DEFINING HIERARCHICAL DECISION TREES FOR ENCARSIA FORMOSA STRATEGIES FROM GREENHOUSE TOMATO CONSULTANTS' PERSPECTIVES

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pest control methods such as IPM (Integrated Pest Management). Growers can access IPM manuals, but these tend to provide generalized advice, which they find difficult to apply to their own situations. Alternatively, growers can use consultants to tailor IPM strategies to their own situations. One method of providing growers with better advice is to capture the knowledge of "expert" consultants and translate this into a form that can be used by growers. To this end, two consultants with expertise in IPM strategy were studied and their knowledge documented.

This paper focuses on the strategies the expert consultants used to tailor *Encarsia formosa*, a natural enemy of greenhouse whitefly, to individual greenhouse's specific needs. Both consultants used an IPM template and seven to eight decision criteria to tailor their advice to individual grower's situations. These decisions were represented as hierarchical decision trees. One consultant started with low *Encarsia* rates for a short time before increasing them while the other consultant started with high *Encarsia* rates for a longer period before decreasing them later. Growers' risk perceptions and acceptance of the consultants' pest threshold levels influenced the success of the IPM strategy.

Keywords: decision trees, consultants, Encarsia, greenhouse tomato

Introduction

The majority of fresh market tomatoes produced in New Zealand are grown in greenhouses.   In the early 1980s, growers were subject only to domestic competition. However, in 1982, the New Zealand Government allowed tomatoes to be imported from Australia. These imported tomatoes were produced outdoors in Australia's tropical regions and as such were cheaper than the New Zealand tomatoes.   As a result, the number of greenhouse tomato growers in New Zealand has declined from 1,000 in 1987 to 675 in 1999. In this competitive market, New Zealand growers must demonstrate that their produce is superior to that of their Australian competitors. To this end, they promote the 'clean green' image of New Zealand tomatoes. This has been enhanced by the shift from a pesticide-dependent production system to more environmentally-friendly methods such as IPM.

Greenhouse whitefly (*Trialeurodes vaporium*) is the most common pest of many greenhouse crops, including tomatoes (Martin, 1990). They feed on the young shoots of the plant and secrete honeydew, which encourage the growth of black sooty mould and eventually reduce the effectiveness of photosynthesis of the plant, spoil the fruit, and increase post harvest handling costs associated with washing the fruit before selling it.   *Encarsia formosa* is introduced into greenhouses as parasitised whitefly scales (black scales), glued to a piece of card, which should be attached to the plant. It kills whitefly in two ways: by adult *Encarsia* wounding and subsequently killing whitefly while feeding (host feeding), and by laying eggs in whitefly nymphs, which will eventually hatch out and kill the hosts from within. The key to success in *Encarsia* introduction into greenhouses is ensuring that whitefly numbers are very low at the time the parasites are released (initial rate), followed by multiple *Encarsia* introduction to stabilize the population dynamics (maintenance rate) (Hoddle et al., 1998; Martin & Marais, 1998).

The IPM manual for greenhouse tomatoes in New Zealand was published in 1995 and has not been updated since then. While this provides relatively detailed information regarding the various strategies for implementing IPM, it lacks adequate information on how to adapt its standard *Encarsia* introduction rates into growers' specific circumstances.   The *Encarsia* recommendations provided in the guidelines make no reference to the differences in crop growth stages and greenhouse environment control levels. It was in this area that growers often lack the knowledge, which can be provided by consultants with expertise in IPM. This paper aims to describe the decision making processes used by two expert consultants in the design of an *Encarsia* introduction strategy. Such information should be of assistance to novice greenhouse consultants and greenhouse growers.

Research methods

This study was conducted as part of a larger study on the processes used by New Zealand expert greenhouse consultants in assisting greenhouse tomato growers to plan and control IPM strategies in their properties. Access was given by two expert consultants in IPM for greenhouse crops in New Zealand (C1 and C2), who were then interviewed (six times each) and observed while visiting growers.   Interviews were transcribed verbatim and the transcripts and observational data were analysed with NUD-IST (Non-numerical Unstructured Data Indexing, Searching, and Theorizing). Summaries of each interview were sent back to the consultants to ensure accuracy in interpreting the information given during the interviews.

Design of *Encarsia* introduction as part of IPM strategies

The consultants' overall IPM strategies consisted of several integrated pest management strategies. This paper focuses only on the design of the *Encarsia* strategy. When designing an *Encarsia* strategy the consultants drew on mental-templates that they had developed through experience, knowledge, discussions with other IPM experts, and access to research on IPM. During consultancy, information about a grower's greenhouse circumstances was collected and used to modify these templates.

The template comprised hierarchically arranged criteria which the consultants considered in tailoring the *Encarsia* initial and maintenance rates to each grower's specific circumstances. The decision criteria are represented in a hierarchical decision tree structure, with the most important decision criteria in the upper part of the tree to allow more efficient decision making (Figure 1).
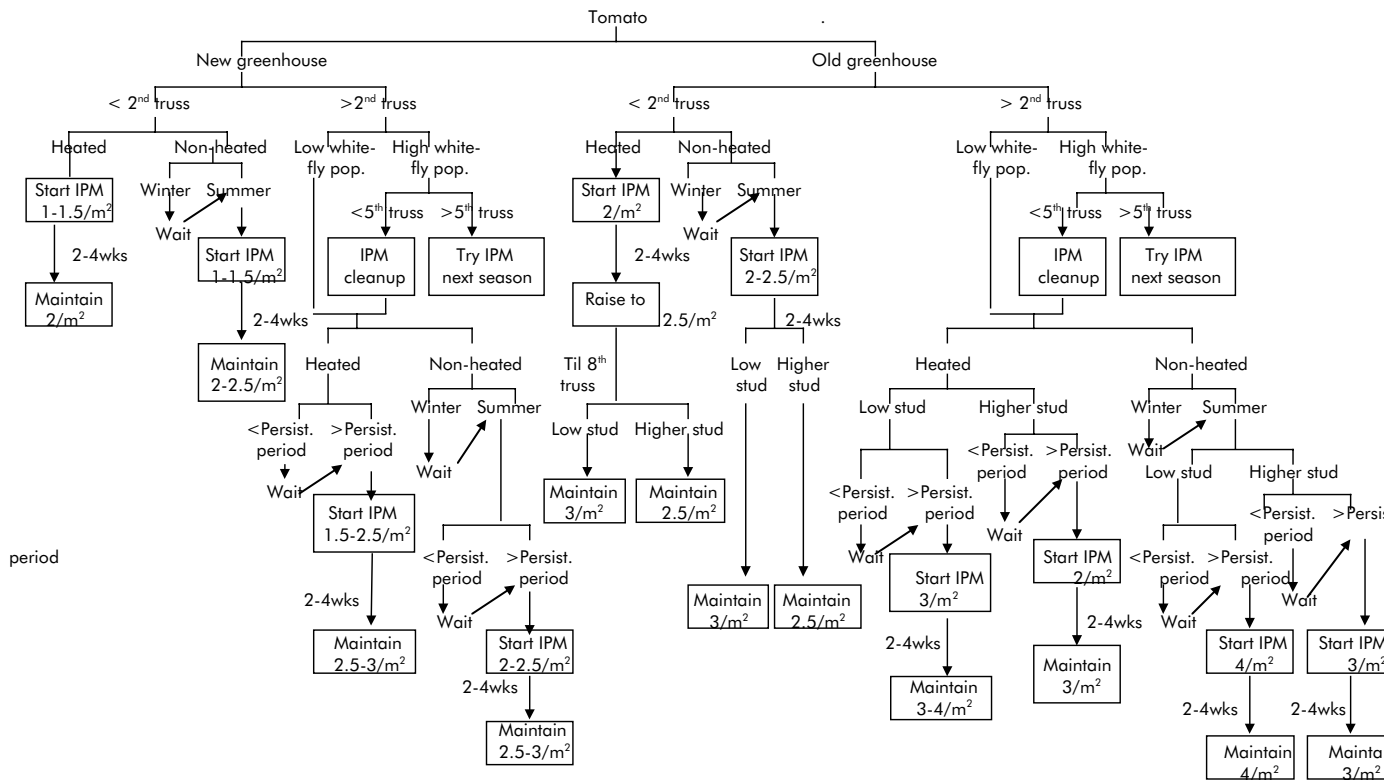

Figure 1   C1's hierarchical decision tree for tailoring Encarsia template plan to a client's situation

Eight decision criteria were identified and these are described below:

• <u>Crop type</u>. It is at the top of the tree because it determines which template to be used, whether it is a tomato, capsicum or cucumber template plan.

• <u>Greenhouse age</u>. New greenhouses, both plastic or glass, have a high stud height (≥ 3 m), compared to old greenhouses which have a lower stud height (2 to 2.5 m). Greenhouse age is important because tomato crops in old greenhouses always need a higher initial rate of *Encarsia* due to the deleafing effect on the black scales and the chemical residues which have been built up in the cladding material.

• <u>Crop age</u>. Young plants (< second truss) tend to have low levels of whitefly, which make them more suitable for the introduction of *Encarsia* compared to older crops (> second truss), which may have high levels of whitefly.

• <u>Whitefly population</u>. Crops with a high whitefly population may need a clean-up spray and *Encarsia* inundation (releasing large numbers of natural enemies for immediate reduction of a damaging or near damaging pest population) to lower the initial whitefly population. However, if the plants have produced more than 5 trusses, they are already about 1.5 m high, and in low stud greenhouses that means they are close to deleafing. Introducing *Encarsia* at this point would be uneconomic because a significant number of black scales would be removed during deleafing. Further, for a short crop, it is also close to being pulled out.

• <u>Greenhouse heating capability</u>. Some growers may have a heating system in their greenhouses, but may not be able to maintain the temperature at the desired level. These greenhouses are classified together with unheated greenhouses. *Encarsia* work best when the temperature is warm, approximately 23°C.

• <u>Season (winter/summer)</u>. Unheated greenhouses have a low success rate for IPM during winter (May to August) because of the slow growth of *Encarsia* and the high disease pressure, which needs to be controlled by spray, hence reducing the effectiveness of *Encarsia*. In such situation growers are recommended to wait until summer (September to April) before starting the introduction. Season itself is not an issue for heated greenhouses, although the low light levels may constrain crop growth during winter. In general, growers with non-heated or inadequately heated greenhouses will need to use a higher rate of *Encarsia*.

• <u>Persistence period</u>. For crops that are older than the second truss, spray history information is used later in the decision tree to determine the start of *Encarsia* introduction. The critical period is the last four weeks during summer or the last six weeks in winter prior to *Encarsia* introduction. A shorter persistence period is possible because chemical residues are degraded more quickly during summer or in heated greenhouses due to faster chemical reactions in high temperatures. The type of chemicals used during those periods would determine the length of the persistence period.

• <u>Stud height in old greenhouses</u>.   If *Encarsia* is introduced in old greenhouses with mature crops, stud height will already have an affect on the initial *Encarsia* rate used. Depending on the design of the greenhouse, the stud height may be increased up to about 2.7 m (higher stud height). Higher studs delay the start of the deleafing process sufficiently to give more time for the *Encarsia* to hatch out from black scales. This means that growers can have a lower initial rate compared to those with a lower stud height. In contrast to this, if *Encarsia* is introduced when the crops are still young, stud height will only affect the maintenance rate, rather than the initial rate. This is because the deleafing activity does not occur until about the sixth truss, when the maintenance rate should be introduced. Stud height is not an issue in new greenhouses because of their high stud (3 - 4 m).

The *Encarsia* initial rates vary from 1 *Encarsia*/m^2/week for new adequately heated greenhouses with a young crop, to 4 *Encarsia*/m^2/week for old unheated greenhouses with a mature crop. These rates need to be maintained for 2-4 weeks, depending on the weather. In warmer weather the low initial rates could be extended to four weeks, while in the cold weather the initial rates may already have to be increased after two weeks to speed up the establishment of the *Encarsia* population.

The maintenance rates vary from 2 *Encarsia*/m^2/week in new greenhouses to 4 *Encarsia*/m^2/week in old greenhouses. Provided that other pest and disease pressures are under control, these rates should be maintained for at least 12 weeks to achieve 80% parasitism or up to 4 weeks prior to harvest. If the crops are beyond the 10th truss and the sustainable level of 80% parasitism have been achieved, growers can stop introducing *Encarsia* and monitor the whitefly population levels. If *Encarsia* reintroduction is needed prior to harvest, the *Encarsia* rate used previously can be applied.

Comparison: *Encarsia* introduction rates

The consultants differed slightly in the number of decision criteria used and their relative importance within the structure. Eight criteria were used by C1 and seven by C2. The one criterion not used by C2 was greenhouse age, which he considered to have already been taken into account when using the stud height criterion.

The main contrast between the two consultants' *Encarsia* strategies was their approach in establishing the sustainable 80%-90% *Encarsia* parasitism level. C1 preferred to start with a low level of *Encarsia* for 2 to 4 weeks, and then increase the rate and maintain it until a sustainable level of parasitism was achieved. In contrast, C2 preferred to start with a high level of *Encarsia* for 6 to 10 weeks, and then decrease the rate and maintain it until a sustainable parasitism level was achieved. C1's approach resulted in lower numbers of *Encarsia* required throughout the season, but also carried higher risks. By having lower initial *Encarsia* rates, a longer time might be needed by the beneficial organisms to establish a sustainable population in a greenhouse. If the whitefly population increased quickly during the early period of *Encarsia* introduction, then quick action needed to be taken, either by increasing the *Encarsia* rates or by applying chemicals, to decrease the whitefly population levels. By having higher initial *Encarsia* rates, a sustainable *Encarsia* population might be established sooner to prepare for the increase in whitefly population towards the middle of the season, and hence, lessened the risk of an outbreak. The trade-off for C2's approach is that more *Encarsia* are required throughout the season, resulting in higher relative costs of using it, compared to C1's approach, given that no inundation is required throughout the season.

The consultants used their decision rules to take into account various factors when determining suitable *Encarsia* introduction rates. In contrast, the IPM manual for greenhouse tomatoes (Martin, 1995) suggested a flat *Encarsia* rate of 1/m^2/week. This was significantly lower than those advocated by the consultants (Table 1). Further, the manual also recommended the use of season and crop duration to determine the time duration over which *Encarsia* should be introduced. The problem with this recommendation was that growers might introduce *Encarsia* for too long, which is costly, or alternatively, not introduce them for a long enough period to achieve a sustainable parasitism level.

Comparison: Whitefly threshold levels

The whitefly threshold levels reflected the consultants' risk taking attitudes. The success of the *Encarsia* strategy depends to a large extent on knowing the correct whitefly threshold levels. Two whitefly threshold levels are critical, the initial threshold level prior to *Encarsia* introduction and the whitefly threshold level after *Encarsia* has been introduced. Whitefly population should be sufficiency low prior to introducing *Encarsia* to ensure adequate parasitism at the beginning of implementing IPM program (Martin, 1995). A self-confessed risk taker, C1 would only suggest an IPM clean up, which consisted of clean up spray program and *Encarsia* inundation, if there were at least two whitefly/plant. C2 in contrast, suggested having less than 2 whitefly/20 plants as the initial whitefly threshold level, much lower than C1's level. Both consultants only took whitefly population into

account if *Encarsia* was introduced after the 2nd truss. In contrast, the manual provided a more comprehensive initial threshold levels based on crop age and when to start introducing *Encarsia*.

Surprisingly, the manual made no mention of the on-going whitefly threshold level. A whitefly population of up to 4 adults/plant was considered acceptable by C1, but C2 suggested a lower level of 1 whitefly/20 plants or 2 whitefly/row. Unlike the initial whitefly threshold levels, the on-going threshold levels were more fluid and were affected by several factors, which may be the reason why they were absent in the manual. Growers located in tomato growing areas or with low stud greenhouses, or limited heating were given lower threshold levels because they would need to react more quickly in case of an outbreak. Mature plants tend to have lower threshold levels because of their larger leaf area, which potentially carries more white scales than young plants. The presence of other pests may also lower the threshold level, particularly if growers need to spray to overcome the problem, reducing *Encarsia* efficacy. On the other hand, the threshold levels could be increased if there were already high levels of parasitism by *Encarsia*. C1 might even increase the threshold slightly to accommodate sampling error when interpreting monitoring results. High whitefly threshold levels may increase the risk of using *Encarsia* because under favourable conditions the whitefly population may increase more rapidly than expected before the *Encarsia* hatch.

The most important determinant of whitefly threshold levels suggested by the consultants however, was the growers' risk perception and experience in dealing with whitefly. Growers who were used to calendar-based spraying were given lower threshold levels. Risk averse growers might easily become uncomfortable with the whitefly population levels in their greenhouses and use pesticides. Costs associated with *Encarsia* inundation and reduced fruit quality as a result of whitefly honeydew secretion were the main concerns associated with the *Encarsia* IPM strategy.

Implications

The findings demonstrate the limitations of the IPM manual. The consultants used a much greater range of decision criteria to design a suitable *Encarsia* strategy for growers. The consultants' strategies, although different, have been implemented successfully by their growers. This work opens up the possibility of formalizing the criteria into a rule-based expert system for *Encarsia* strategy, which might benefit the greenhouse industry in New Zealand. This however, would not replace the consultants' role in increasing growers' confidence and advancing their pest management problem-solving skills.

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Table 1.   Comparisons of Encarsia strategy recommended by the consultants and the IPM manual

	C1	C2	Manual
Initial *Encarsia* rate	1-4/m^2/week	2-8/m^2/week	1/m^2/week
Maintenance *Encarsia* rate	2-4/m^2/week	1-3/m^2/week	1/m^2/week
Initial whitefly threshold	Clean up if ≥ 2/plant	Clean up if ≥ 2/20 plants	If introduce at planting ≤1/20 plants. If introduce after 5th flowering: < 1/100 plants during propagation; < 1/50 plants until 2nd truss flowering; 1/20 plants between 2nd & 5th truss flowering.
Whitefly threshold after *Encarsia* introduction	≤ 4/plant	≤ 1/20 plants or ≤ 2/row	-

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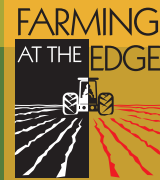
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