 5. (for definition of growth stages see page 34).

Table 16 (a).: Growth stage 1 (GS1).

Insect	Total number of paddocks at GS1	Total number of paddocks where insects occurred	Number paddocks classified: Low	Number paddocks classified: Medium
Aphids	21	16	15	1
Thrips	21	13	13	_

Table 16 (b).: Growth stage two (GS2).

Insect	Total number of paddocks at GS2	Total number of paddocks where insects occurred	Number paddocks classified: Low	Number paddocks classified: Medium
Aphid	8	5	4	1
Thrips	8	4	4	_
Tomato Fruit Worm	8	1	1	_

Table 16 (c). Growth Stage Three (GS3).

Insect	Total number of paddocks at GS3	Total number of paddocks where insects occurred	Number paddocks classified: Low	Number paddocks classified: Medium
Aphid	11	7	7	_
Thrips	11	8	7	1

Table 16 (d). Growth Stage Four (GS4).

Insect	Total number of paddocks at GS4	Total number of paddocks where insects occurred	Number paddocks classified: Low	Number paddocks classified: Medium
Aphids	45	25	25	_
Thrips	45	28	24	4
Tomato Fruit Worm	45	13	13	_

Table 16 (e). Growth Stage Five (GS5).

Insect	Total number of paddocks at GS5	Total number of paddocks where insects occurred	Number paddocks classified: Low	Number paddocks classified: Medium
Aphids	15	9	9	_
Thrips	15	10	9	1
Tomato Fruit Worm	15	6	6	_

5.5 Insect identification

Identifications of commonly occurring insects collected on January 24th and 25th 1991, are shown in table 17.

It was noted that the thrips species most commonly referred to as the vector of tomato spotted wilt *Frankliniella occidentalis* (western flower thrips) (Kale Pers.Comm., 1990, Cho et al 1986, Tate et al 1991, Yudin et al 1990) was not identified from the samples collected.

Table 17. Identification of commonly occurring insects in process tomato crops, Hawkes Bay. (Collected 24th and 25th January, 1991).

Identified Insect	
Scientific name	**Common name**
Myzus persicae	Green peach aphid
Brevicoryne brassicae	Cabbage aphid
Macrosiphum euphorbiae	Potato aphid
Brachycaudus helichrysi	Leafcurl plum aphid
Thrips tabaci	Onion thrips
Chirothrips manicatus	Timothy thrips
Helicoverpa armigera conferta	Tomato fruit worm
Chrysodeixis eriosoma	Green Looper Caterpillar

5.6 Spray Diaries

The average number of sprays applied by growers is shown in table 18. A noticeable feature was that all spray programmes were based on protectant fungicide schedules.

Five growers applied insecticides routinely with each fungicide application (with the exception of the last fungicide spray at the end of the season with the application of ethral). The remaining two growers did not include insecticides with every fungicide application.

Table 18.: **Average number of fungicide and insecticide applications* for the 1990/1991 season.**

Grower	Fungicides	Insecticides
A	8	7
B	8	5
C	4	3
D	5	4
E	9	8
F	11	4
G	7	3

* all averages are for paddocks sampled in the survey.

5.7 Insecticide application

Of the three growers (B, F, and G) who did not apply insecticide with every fungicide spray only one grower's (G) records suggested that he used field inspection data in determining the need for insecticide application. Grower F's results suggested that the weekly inspection data were used later in the season for insecticide use. With grower B there was no indication that inspection data was used. Over all, therefore there was little indication that inspection data was used, resulting in many insecticide sprays being applied at times when there were no detectable, or low insect numbers. However, it should be noted that grower's tolerance to its presence will depend on the insect i.e. a low infestation of aphids is tolerated more than a low infestation of tomato fruitworm due to the high potential loss of yield that the latter can cause. For those growers whose spray records did not relate to either the weekly field reports or insect presence no other determinant other than protective insurance spraying can be suggested.

5.8 Fungicide application

Fungicide application in relation rainfall is shown in table 19. This data indicates that, averaged over all growers, 72% of fungicides were applied after as little as 0.2mm of rainfall per day. This suggests that rainfall may be being used by growers as an indicator for spray timing. However results are not conclusive and seem highly improbable considering the levels of rainfall and the complexity of rainfall pattern, i.e. 0.2 mm of rainfall is not a significant quantity of rainfall (Heerdegan Pers. Comm. 1991, Neale 1985).

Table 19.: Fungicide application in relation to rainfall

Grower	Percentage of fungicide sprays applied for a defined period of rain see page 49.	Lowest rainfall (mm) recorded after which fungicide application occurred.
100	66	0.4
200	67	0.5
300	64	0.4
400	84	0.5
500	63	0.8
600	79	0.2
700	85	0.7

It is possible for a grower to follow a calendar spray schedule and for those sprays to occur within seven days of rainfall by chance. Table 20. shows that the chance of this occurring is quite high. 2mm rainfall was used as it was considered a significant rainfall that would be noticed (Heerdegan Pers. Comm, 1991).

Table 20.: Chance occurrence of fungicide application after >2mm rainfall with paddocks sprayed on a calendar schedule. Grower F, three paddocks.

Paddock number	Total number sprays for the season	Number of rainfalls ≥ 2mm	Number of sprays applied after ≥ 2mm rainfall	Percentage chance of fungicide spray occurring after ≥ 2mm rain
1	11	8	4	50.0
2	10	8	3	37.5
3	13	11	8	72.7

5.9 Pre-harvest Samples

Table 21. shows the defects found in a pre-harvest sample taken on the 19 March 1991 by the J. Wattie Foods representative, and by the author.

A noticeable difference occurred only in defects attributed to black mould. This occurred as all fruit which had splits in addition to black mould I classified under 'split fruit', whereas J.Wattie Foods' field officer classified them under black mould. The majority of these problems found in the pre-harvest sample are related to pests and diseases that develop during the last months of ripening (table 22.)

Table 21.: Pre-harvest defects as assessed J.Wattie Foods field officer and myself from one field. (Collected 19 March 1991).

	Red	Deductions (kg)
Deduction Categories	My-own	Watties
Split Fruit	0.94	1.2
Black Mould	0.05	0.9
Ground and Water Rot	1.63	1.1
Anthracnose	0.48	–
Insect Damage	0.35	0.35

Of the 819.45kg taken over all sites as pre-harvest samples, 10.8% was made up of the defects listed in table 22. From this data it is clear that the major defects that occur are a result of black mould, and ground and water rots (79% of the defect total weight). These generally develop in the last months before harvest, with the increasing number of ripe fruit present on vines. These are rots that the spray programme is not able to prevent.

In comparing the percentage of defects documented in relation to the intake weight into the factory (harvest sample), and the percentage in the pre-harvest sample it was apparent that the pre-harvest sample does not give a very accurate prediction of the reject level at actual harvest. Out of 47 samples only 10.64% of the harvest samples were within 1% of the pre-harvest sample, with 38.30% being higher, and 51.06% lower than the pre-harvest sample. It would be expected that the pre-harvest sample defect estimate would be higher as all fruit is weighed, including rotten fruit that would normally fall through the harvester at harvest and, because the sample is gone over more thoroughly, fruit that would be acceptable to the factory can be sorted out. For example, in the case of bacterial speck which at low levels is a superficial blemish on the fruit surface.

Table 22.: Major defects identified in surveyed paddocks from pre-harvest samples taken by J. Wattie Foods, as a percentage of defect weight, and of total sample weight.

Defect identified	Percentage of each defect category in relation to the defect weight	Percentage of each defect in relation to total sample weight
Black Mould	41.34	3.83
Ground and Water Rots	29.35	3.84
Split Fruit	12.78	1.3
Insect Damage	9.08	0.74
Blossom End Rot	3.16	0.54
Bacterial Speck	2.47	0.29
Others	1.83	0.03

With the high percentage of defects in the "rot" categories an examination of the final fungicide spray (applied with ethral for ripening) is of interest. 79.17% of final fungicidal sprays consisted of chlorothalonil (Bravo) (see table 23.). This is a broad-spectrum, protectant fungicide with good adherence characteristics to improve resistance to wash off by rain (Anon, 1989). The use of a broadspectrum fungicide is recommended at this time by Watterson (1985), as well as cultural methods that keep the fruit from coming in contact with the ground, to limit fruit rots. This in practice is very difficult due to the growth habit of the tomato vine, the commonly increased rainfall during the time of harvest, and the increased exposure of tomato fruit to climatic elements due to ethral sprays causing canopy die back.

Table 23.: Fungicides used for final sprays.

Spray used	Number of paddocks sprayed with specific fungicide.	Percentage of sample paddocks sprayed (%)
Bravo	38	79.17
Semisclex	1	2.08
Mancozeb	3	6.25
Bravo + Mancozeb	1	2.08
Semisclex + Copper*	3	6.25
Mancozeb + Copper*	2	4.17

* Range of copper sprays were used, though generally these were Kocide.

5.10 Weather

The hypothetical rainfall threshold worked out (see page 54.) at which fungicide sprays should ideally have been applied indicated that five sprays should have been applied for the season. This includes the final fungicide applied with the ethral spray. When a horizontal line was drawn on the Havelock North rainfall graph, and compared to a point where 5 rainfall peaks were above or near that horizontal line, the rainfall associated with this point was determined to be 12mm/day. When this rainfall threshold was applied to other sites (see appendix one) the theoretical number of sprays that needed to be applied in the 1990/1991 in each area are shown in Table 24.

Table 24.: The theoretical number of fungicide sprays that should have been applied in the 1990/1991 season using a rainfall threshold level of 12mm/day.

Area (as shown in table 7.)	Number of sprays
1	5
2	6
3	6
4	5
5	6
6	8

Most growers sprayed more than this, with the exception of grower D, located at Waipawa. The tomato fields in Waipawa received more regular rainfall through the season than the fields closer to Hastings and theoretically required three more sprays than the five sprays that were applied. This may be relevant with respect to the *Sclerotinia* problem that developed on this site.

5.11 Spray determinants used by growers

The determinants that growers said they used for spraying are summarised in Table 25.

If the grower was using a calendar spray schedule one would expect concentrated bars over three to four days on the graph, If he was not one would expect a wide or irregular spacing of bars with no concentration of bars in one area of the graph. Figure 5 summarises the time interval between sprays over all surveyed growers for the 1990/1991 season. Figure 6 a, b, c, d, e, f, g, gives this data on a per grower basis. The general pattern of figure 5 suggests some type of calendar spray schedule, but closer investigation of the area of concentrated bars reveals a wide spread between sprays of 9 - 18 days. A summary of calendar spray on a per grower basis is given in table 26. Growers B, C, D, and E identified a number of thresholds that they said they used to determine spray applications (table 25). However from an analysis of the data collected throughout the season (table 26) there is no suggestion that any of the thresholds were in fact used. Figure 6 b, c, d, e do not suggest a calendar basis either, and analysis of weather data and Watties field reports does not indicate that weather or insect presence resulted in spray application.

Grower F was the only grower for whom thresholds stated in the survey were substantiated by analysis of the season's data. He stated that he calendar sprayed all his tomato crops and Figure 6 graph f results suggests that this is true.

Grower G stated that he had a basic calendar programme that was influenced by weather, but Figure 6 graph g does not support this. The spread of bars in time interval between sprays is too wide, and information from spray diaries compared to rainfall data does not suggest that weather was used.

Table 25.: **Determinants that growers indicated they used for spraying. ✓ - used, x - not used.**

Grower	Calendar basis	Weather	Presence of insect	Plant growth	Watties sheet
B	x	✓	✓	x	x
C	x	✓	✓	x	x
D	✓	x	✓	x	x
E	x	✓	✓	✓	✓
F	✓	x	x	✓	x
G	✓	✓	x	x	x

Figure 5.: **Time interval between spray applications over all growers for the 1990/1991 season.**

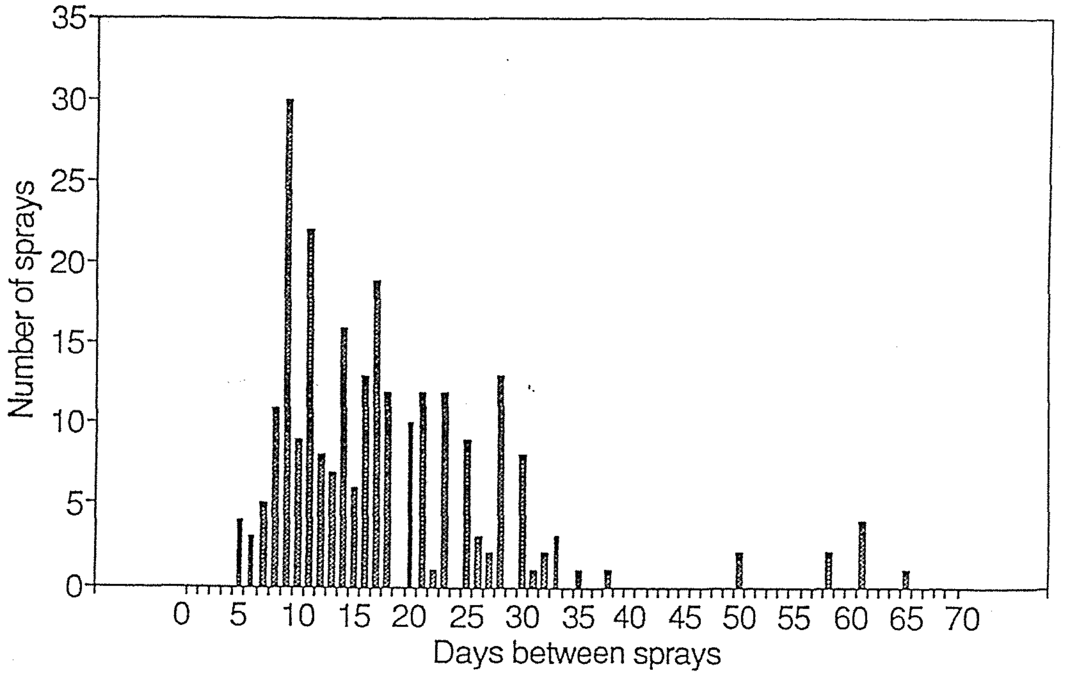


Figure 6 (a).: **Spraying frequency - Grower A**

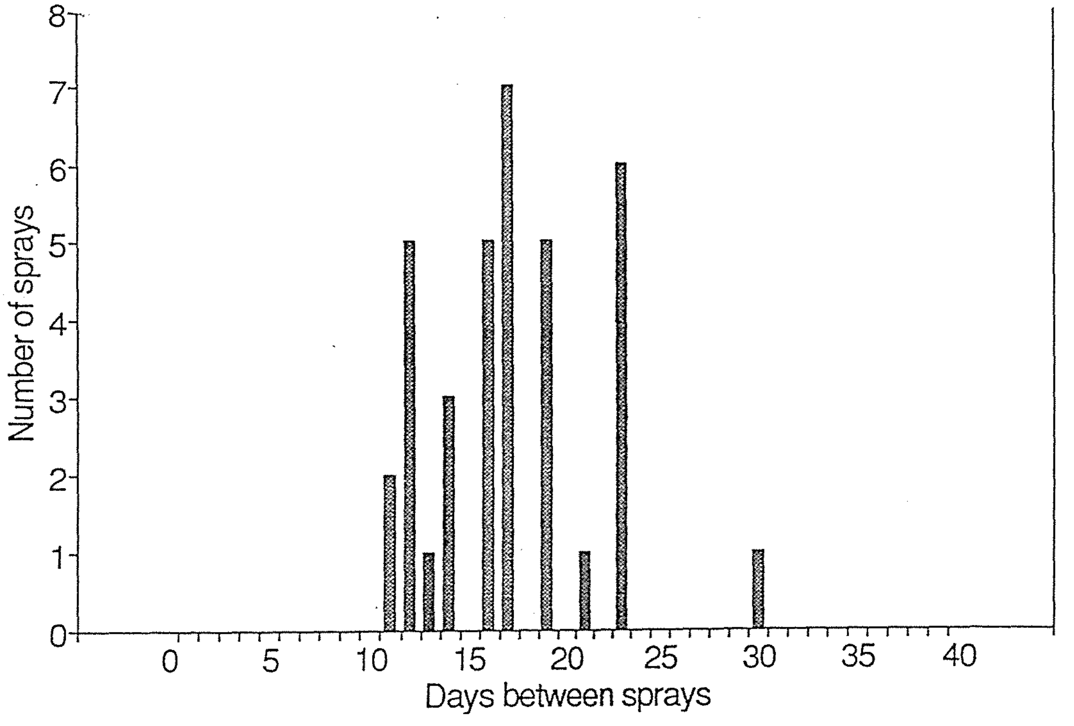


Figure 6 (b).: **Spraying frequency - Grower B**

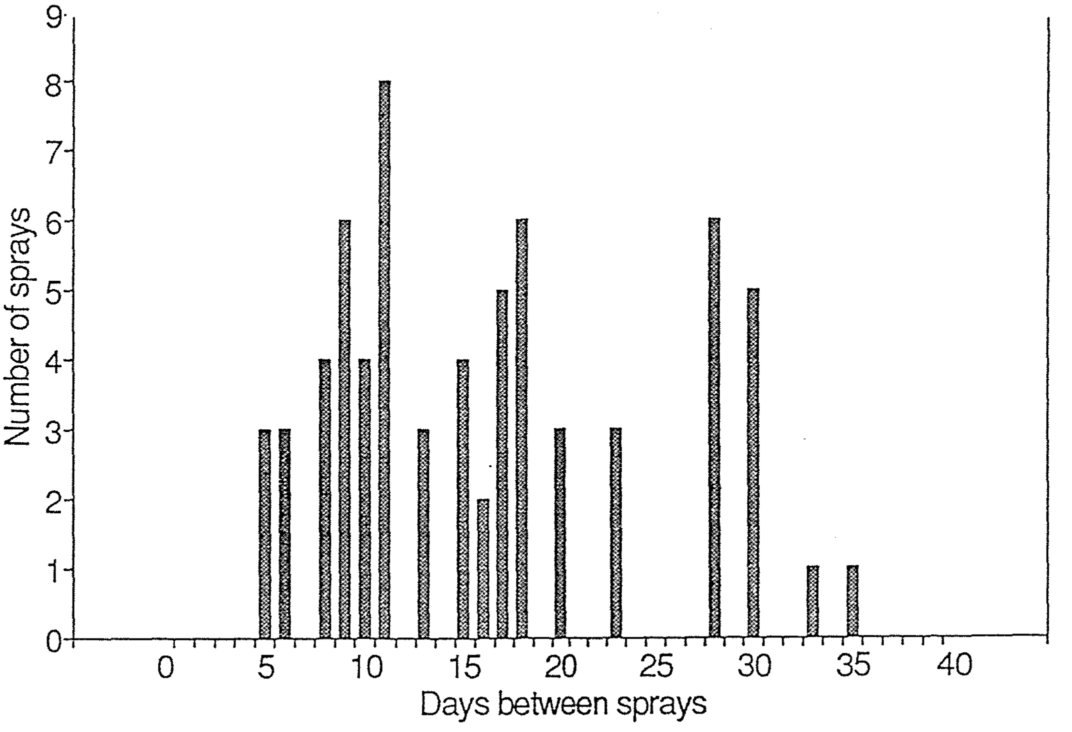


Figure 6 (c).: Spraying frequency - Grower C

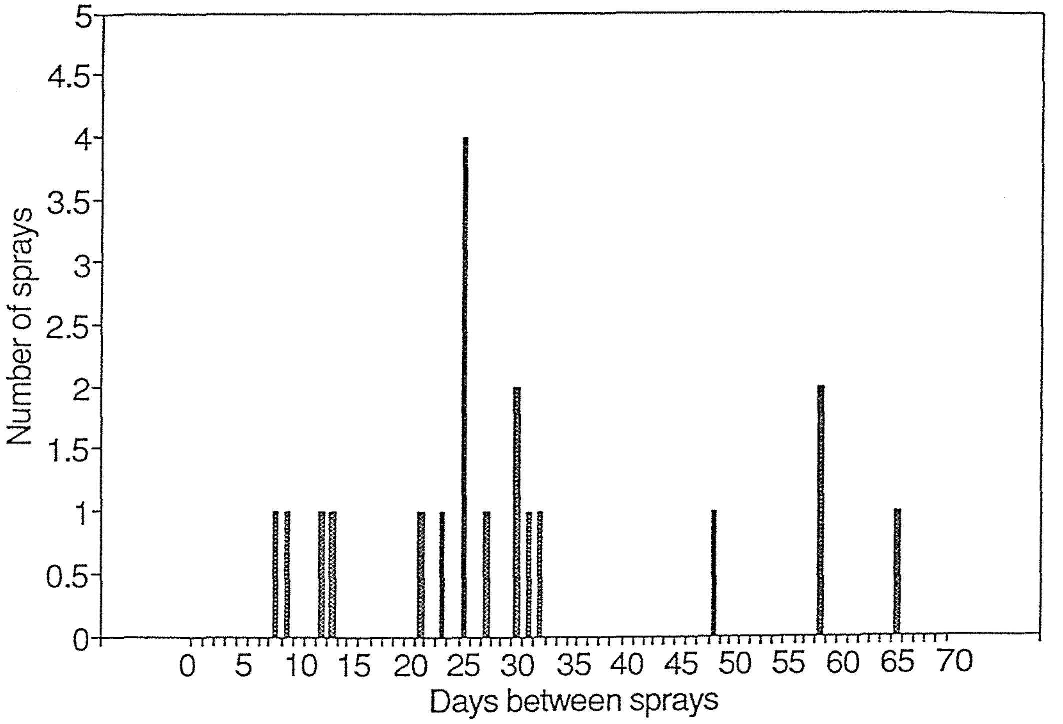


Figure 6 (d).: Spraying frequency - Grower D

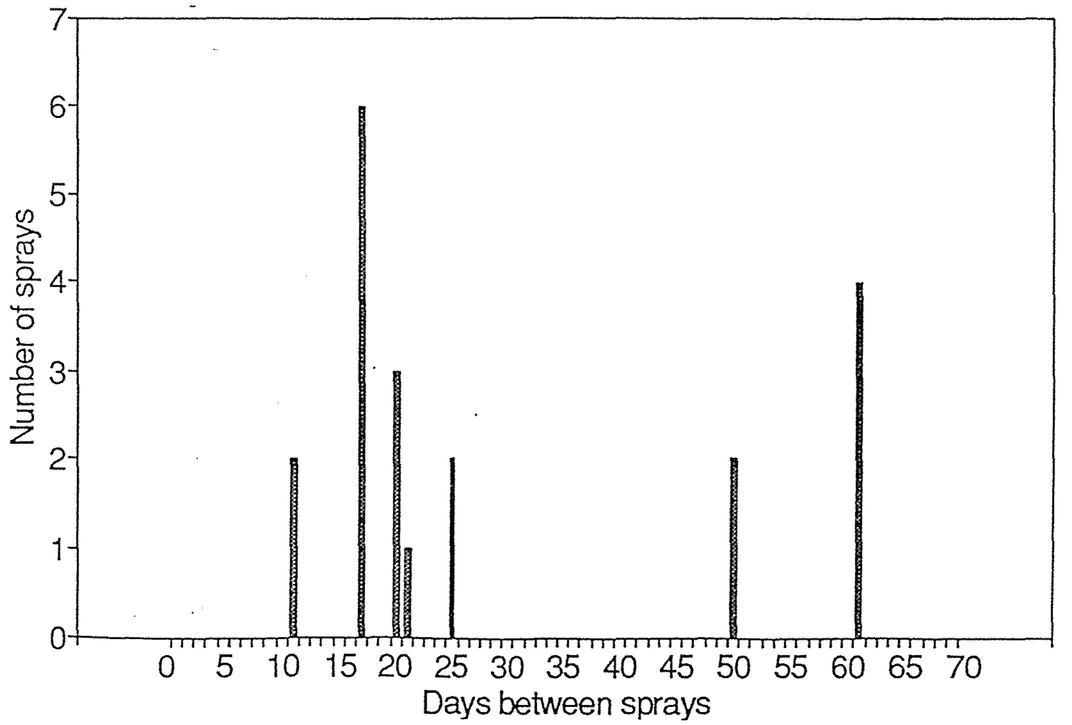


Figure 6 (e).: **Spraying frequency - Grower E**

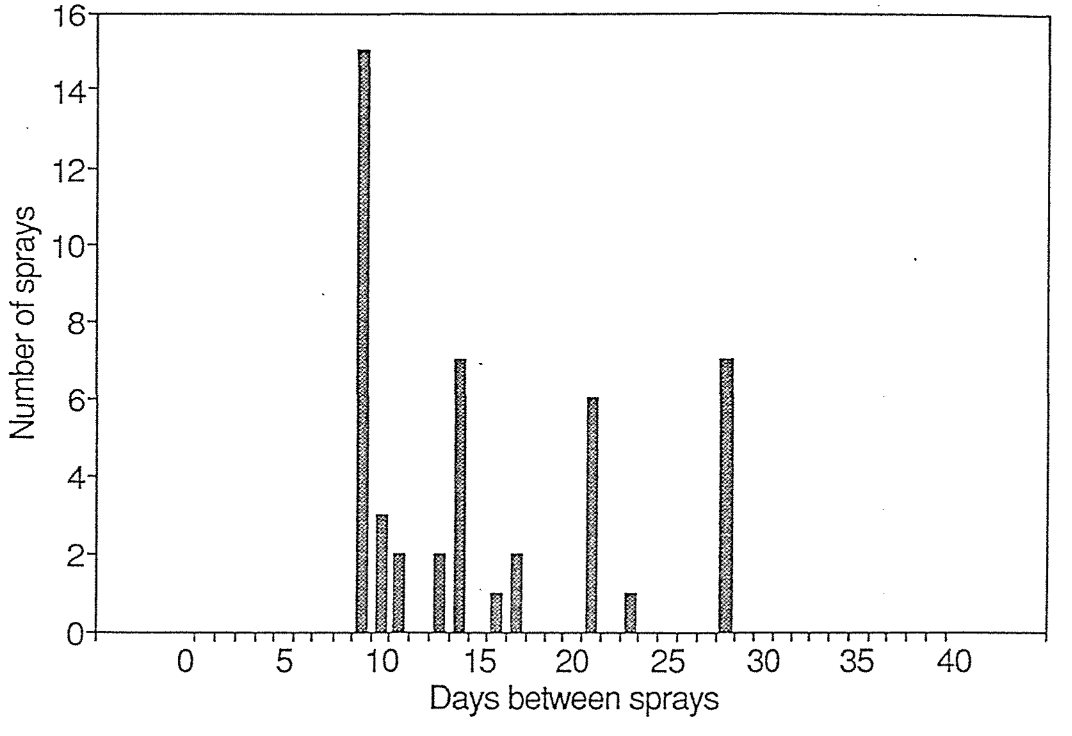


Figure 6 (f).: **Spraying frequency - Grower F**

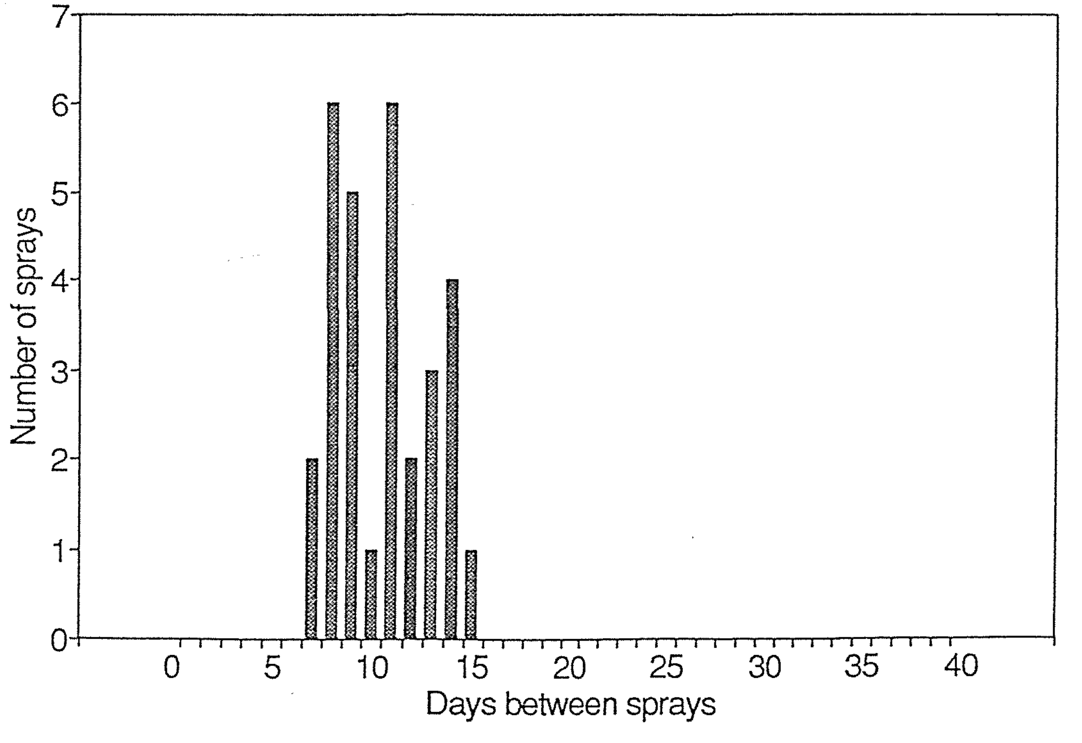


Figure 6 (g).: **Spraying frequency - Grower G**

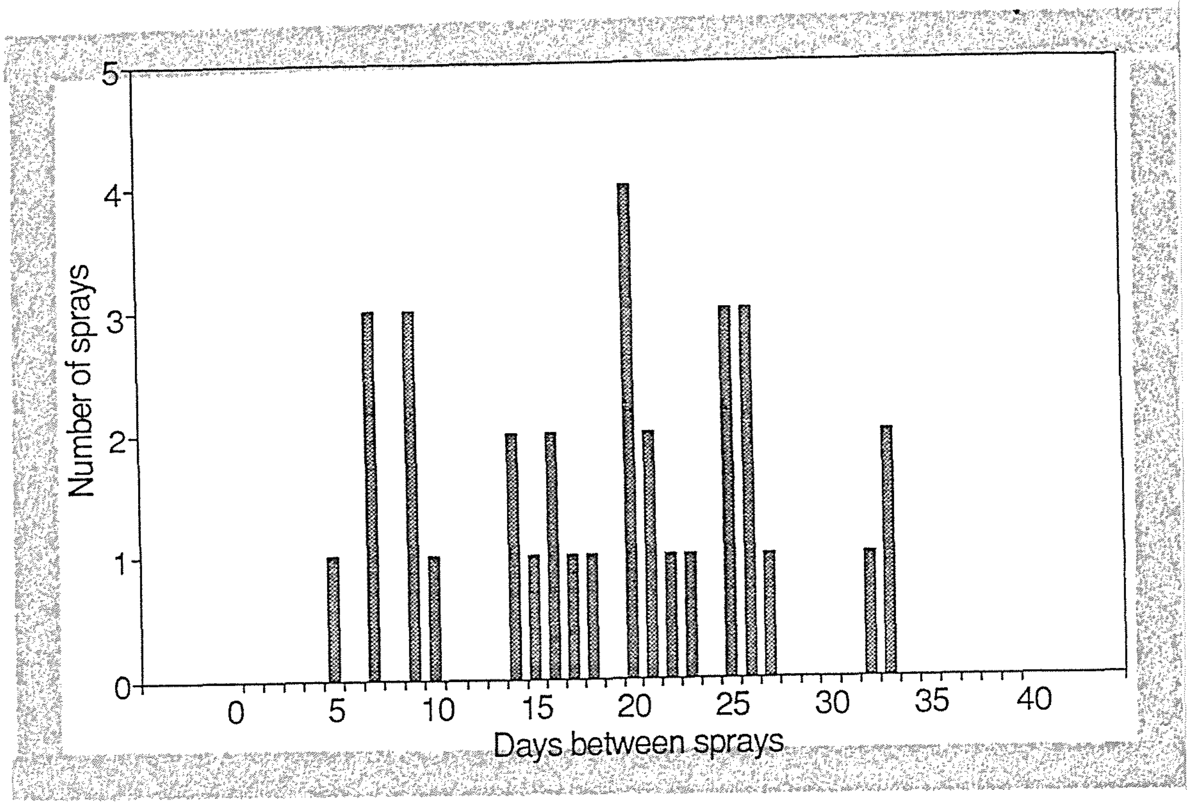


Table 26.: Summary of analysis showing spray threshold apparently used by growers.

Grower	Calendar basis	Rainfall	Presence of insect	Plant growth
B	x	x	x	x
C	x	x	x	x
D	x	x	x	x
E	x	x	x	x
F	✓	x	✓*	x
G	x	x	✓	x

* Data suggests this was used later in the season.

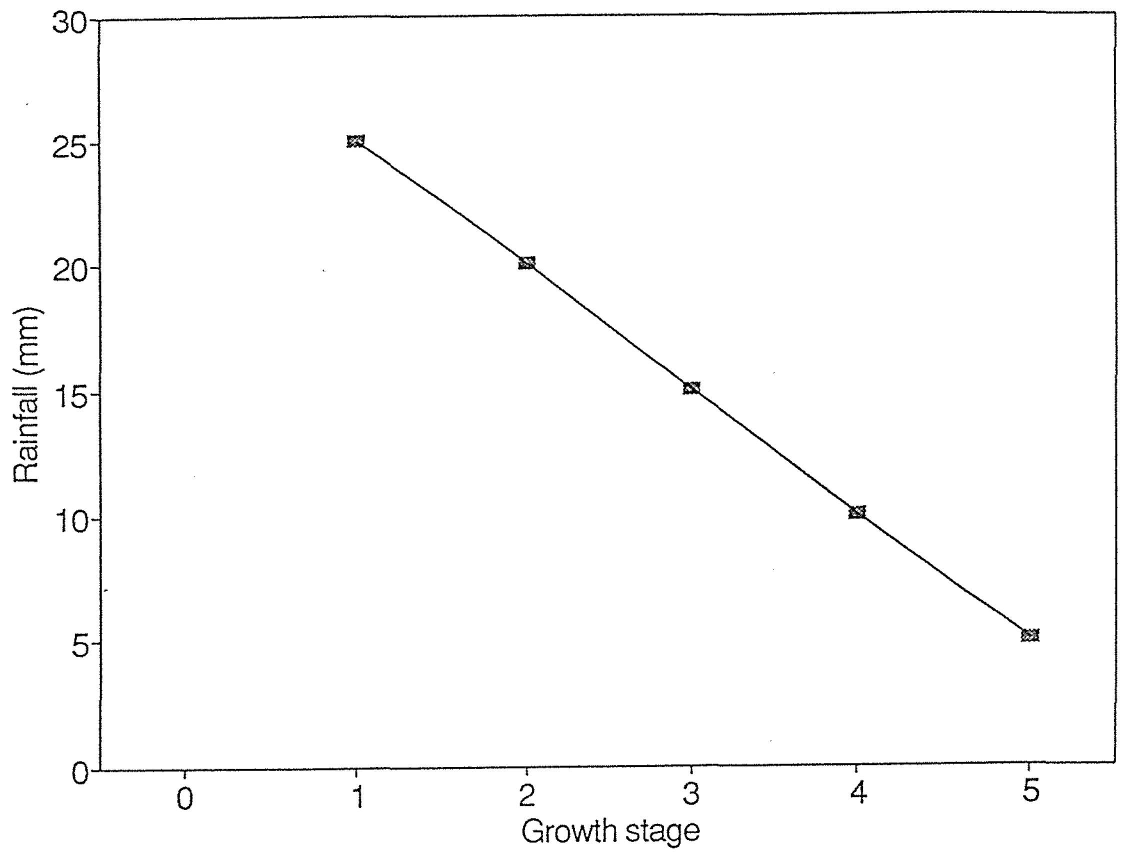
No definite spray determinant could be identified, and what initiates growers to spray seems to be based on unquantifiable feelings.

CHAPTER 6

Discussion

In this thesis an arbitrary threshold rainfall level was selected, based on consideration of two fields in the same area where one grower used the highest number of sprays in the season and the other grower the least. Yield, and pest and disease incidence were compared and found to be similar. From this it was assumed that the grower with the lowest number of sprays used the minimum number necessary for that season. The rainfall threshold is shown as a horizontal line placed on the rainfall graph at a level where the peaks on the rain graph, above the horizontal line, equal the number of sprays applied by the grower with the least number of sprays (see appendix one). With the volume of rain identified as a threshold in this way a further consideration is the time needed before it is physically possible to get onto a field after such an amount of rainfall. Disease infection could occur during that period. A rainfall threshold may not necessarily be horizontal but could be angled (see figure 7.) or even curved to take into account varying thresholds with different stages of crop growth. Small plants dry quicker after rainfall compared to plants at growth stages 4 and 5 which maintain higher humidity longer and therefore have a greater chance of pathogen development occurring. Such considerations may also be important in relation to the yield forming part of the crop. Pennypacker *et al* (1983) reported that a reduction in fungicides resulted in increases in fruit rots in some years. However, it may be possible to reduce the number of fungicides in the early stages of plant growth, and through periods of dry weather, yet still apply enough in the latter parts of the season to restrict losses due to fruit rots.

Figure 7. Rainfall threshold related to plant growth stage.



With respect to insect pests a factor given by growers as an indicator of the need to spray was insect presence. However, comparison of Wattie's survey results with spray diaries gave no indication that this was the case. In fact there were no serious insect pest problems through the 1990/1991 season, but when an indication of pest presence did occur in Wattie's data there was no correlation with insecticide sprays. One factor not considered was the possibility of growers going into the field themselves to look for pest problems before field reports were received. However, the author is sceptical that growers do check their fields on a regular basis, and even if they do they may not take a thorough look around the whole field. It is more likely that they would look at plants just inside the gate or look at plants just over the fence. As Wattie's field reports are available weekly, the author feels that growers should use this information as an indicator, as well as monitoring fields themselves. Monitoring systems have been investigated in Hawkes Bay and Gisborne for tomato fruitworm (TFW)

(Walker and Cameron, 1990), and results have suggested peak periods when growers should be more aware of the increased potential of TFW occurring. Ideal systems would predict potential pest problems before they arise, either by monitoring environmental factors that stimulate mating, egg laying or egg hatching. Other systems might monitor over-wintering lifestages to obtain an indication on what scale the pest problem may be, and when to expect an outbreak. Such systems would help to formulate control action thresholds for growers.

Several growers indicated that they used a calendar based spraying system, but the wide variation in the days between sprays as shown in figures 6 (a)-(g), gives no indication that this system was in fact used. If a true calendar spray system had been applied a graph with one tall bar concentrated on a specific "days between sprays" point (see figure 8.) would be expected, or at least two or three bars very close together concentrated in one area (see figure 9). There is little evidence for this type of pattern.

Figure 8.: Example of a graph depicting true calendar spraying timing.

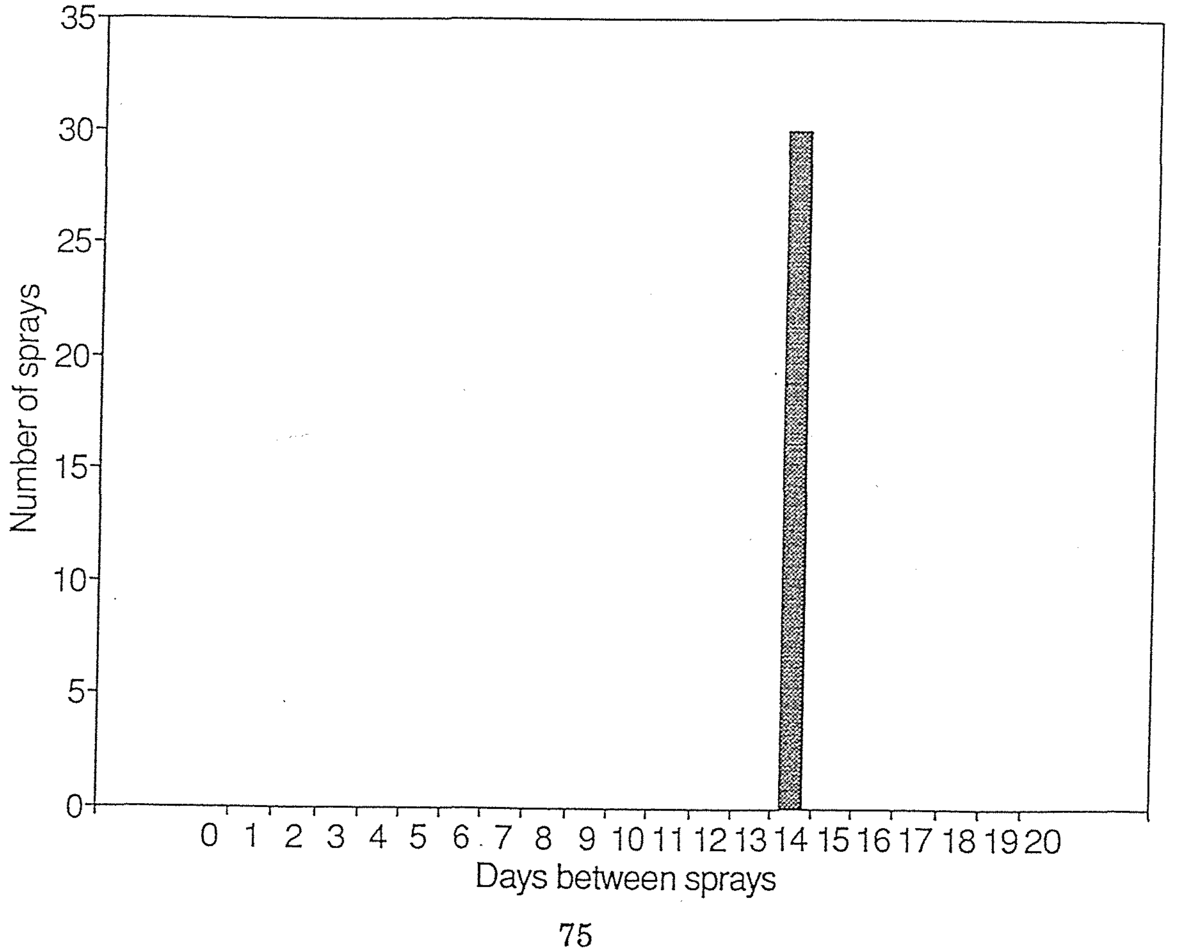
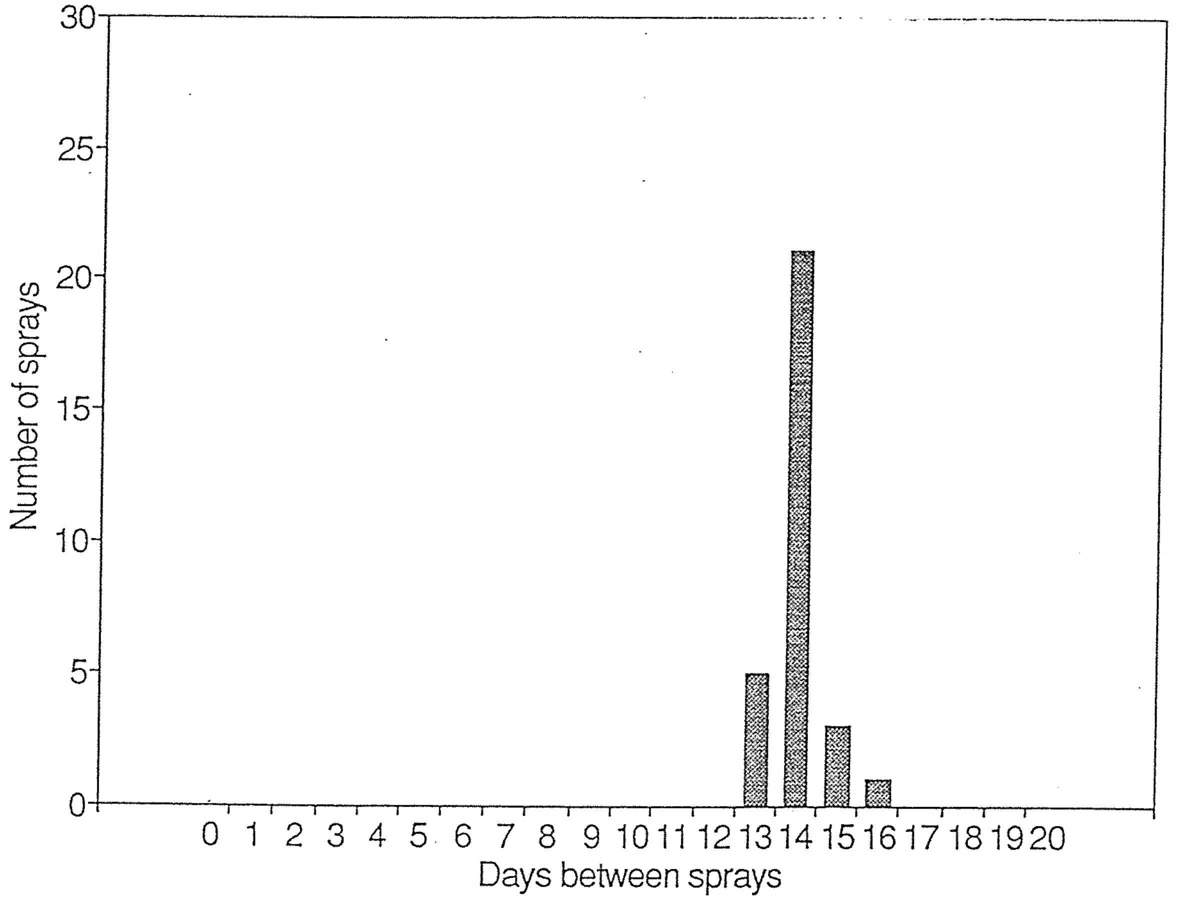


Figure 9.: Example of a graph where calendar based spraying (14 day interval) appears to be the objective.



If growers are not using a calendar based system, or spraying in reaction to insect presence or weather conditions (especially rainfall) for disease, then the question needs to be asked "what factors are being used"? Is it a "gut feeling" on the part of the grower or are there other factors involved? There are a number of factors that could influence spray timing including grower experience, financial situation, or social/family considerations. Comparing the number of years of grower experience with yield and number of sprays applied per season might reveal that growers with more years experience consistently use more sprays per season and obtain consistently good yields, compared to growers with less experience.

As on average spray costs at present account for only 13-16% of total production costs, incentives for growers to adopt new pest management or integrated pest management systems are small. If a 50% saving in spray costs could be attained, that would represent only approximately 7% saving of total production costs. Other incentives, or pressure from outside sources, are needed if pest management practices are to be adopted. Pressure is increasing from the public for pesticide "residue free" produce, but whether this will affect large scale production systems is yet to be determined.

The financial situation of a grower may affect his spraying practices. Growers in a good financial position may be willing to take up new ideas that involve higher risk. In contrast, growers in tighter financial situations may either decide that the possibility of crop loss out-weighs the cost of extra spray applications, and therefore spray often, or they may take more chances by extending times between applications to reduce expenditure. To elucidate this would need a detailed survey to determine grower's attitude to risk in relation to potential yield, pest and disease incidence, and the financial situation of the grower.

The ultimate in pest management is the combination of a number of monitoring and/or forecasting systems into one "integrated" management system that encompasses all pests and diseases that may occur in the crop. With data and knowledge that are already available it is possible to monitor or predict some pests and diseases. An example of a computerised monitoring system that has already been developed is "Pestcaster" (Anon, 1987). This system measures different weather factors hourly, applies these to mathematical formulae, and then calculates control action thresholds for insects (e.g. codling moth and leaf miners) and undesirable levels of spore production for fungi (e.g. tomato early blight, tomato late blight).

Even with the availability of forecasting and monitoring systems it is still essential to use some basic common sense to avoid certain pest or disease problems in a crop. For example, accurate record keeping of past crops and previous problems that have occurred in specific fields is essential. This allows a grower to anticipate potential pest and disease problems before they occur. In some cases the past history may cause a grower to reject a paddock for planting if the risk too high. In certain fields surveyed for this thesis there was a past history of *Sclerotinia sclerotiorum*. Though not a serious problem in previous years it proved to be a greater problem affecting a large number of plants in the 1990\1991 season. This should have been noted from the 1989/1990 season and fields either avoided or the appropriate control methods used (i.e. systemic fungicide).

In the author's opinion the most important pest and disease problems in process tomato production in Hawkes Bay are bacterial speck, and tomato fruit worm. Bacterial speck, because of its epiphytic nature, can always be assumed to be present in the field and if symptoms develop it is difficult to control. Tomato fruit worm *Heliocoverpa armigera* is a problem because it directly damages fruit, and causes serious yield loss in low numbers if not controlled. At present preventative fungicide application schedules are the basis of all sprays applied (Kale, 1990 Pers. Comm.).

It is realised that the complexities of pathogen growth and infectivity of micro-organisms depend on other climatical factors in addition to rainfall but due to the limitation of available data needed for appropriate models to be applied meant that further analysis was not possible. Forecasting models are available for late blight (Hyre 1954 and Wallin cited MacHardy 1979, Krause *et al* 1975) early blight (Madden *et al*, 1978) and bacterial speck (Basu 1966, and Jardine and Stephen 1987) . With relevant information, and research into local weather conditions favouring pathogen increase and infectivity, forecasting methods could be used. Other climatic factors that must be considered are relative humidity, hours of leaf-wetness, temperature, and rainfall data that is more precise e.g. hourly data. The literature indicates that there is potential to reduce fungicide sprays without significant increase in disease incidence using such forecasting systems.

There is also the potential to decrease the use of insecticides. Spray diaries show a variety of different practices in applying insecticides, with most either applying insecticide with every fungicide spray or with approximately half them. However, the basis for spraying half the time was not known and is not related to insect presence. There are monitoring systems available for some pests and one tested in New Zealand (Walker and Cameron (1990)) showed that late season spraying, particularly in late January, early February was sufficient to control tomato fruit worm. There is a need for continuation of research into a forecasting/ monitoring programme for tomato fruit worm in Hawkes Bay as initiated by Walker and Cameron (1990). A system that uses pheromone trapping as an initial indicator of increasing adult presence in tomato fields, and as a specific threshold which initiates field monitoring/scouting to identify larval presence and thus recommend timing of spray application, would be beneficial.

Late season insecticides are directed at tomato fruit worm but early season treatments are generally applied for aphid and thrips control. The importance of these insects must be considered in relation to both the direct effect on the plant (i.e feeding), and indirect effects (i.e. as virus vectors). Generally aphids and thrips at low levels do not significantly affect plant growth, but if they are vectors of virus diseases the potential problems can be serious. Currently there are no effective chemical or biological pesticides available to control virus disease vectors sufficiently to prevent spread of virus from surrounding crops and weeds into production fields. In fact the use of broad spectrum insecticides may eliminate beneficial arthropod predators and lead to explosions in the vector populations (Anon, 1990). More research in relation to viruses needs to be carried out especially with respect to the inoculum sources. Depending on results, it may be found that better weed control in the field and control of weeds along roadside edges may significantly reduce the virus problem. This could be a better approach than attempting to eliminate vectors.

The development of monitoring systems is essential to pest management but these need to be coupled to control action thresholds however crude initially. The author in this thesis has given a rough quantification of the high, medium, low classification system used in field reports. It is an arbitrary system based on experience. However, experience is often the first step in the development of pest thresholds in different crops. From such experience research can define more precise thresholds. Stern (1973) commented that, the determination of an economic (control action) threshold can be based provisionally on empirical evidence, i.e. by replicated observations and the crop protection specialist's past experience. This knowledge can be used as a first approximation to establish the degree of infestation which can be tolerated while still maintaining normal yields.

A problem with forecasting and monitoring systems is that growers are sceptical of using remote determinants to schedule fungicide applications. Grower acceptance of the delivery programme (computer, calculator, microprocessor, extension agent, etc.) is every bit as important as the precision and reliability of the forecasting system (Nutter F.W., and W.E. MacHardy, 1980). Before any forecasting program can be introduced into any crop situation in New Zealand, work needs to be done to modify it to New Zealand regional conditions, and also to present it in a form that would be readily accepted by growers. Development of a "grower centred programme" where the decision making process is fast, simple, accurate and "on location" is essential to fungicide application decisions. MacHardy (1979) discussed the use of a record sheet where daily environmental data could be written, and which could be overlayed by a template, allowing growers to forecast for late blight fungicide sprays.

As has been shown, spray timing at present in field process tomatoes in Hawkes Bay is not based on either a calendar or a threshold spraying system. The reason why growers do not use either of these spray timing techniques could not be determined, but there are possibilities for new techniques to be applied such as tomato fruit worm monitoring, and forecasting of diseases. In introducing possible new pest management or integrated pest management systems it is necessary for researchers to remember the people who are to use the systems. A good system will need to be simple, easy to use, quick, and proven effective before it will be accepted.

CHAPTER 7

Conclusion

The following conclusions have been drawn from this study: process tomato growers in Hawkes Bay do not use any specific thresholds to determine fungicide and insecticide application, possibly because of the complexity of factors involved in the decision making process and lack of definite information. However, there is potential to use pest management techniques to decrease the number of pesticides applied.

The basis for such techniques already exists in the form of weekly field monitoring carried out by J. Wattie Foods but at present the Watties representatives do not give specific advice to growers. An extension of this weekly survey through the use of defined monitoring and forecasting systems adapted to local conditions, possibly combined with computer modelling, would make reduced pesticide application a possibility.

However, there are two factors limiting implementation of pest management. The first is grower resistance to new techniques. This is understandable as they are growing the crop for a living, and therefore want to reduce risk as much as possible. Thus growers will tend not to take too many chances in experimenting with new techniques.

The second limiting factor is inadequate research, and how to finance the extensive research needed to adapting the monitoring and forecasting techniques available for some pests and diseases to New Zealand conditions. The cost prohibits individual growers or even a collective of growers financing research of this nature. Thus such research would need to be funded either by corporate or government bodies.

CHAPTER 8

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Appendix One

Figure 10 (a).: **Rainfall threshold for fungicide sprays - Hastings.**

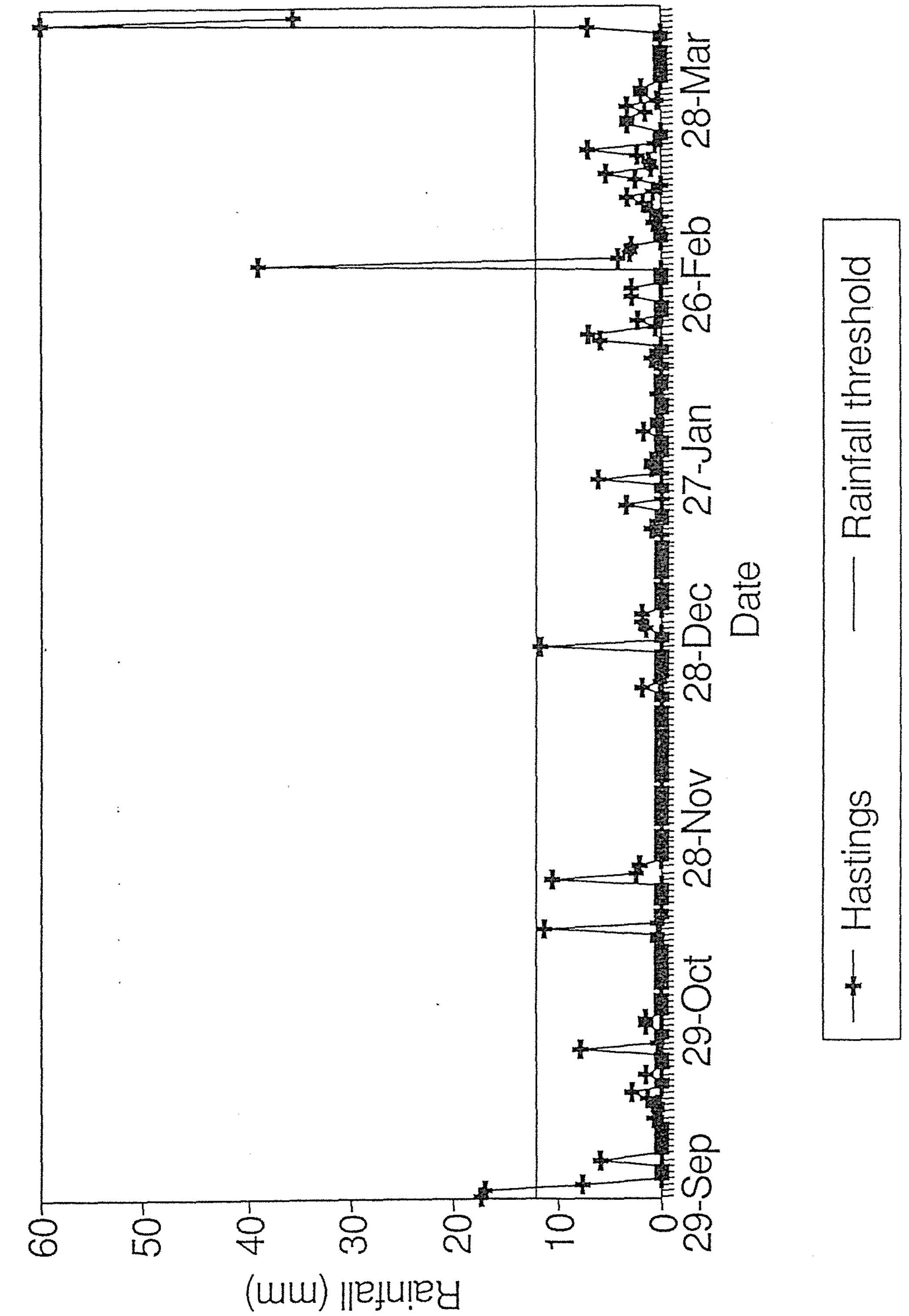

Figure 10 (b).: **Rainfall threshold for fungicide sprays - Napier.**

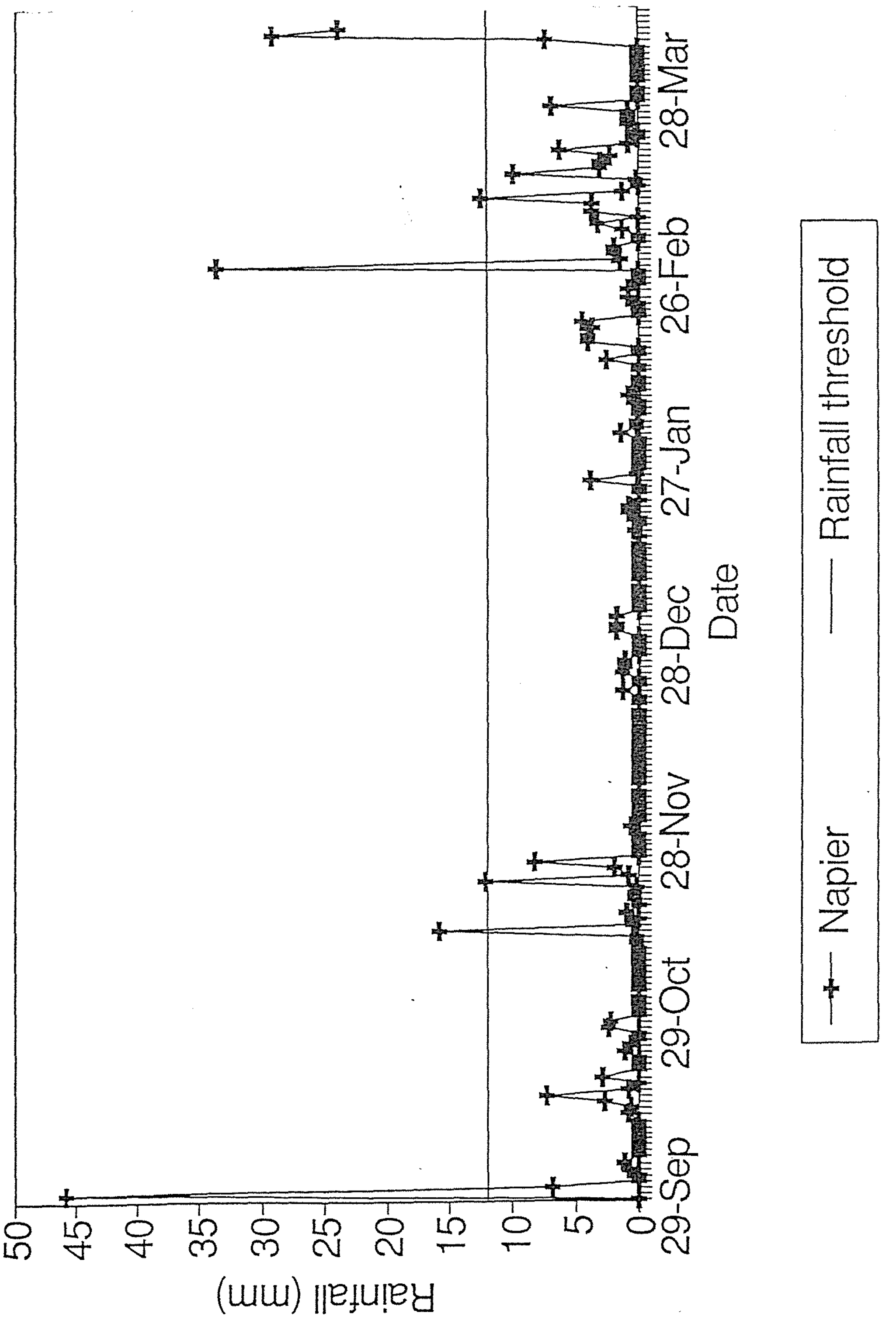

Figure 10 (c).: **Rainfall threshold for fungicide sprays - Havelock North.**

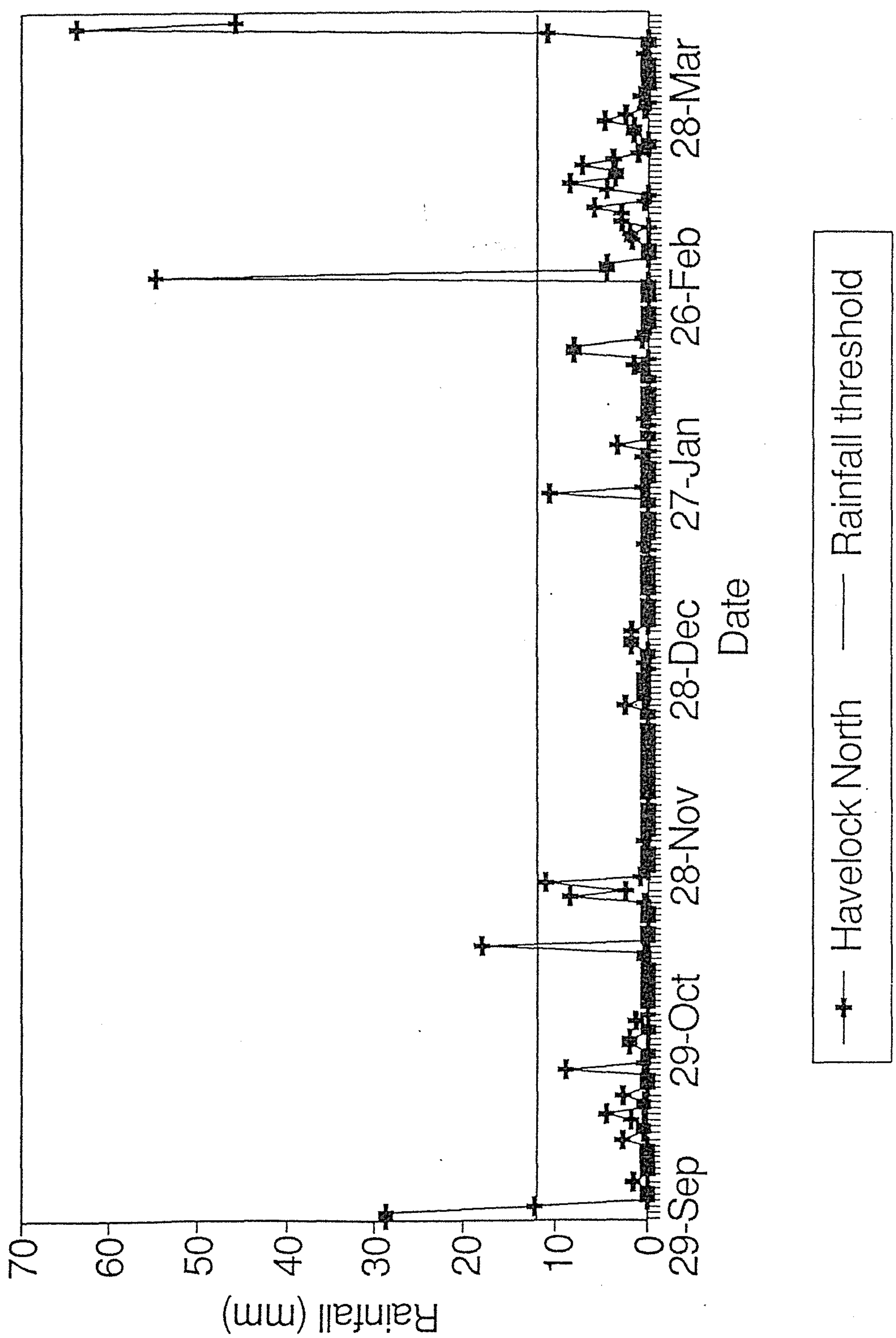

Figure 10 (d).: **Rainfall threshold for fungicide sprays - Waipawa.**