DEVELOPMENT OF A PEST MANAGEMENT SYSTEM FOR TABLE GRAPES IN THE HEX RIVER VALLEY

by

MARELIZE DE VILLIERS

Dissertation presented for the Degree of Doctor of Philosophy (Agriculture) at the University of Stellenbosch.

Promotor: Dr. K.L. PRINGLE

April 2006

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: ……..

Date: ……..

ABSTRACT

A study was performed to develop a generic pest monitoring system for sampling the main table grape pests in vineyards in the Hex River Valley, Western Cape Province of South Africa. The presence of phytophagous and predatory mites on cover crop plants was also investigated as this may contribute to biological control of the phytophagous mites in vines. Life table studies for *Epichoristodes acerbella* (Walker), an important phytosanitary pest, were conducted to determine whether or not this pest was sensitive to high temperatures. Information gained from the latter can also be used for breeding purposes in the possible future development of a sterile insect technique (SIT) programme to control this pest.

The sampling system consisted of inspecting 20 plots of five vines per plot per one to two hectares. The top fork of each of the five vines per plot was examined for *Planococcus ficus* (Signoret) to a distance of within 30 cm of the stem, as well as the distal 15 cm of one cane per vine for the presence of *P. ficus* and damage caused by *Phlyctinus callosus* Boh. One bunch per vine was examined for insect damage or presence, and one leaf per vine for the presence of leaf infesting arthropods, such as *Tetranychus urticae* Koch, *P. ficus* and *Frankliniella occidentalis* (Pergande). Corrugated cardboard bands, tied around the stem of one vine per plot, were used to monitor activity of *P. callosus*. Blue sticky traps, at a density of four to five traps per one to two hectares, were used to monitor activity of *F. occidentalis*. Pheromone traps, at a density of one trap per one to two hectares, were used to monitor activity of *P. ficus*, *E. acerbella* and *Helicoverpa armigera* (Hübner). All the above-mentioned inspections were done at two-weekly intervals, except traps for *E. acerbella* and *H. armigera*, which were inspected weekly. In each of the rows in which the sample plots were situated, one leaf of each of the cover crop plant species was examined for the presence of phytophagous mites and their predators. The abundance and distribution of cover crop plants were determined using a co-ordinate sampling system. Cover crop sampling was done at monthly intervals.

The current threshold for *P. ficus* is 2% stem infestation, which is reached when more than 65 males per pheromone trap are recorded. Counting mealybugs on the sticky pads in the pheromone traps is time consuming. However, the number of grid blocks on the sticky pad with males present can be counted. When *P. ficus* males are found

in 27 blocks on the sticky pad, stem inspections should commence. Due to the spatial association between *P. ficus* bunch and stem infestation, stem infestation could give an indication of where bunch infestation could be expected.

The use of blue sticky traps for predicting halo spot damage, caused by *F. occidentalis*, is not recommended. The presence of thrips on the vine leaves could not give an indication of where to expect bunch damage, since thrips on the leaves and halo spot damage were not spatially associated. A suitable sampling method for *F. occidentalis* still needs to be developed. The monitoring system described here can only provide information on the infestation status of the vineyard.

For *E. acerbella*, *H. armigera* and *P. callosus*, the traps and cardboard bands could be used to identify vineyards where these pests are present and therefore, where phytosanitary problems may arise. The presence of *P. callosus* under the bands was spatially associated with *P. callosus* damage and could be used as an indicator of the latter. The presence of drosophilid flies in the bunches could not be used as an indicator of the presence of *E. acerbella* in the bunches. If 5% bunch damage is used as an economic threshold for *E. acerbella* and *P. callosus*, there will be a good chance of not under spraying if control measures are applied at 1% bunch damage. *Epichoristodes acerbella* favoured more moderate constant temperatures, with constant temperatures of 28°C and above being unfavourable for development.

The economic threshold for *Tetranychus urticae* Koch is six mites per leaf, or if presence-absence sampling is used, 11 to 29% leaf infestation. Three important predatory mites, that kept *T. urticae* under control, were found in the Hex River Valley, namely *Euseius addoensis* (Van der Merwe & Ryke), *Neoseiulus californicus* (McGregor) and an undescribed phytoseiid in the genus *Typhlodromus*. Various cover crop plants served as hosts for *T. urticae* and predatory mites. The presence of these plants created suitable conditions for the survival of these mites and may have influenced their presence on the vine leaves.

In the case of phytosanitary pests, both field and pack shed inspections can be used to conclude with a 99% degree of certainty that infestation levels in the pack shed will be 10% or less, since similar results for both methods were obtained. However, more than 20 plots will have to be inspected.

UITTREKSEL

'n Studie is uitgevoer om 'n generiese moniteringstelsel te ontwikkel om die vernaamste plae van tafeldruiwe in die Hexrivier Vallei, Wes-Kaapprovinsie van Suid-Afrika te monitor. Die teenwoordigheid van plantvoedende en predatoriese myte op dekgewasplante is ook ondersoek aangesien dit kan bydra tot biologiese beheer van plantvoedende myte in wingerde. Lewenstabelstudies is vir *Epichoristodes acerbella* (Walker), 'n belangrike fitosanitêre plaag, gedoen om te bepaal of hierdie plaag sensitief vir hoë temperature is. Inligting wat vanuit laasgenoemde verkry is, kan ook gebruik word vir teëldoeleindes in die moontlike toekomstige ontwikkeling van 'n steriele insek tegniek (SIT) program om hierdie plaag te beheer.

Die moniteringstelsel het uit die inspeksie van 20 plotte van vyf wingerdstokke per plot per een tot twee hektaar bestaan. Die boonste vurk van elk van die vyf stokke is vir *Planococcus ficus* (Signoret) tot 'n afstand van 30 cm vanaf die stam deursoek, asook die distale 15 cm van een loot per stok vir die aanwesigheid van *P. ficus* en skade veroorsaak deur *Phlyctinus callosus* Boh. Een tros per stok is vir insekskade of –aanwesigheid deursoek en een blaar per stok vir die aanwesigheid van arthropode op blare, soos *Tetranychus urticae* Koch, *P. ficus* en *Frankliniella occidentalis* (Pergande). Die aktiwiteit van *P. callosus* is deur geriffelde kartonbande, gedraai om die stam van een stok per plot, gemonitor. Blou taai valle, teen 'n digtheid van vier tot vyf valle per een tot twee hektaar, is gebruik om die aktiwiteit van *F. occidentalis* te monitor. Feromoonvalle, teen 'n digtheid van een val per een tot twee hektaar, is gebruik om die aktiwiteit van *P. ficus*, *E. acerbella* en *Helicoverpa armigera* (Hübner) te monitor. Al die bogenoemde inspeksies is op 'n twee-weeklikse basis gedoen, behalwe valle vir *E. acerbella* en *H. armigera* wat weekliks nagegaan is. In elke ry van die moniteringsplotte is een blaar van elke soort dekgewasplant vir die aanwesigheid van plantvoedende myte en hul predatore deursoek. Die volopheid en verspreiding van dekgewasplante is met behulp van 'n koördinate monsternemingsmetode bepaal. Monitering van dekgewasplante is maandeliks gedoen.

Die huidige drempelwaarde vir *P. ficus* is 2% stambesmetting, wat bereik word wanneer meer as 65 mannetjies per feromoonval aanwesig is. Om witluise op die taai bodems in die feromoonvalle te tel is tydrowend. Die aantal blokke in die telraam op die bodem met witluise teenwoordig kan egter getel word. Wanneer *P. ficus*

mannetjies in 27 blokke op die taai bodem gevind word, moet staminspeksies begin. Weens die ruimtelike assosiasie tussen *P. ficus* stam- en trosbesmetting, kon stambesmetting ‘n aanduiding gee van waar trosbesmetting verwag word.

Die gebruik van blou taai valle om “halo spot” skade, veroorsaak deur *F. occidentalis*, te voorspel, word nie aanbeveel nie. Die aanwesigheid van blaaspootjies op die wingerdblare kon nie ‘n aanduiding gee van waar trosskade verwag word nie aangesien daar nie ‘n ruimtelike assosiasie tussen blaaspootjies op die blare en “halo spot” skade was nie. ‘n Geskikte moniteringsmetode vir *F. occidentalis* moet nog ontwikkel word. Die monitorstelsel wat hier beskryf word kan slegs inligting oor die die besmettingstatus van die wingerd verskaf.

Vir *E. acerbella*, *H. armigera* en *P. callosus* kon die valle en kartonbande gebruik word om wingerde te identifiseer waar hierdie plae teenwoordig is en waar fitosanitêre probleme gevolglik kan ontstaan. Die aanwesigheid van *P. callosus* onder die bande was ruimtelik geassosieërd met *P. callosus* skade en kon ‘n aanduiding gee van waar laasgenoemde verwag kon word. Die aanwesigheid van drosophilid vlieë in die trosse kon nie gebruik word om ‘n aanduiding te gee van die aanwesigheid van *E. acerbella* in die trosse nie. Indien ‘n drempelwaarde van 5% trosskade vir *E. acerbella* en *P. callosus* gebruik word, sal daar ‘n goeie kans wees dat daar nie onderbespuit word nie indien beheermaatreëls by 1% trosskade toegepas word. *Epichoristodes acerbella* het meer matige konstante temperature verkies, met konstante temperature van 28°C en hoër ongunstig vir ontwikkeling.

Die ekonomiese drempelwaarde vir *Tetranychus urticae* Koch is ses myte per blaar, of in die geval van aanwesigheid-afwesigheid monitering, 11 tot 29% blaarbesmetting. Drie belangrike predatoriese myte, wat *T. urticae* beheer het, naamlik *Euseius addoensis* (Van der Merwe & Ryke), *Neoseiulus californicus* (McGregor) en ‘n onbeskryfde phytoseiid in die genus *Typhlodromus*, is in die Hexrivier Vallei gevind. Verskeie dekgewasplante het as gashere vir *T. urticae* en die predatoriese myte gedien. Die teenwoordigheid van hierdie plante het gunstige toestande vir die oorlewing van hierdie myte geskep en kon hul aanwesigheid op die wingerdblare beïnvloed.

In die geval van fitosanitêre plae, kan beide veld- en pakhuisinspeksies gebruik word om met ‘n 99% graad van sekerheid af te lei dat besmettingsvlakke in die pakhuis minder as 10% sal wees, aangesien ooreenstemmende resultate vir beide metodes verkry is. Meer as 20 plotte moet egter geïnspekteer word.

ACKNOWLEDGEMENTS

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

I would also like to thank the following persons/organizations:

The Deciduous Fruit Producers' Trust (DFPT), Harry Crossley Foundation and University of Stellenbosch for funding the research.

Owners and managers of the farms Klipheuwel, Boplaas and De Vlei Boerdery for availability of vineyards that were used in the study and co-operation during the study.

The following personnel from the Department of Conservation Ecology and Entomology, University of Stellenbosch:
My promoter, Dr K.L. Pringle, for support, advice and help with statistical analysis.
Adam Johnson for trap and band monitoring.
Dr J.M. Heunis for cover crop sampling and help with identification of predatory mites.
Juanita Liebenberg for cover crop sampling, helping with mite counting and identification of predatory mites.
Prof. H. Geertsema for help with collection of pear leafroller moths.
Leslie Brown for help with ArcView and its extension Spatial Analyst, as well as the cybertracker programme.
Prof. M. McGeoch for help with spatial analysis, using SADIE.

Dr P.J. Pieterse from the Department of Agronomy, University of Stellenbosch, and the Compton Herbarium for identification of cover crop plants.

My parents for moral support.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1. Monitoring systems

Insects compete with humans at many levels for the crops they grow and the living they try to make from all forms of production, including agriculture, horticulture and forestry (Speight *et al*. 1999). If insect pests are not controlled or properly managed, unacceptable losses will frequently occur all over the world (Speight *et al*. 1999). In addition, due to the high cost of chemicals, as well as the negative impact they have on the environment, more pressure is put on producers to minimize chemical sprays. This can only be achieved with minimum risk if detailed monitoring of the pests is done. Efficient field sampling is a corner stone of pest management, since knowledge of pest status provides growers and consultants with the necessary basis for selecting optimum management options (Binns *et al*. 2000). The use of a monitoring system can ensure pest detection, thereby making it possible to avoid over or under spraying.

Sampling methods can be divided into absolute methods, relative methods and population indices (Romoser & Stoffolano 1998). Absolute sampling methods provide information on pest population levels per unit habitat (Romoser & Stoffolano 1998) like the number of mites per leaf. Relative sampling methods relate pest activity to the particular sampling method used and not to a unit of the habitat within which the sampling is being conducted. An example of the latter is the number of moths per trap (Romoser & Stoffolano 1998). When using population indices insects are not counted, but insect products or the effects of insect activity, like plant damage, are measured (Romoser & Stoffolano 1998). A combination of all these methods can be used.

In South Africa, a suitable system for monitoring population levels of the grapevine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), the key pest of table grapes (*Vitis vinifera* L.), has been developed (Walton 2003). However, table

grapes are prone to attack by a number of other insect and mite pests, causing either direct damage, which can lead to unmarketable fruit, or indirect damage, which can adversely affect production. Various pests are also of phytosanitary importance, hindering international trade. Pests, other than *P. ficus*, that are considered problems in South African vineyards are the western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), banded fruit weevil *Phlyctinus callosus* Boh. (Coleoptera: Curculionidae), vinegar flies in the family Drosophilidae, the pear leafroller *Epichoristodes acerbella* (Walker) (Lepidoptera: Tortricidae), African bollworm *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) and spider mites in the genus *Tetranychus* (Acari: Tetranychidae). Locally the extent of the damage caused by these pests is unknown due to a lack of a proper monitoring system. However, data on the extent of rejections of grapes destined for overseas markets are available from the Deciduous Fruit Producer's Trust (DFPT). During the 2001/2002 season, 32% of the table grapes presented for export to the USA market were rejected. This was mainly due to *P. callosus*, which caused 35% of the rejections, and *E. acerbella*, causing 28% of the rejections. For the Israeli market, 16% of the table grapes presented were rejected during the 2001/2002 season. For the Hex River Valley, all the rejections were due to *E. acerbella*.

Various sampling methods, including the use of traps and physical plant inspections, have been used previously to monitor activity levels of the above-mentioned pests. The inspection of plant leaves for the presence of *Tetranychus urticae* Koch and subsequent control when a certain number of mites per leaf have been reached or when a certain proportion of the leaves are infested is well documented. This includes monitoring for *T. urticae* on leaves of greenhouse roses (Gilli *et al*. 2005), ivy geranium (Opit *et al*. 2005), hops (Weihrauch 2004), blackcurrent (Labanowska & Gajek 1999), tomatoes (Bezert 1999), apple (Pringle 1987; Botha *et al*. 1994) and grapevines (Hluchy & Pospisil 1991). Schwartz (1990, 1993) sampled for mites in local vineyards. However the object of Schwartz's (1990, 1993) studies was not for developing a monitoring system, but to investigate the effect of pesticides and fungicides on *T. urticae* and its natural enemies. The use of plant inspections for monitoring *P. ficus* activity levels in South African vineyards was described by Walton (2003). The system was based on inspecting vines in 20 plots per hectare with

five vines per plot. Stems, leaves and bunches were inspected for the presence of *P. ficus*. These inspections were conducted biweekly.

Pheromone traps have been used for monitoring activity levels of a number of pests. Millar *et al*. (2002) in California developed the use of pheromone-baited traps for monitoring *P. ficus* in vineyards. Walton *et al*. (2003, 2004) also studied the use of pheromone traps to monitor activity levels of *P. ficus*. He inspected one trap per hectare at biweekly intervals and successfully incorporated trap catch information with the data obtained from plant inspections described above into a system for managing *P. ficus* in local vineyards (Walton *et al*. 2003). Nel (1983) recommended the use of pheromone traps, inspected weekly, for monitoring activity levels of both *H. armigera* and *E. acerbella* in deciduous fruit orchards. Blomefield *et al*. (2004) also recommended using pheromone traps to monitor *E. acerbella* in local vineyards. He suggested a density of one trap per vineyard block or one trap per two hectares, starting monitoring during mid-July. It was argued that an increase in trap catches would be followed by an increase in egg laying and larval populations (Blomefield *et al*. 2004). In addition, Blomefield *et al*. (2004) recommended that bunches be inspected for the presence of *E. acerbella* larvae. An exact protocol for bunch inspections was however not given (Blomefield *et al*. 2004).

Coloured sticky traps are frequently used to monitor activity levels of thrips. This is to detect the initial presence of thrips and to predict outbreaks (Koschier *et al*. 2000). Blue sticky traps are especially important for monitoring the activity of *F. occidentalis* (Gaum & Giliomee 1994; Chu *et al*. 2000). This has been reported for monitoring *F. occidentalis* in fig orchards in Japan (Morishita 2002), nectarine orchards in Northern Italy (Tommasini & Burgio 2004), apple orchards in South Africa (Jacobs 1995), seedless grape vineyards in Greece (Tsitsipis *et al*. 2003), greenhouse grown strawberries in Japan (Katayama 2005), greenhouse cyclamens in Italy (Colombo & Biondo 1996), greenhouse sweet pepper in Spain and Canada (Shipp & Zariffa 1991; Gonzalez Zamora & Moreno Vazquez 1996) and ornamental plants in greenhouses in Germany (Buhler & Zohren 1992).

Activity levels of *P. callosus* in deciduous fruit orchards have been monitored using a 10 cm wide strip of single sided corrugated cardboard, tied around the tree trunk with

the open corrugations on the inside (Nel 1983; Nel & Addison 1993). Inspections of these bands were done weekly in apple orchards in Elgin, South Africa (Nel & Addison 1993). Corrugated cardboard bands have also been used in vineyards in coastal California to monitor the black vine weevil *Otiorhychus sulcatus* (Phillips 1989). It will therefore be possible to use these bands to monitor *P. callosus* in vineyards in South Africa.

From the above it is clear that there is an array of sampling systems that can be used for monitoring pest population levels in vineyards. However, only in the case of the inspection system for monitoring *P. ficus* (Walton 2003), has the reliability of decisions regarding control intervention been determined. In addition, it would be impractical for producers to have to use different sampling plans, for example using different numbers of vines per hectare, for each pest. Therefore, a generic sampling plan, which covers the whole pest complex, should be developed. Such a system is lacking for South African vineyards. In addition, searches of the databases Inspec (1969 to 2005), CAB Abstracts (1990 to 2005) and Web of Science (1987 to 2005) did not reveal published information on the development of similar systems.

1.2. Important table grape pests

Information on the biology, seasonal occurrence and damage caused by the pests is necessary for the development of sampling systems for monitoring pests as these factors will influence the way sampling will be conducted, especially regarding the timing of sampling and the plant parts that need to be inspected.

1.2.1. *Planococcus ficus*

The grapevine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), also known as the vine mealybug, is considered to be one of the most important grape pests (De Klerk 1981; Myburgh *et al*. 1986b). It has caused substantial economic losses in California, the Middle East, South America, Pakistan, South Africa and the Mediterranean (Joyce *et al*. 2001). It is the dominant mealybug in grapevines in the Western Cape Province (Walton & Pringle 2004). It may also attack other crops such

as figs, guavas, apples, citrus, dates, bananas, avocado pears and mangos (Myburgh *et al*. 1986b; Blumberg *et al*. 1995; Millar *et al*. 2002). *Planococcus ficus* may be native to the Mediterranean region (Blumberg *et al*. 1995).

1.2.1.1. Biology and seasonal cycle

There is a distinct pattern of seasonal movement (Myburgh *et al*. 1986b). During winter the mealybugs shelter in colonies underneath loose bark on the vines. During late spring and early summer, there is an upward movement into the vines (De Klerk 1981; Annecke & Moran 1982; Nel 1983; Myburgh *et al*. 1986b). This migration from the stems may continue throughout the season and part of the mealybug population may be found under the bark throughout the summer (De Klerk 1981; Annecke & Moran 1982). They first form colonies at the base of young shoots. From there young buds are infested (Nel 1983). They then move to the leaves (Nel 1983). As the weather warms they start breeding rapidly (Myburgh *et al*. 1986b). Eventually they infest the bunches from midsummer onwards (De Klerk 1981; Annecke & Moran 1982; Nel 1983; Myburgh *et al*. 1986b). Many of them are removed with the bunches during harvest (Annecke & Moran 1982). During autumn the mealybugs are concentrated on the leaves (Nel 1983). They start to move off the leaves as these become senescent (Annecke & Moran 1982). After leaf drop they are again found underneath the lose bark of the stems where they overwinter (De Klerk 1981; Annecke & Moran 1982; Nel 1983; Myburgh *et al*. 1986b).

1.2.1.2. Damage

The grapes become infested with mealybugs and are contaminated by their wax secretions, egg sacs and honeydew, causing blemishes resulting in unmarketable fruit (Nel 1983; Myburgh *et al*. 1986b). Black, sooty mould fungus grows on the honeydew, causing heavily infested branches and stems to become black (De Klerk 1981; Nel 1983; Myburgh *et al*. 1986b; Blumberg *et al*. 1995; Joyce *et al*. 2001; Millar *et al*. 2002). In addition, ants are attracted by the sweet honeydew and interfere with biological control of the mealybug by its natural enemies, such as coccinellid predators and parasitic Hymenoptera (De Klerk 1981; Nel 1983; Addison & Samways 2000; Addison 2002; Walton 2003; Walton & Pringle 2003).

Severe infestation inhibits the normal ripening processes, resulting in lack of taste and colour and eventually causing the bunches to wither (De Klerk 1981; Myburgh *et al*. 1986b; Blumberg *et al*. 1995). Yellowing of the leaves and premature leaf drop may occur (Myburgh *et al*. 1986b; Walton & Pringle 2004). The vine becomes weakened, vigour decreases and the lifespan of the vine is shortened (De Klerk 1981; Myburgh *et al*. 1986b; Joyce *et al*. 2001; Walton & Pringle 2004). In addition, *P. ficus* transmits the virus causing grapevine leafroll disease, which results in redness and rolling of the leaves. This results in delayed fruit ripening, yield reductions and reduced sugar accumulation (Joyce *et al*. 2001). *Planococcus ficus* also transmits corky-bark disease, which causes abnormal swelling at the basal internodes of canes (Joyce *et al*. 2001).

1.2.2. *Frankliniella occidentalis*

The western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) was originally distributed in the western parts of the United States (Morishita 2001). It was endemic to an area west of the Rocky Mountains (Jensen 2000) and became widespread throughout the world in the 1970s and 1980s (Morishita 2001). It is a serious pest on a large variety of crops worldwide, including ornamentals, vegetables, fruit trees, garden and agricultural crops, causing substantial economic losses (Jensen 2000; Koschier *et al*. 2000; Morishita 2001; Malais & Ravensberg 2003).

1.2.2.1. Biology and seasonal cycle

In California, the eggs are laid singly into the parenchyma tissues of leaves, flowers and fruits (Jensen 2000). There is a preference for soft tissues, especially the flowers (Jensen *et al*. 1992). The nymphs feed on the host (Jensen *et al*. 1992; Jensen 2000). At the end of the second instar, feeding stops and the nymphs move down the plant into soil or leaf litter to pupate (Jensen 2000). The prepupal and pupal stages are spent in soil debris (Jensen *et al*. 1992). During this stage no feeding and little movement occurs (Jensen 2000). The thrips emerge as adults and are attracted to grape blossoms (Jensen *et al*. 1992). The adults feed on pollen (Jensen *et al*. 1992; Kirk 1997a). The nymphs feed only on stem tissue, if the flowers have been shed, or

on both stem and fruit tissue, if flowers persist. It is however not clear to what extent the adults feed on the stems or fruits (Jensen *et al*. 1992). Although the thrips are much more abundant on flowers (Terry 1997; Malais & Ravensberg 2003), they can be found feeding on young shoots in early spring, especially if there is grass or weed cover in the vineyard, or adjoining weedy areas or crops such as lucerne (Jensen *et al*. 1992).

The adult female has three colour forms (light, intermediate and dark), which are under genetic control, varying from pale yellow to dark-brown or black (Jensen *et al*. 1992; Kirk 1997b; Jensen 2000). The dark form of the female is better adapted to survive cold and wet periods (Kirk 1997b). It dominates during early spring (Jensen *et al*. 1992). The light and intermediate forms are most common later on, with the light form being the most abundant. Males are only abundant in spring (Jensen *et al*. 1992). The developmental time is temperature dependent. The developmental rate will increase with increasing temperatures up to 30°C, above which the rate of development and possibly feeding will decrease (Kirk 1997b).

1.2.2.2. Damage

Frankliniella occidentalis causes three types of damage, namely halo spotting, berry scarring and shoot stunting and foliage damage (Weaver 1976; Flaherty & Wilson 1988b; Jensen *et al*. 1992; Childers 1997; Morishita 2001). Halo spots are formed during oviposition in the berries. This causes a small dark scar at the puncture site. The surrounding tissue becomes whitish, making the fruit of certain white cultivars unsightly and unmarketable (Weaver 1976; Flaherty & Wilson 1988b; Jensen *et al*. 1992). On large-berried cultivars these spots may crack when the grapes grow, allowing entry of rot organisms (Flaherty & Wilson 1988b; Jensen *et al*. 1992). Halo spots are not a serious problem on dark coloured cultivars, because they are obscured when the red or black colour develops. The dark scar in the centre of the halo will remain visible but is too small to be unsightly (Jensen *et al*. 1992). In susceptible cultivars a higher percentage of the eggs are deposited in the berries than in the stem, which is normally the preferred oviposition site (Jensen *et al*. 1992).

Halo spots are produced during bloom and up to fruit set or shortly thereafter (Jensen *et al*. 1992). On cultivars where severe halo spotting may occur, numerous small, dark scars without the surrounding halo are seen at times. This is probably due to probing by the female without egg deposition (Jensen *et al*. 1992). *Frankliniella occidentalis* can also be a vector for viruses, bacteria and fungi (Jensen 2000).

1.2.3. *Phlyctinus callosus*

The vine weevil *Phlyctinus callosus* Boh. (Coleoptera: Curculionidae), also known as the vine snout beetle (Annecke & Moran 1982), grapevine snout beetle, apple snout beetle, V-back snout beetle (Barnes *et al*. 1986) or the banded fruit weevil (Barnes *et al*. 1994, 1995; Witt *et al*. 1995), is indigenous to South Africa (Buchanan & Amos 1992), specifically the Cape (Perold 1927; Pongrácz 1978). This pest is well known on grapes and has also become a severe pest of apples. Other plants that become infested include strawberry, plum, peach, pear and various ornamental shrubs and flowers. The presence of *P. callosus*, as well as other snout beetles, in bunches at harvest leads to rejections for export to certain overseas markets for phytosanitary reasons (Barnes *et al*. 1986).

1.2.3.1. Biology and seasonal cycle

The eggs are laid during summer and autumn on or in the soil, close to the surface (De Klerk 1981; Annecke & Moran 1982; Nel 1983). They only hatch if there is enough moisture present in the air or soil (Nel 1983). The larvae burrow into the soil where they feed on the roots of weeds and vines (De Klerk 1981; Annecke & Moran 1982; Nel 1983; Barnes *et al*. 1986). The larvae develop throughout the winter and when fully grown, they pupate in cells in the soil during spring (Perold 1927; Annecke & Moran 1982; Nel 1983). The adults emerge in spring (Barnes *et al*. 1986) or early summer (Annecke & Moran 1982; Nel 1983). There is usually only one generation per year (Perold 1927; Smit 1964; Annecke & Moran 1982).

The adults are nocturnal, only feeding at night (Perold 1927; Smit 1964; Pongrácz 1978; De Klerk 1981; Annecke & Moran 1982; Nel 1983; Barnes *et al*. 1986; Witt *et al*. 1995). By day they hide under rough bark or in crevices in the bark, between fruit

clusters, in grape bunches, under foliage, under debris or clods on the ground or in the soil near the base of the plant (Perold 1927; Pongrácz 1978; De Klerk 1981; Annecke & Moran 1982; Nel 1983; Barnes *et al*. 1986; Witt *et al*. 1995; Pryke 2005). When touched, the weevils drop to the ground, faking death. Since their colour is so similar to that of the soil, it is difficult to see them on the ground (Perold 1927; Pongrácz 1978).

1.2.3.2. Damage

Early in the season, the leaves and young shoots are attacked (De Klerk 1981). Holes are eaten in the leaves and semi lunar holes around the edges (De Klerk 1981), giving them a serrated appearance (Nel 1983; Barnes *et al*. 1986). Damage at the centre of the leaf is usually in the form of small holes with some of the fibrous leaf veins still undamaged to give it a lacy appearance. Chew-marks are also typically seen on the leaf stalks (Nel 1983). Leaf damage is however only of economic importance in nurseries and young plantings, where the young vines can be entirely defoliated (Barnes *et al*. 1986).

Damage is also done to the shoots, leaving distinctive superficial spots or holes (De Klerk 1981). The shoots are often ringbarked, causing them to wither and die (Nel 1983). Later in the season young bunches are attacked (De Klerk 1981). Holes are eaten in the stems of bunches and berries, as well as the berries themselves (De Klerk 1981; Annecke & Moran 1982; Nel 1983; Barnes *et al*. 1986). Damage to the stems causes ringbarking and dying-off, leading to reduced bunch size (Nel 1983; Barnes *et al*. 1986). Feeding damage also causes the berries to drop or desiccate (Perold 1927; De Klerk 1981; Annecke & Moran 1982; Barnes *et al*. 1986). Even whole bunches can wilt and if beetle numbers are allowed to increase to sufficiently high levels, the whole crop can be destroyed (De Klerk 1981).

1.2.4. Drosophilid species

Vinegar flies (Diptera: Drosophilidae) are sometimes confused with fruitflies (Myburgh *et al*. 1986a). They are regarded as a secondary pest on deciduous fruit, being particularly serious on grapes (Myburgh *et al*. 1986a). These flies are well

known because they are attracted to fermenting, overripe fruit (Smit 1964; Weaver 1976; Buchanan & Amos 1992; Flaherty 1992). They are often found hovering above garbage cans, culled fruit and vegetable dumps (Flaherty 1992).

1.2.4.1. Biology and seasonal cycle

The flies can be found throughout the year, breeding in garbage and overripe fruit or vegetables, such as tomatoes, especially in neglected home gardens (Myburgh *et al*. 1986a). They are attracted to these breeding sites by the alcohol and acetic acid or vinegar (Smit 1964). Population numbers and therefore the infestation potential gradually builds up during the growing season to reach a peak in late summer and autumn at the peak of the harvest season (Myburgh *et al*. 1986a). This population build up, which can take place on culls and wastes of fruit and vegetables grown in the vicinity of the vineyards, is slowed down by hot weather, but large populations can develop very rapidly if light rain or cool temperatures occur during harvest (Weaver 1976; Flaherty 1992). The vinegar fly has a very short life cycle of less than two weeks (Smit 1964).

1.2.4.2. Damage

The vinegar fly attacks berries that have already been damaged by other pests (Myburgh *et al*. 1986a). They are attracted to the fermenting bunches and are responsible for the spread of bunch rot pathogens (Weaver 1976; Buchanan & Amos 1992; Flaherty 1992) such as *Botrytis cinerea* (Louis *et al*. 1996). It has also been argued that they may cause primary damage. While the berries are ripening they may pull away from the stems, exposing the fleshy part of the fruit. This happens especially when the clusters are tight. The flies then lay their eggs in these exposed areas (Weaver 1976; Flaherty 1992). When the larvae hatch, they feed in the berries (Smit 1964; Weaver 1976; Flaherty 1992). The greatest damage caused by them in vineyards is the secondary spread of bunch rot (Weaver 1976; Flaherty 1992).

1.2.5. *Epichoristodes acerbella*

The pear leafroller *Epichoristodes acerbella* (Walker) (Lepidoptera: Tortricidae), also known as the South African carnation worm (Bolton 1979; Gabarra *et al*. 1986), is polyphagous and may therefore cause damage to a wide variety of crops (Van de Vrie 1991). It is a serious pest of carnations and in South Africa it is also known as a pest of pears (Smit 1964; Bolton 1979; Gabarra *et al*. 1986; Van de Vrie 1991). It is indigenous to South Africa (Van de Vrie 1991; Anonymous 1997) and found on many host plants.

1.2.5.1. Biology and seasonal cycle

Epichoristodes acerbella breeds throughout the year on weeds (Nel 1983; Blomefield *et al*. 1986). It has been recorded on orchard weeds such as Cape weed and its relatives (*Arctotheca* spp.), spotted cat's ear (*Hypochoeris radicata*), sheep sorrel (*Rumex angiocarpus*) and wild radish (*Raphanus raphanistrum*) (Bolton 1979; Annecke & Moran 1982; Nel 1983; Anonymous 1997). These weeds serve as alternative hosts, especially during the winter months (Anonymous 1997). There is a strong relationship between the occurrence of *E. acerbella* in table grapes and the cultivation of post-harvest weed cover crops (Blomefield & Du Plessis 2000). Moth activity increases sharply from May and stays high between June and August. This increase is due to an increase in the emergence of cover crop weeds in April (Blomefield & Du Plessis 2000).

This insect is temperature sensitive, preferring moderate temperatures between 15 and 25°C (Bolton 1979; Anonymous 1997). There can be six to seven generations per year (Blomefield & Du Plessis 2000).

1.2.5.2. Damage

Damage is done by the leafroller larvae, which are mainly leaf feeders (Nel 1983; Blomefield *et al*. 1986). The larvae roll and spin one or more leaves or other plant material together with silken threads, providing them with shelter (Annecke & Moran 1982; Nel 1983; Blomefield *et al*. 1986; Anonymous 1997; Blomefield & Du Plessis

2000). The larvae can also damage the grape bunches when several berries are spun together and when the larvae feed on the surface of the berries (Anonymous 1997; Blomefield & Du Plessis 2000; Blomefield *et al*. 2004). They can also bore into a berry where development is completed (Blomefield & Du Plessis 2000; Blomefield *et al*. 2004). The damaged berries are then infected with *Botrytis* and other decaying organisms, causing the bunches to become unmarketable. The rotting bunches also attract vinegar flies which cause fruit decay and unmarketable bunches (Anonymous 1997).

Infestation occurs from the onset of leaf and flower formation in spring and continues through harvest (Blomefield & Du Plessis 2000). The highest infestation levels occur on late cultivars such as Dauphine (Blomefield & Du Plessis 2000). This is a phytosanitary pest. Therefore, even low levels of infestation can lead to rejections for export (Blomefield & Du Plessis 2000; Blomefield *et al*. 2004).

1.2.6. *Helicoverpa armigera*

The African bollworm *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is the most poplyphagous and injurious pest of agriculture and home gardens in South Africa (Annecke & Moran 1982). It attacks a wide range of host plants and is a pest of all deciduous fruit, grapes and berries, as well as vegetables and various field crops (De Klerk 1981; Annecke & Moran 1982; Nel 1983; Blomefield *et al*. 1986). In grapes, it is a sporadic pest, which can cause severe damage when epidemic numbers are reached (De Klerk 1981).

1.2.6.1. Biology and seasonal cycle

The eggs are layed singly on flowers or leaves during spring (Smit 1964; De Klerk 1981; Annecke & Moran 1982). The larvae pupate in the soil (De Klerk 1981; Annecke & Moran 1982). The whole life cycle can be completed in two months and up to four generations per year can occur (De Klerk 1981). *Helicoverpa armigera* can therefore rapidly build up to injurious population levels (De Klerk 1981).

The seasonal occurrence of infestation varies on a yearly basis (Blomefield *et al*. 1986). Although there is generally some activity during spring, infestation levels peak in November to December and sometimes again in January or February (Blomefield *et al*. 1986). Numbers are then reduced by natural enemies and winter cold (Blomefield *et al*. 1986). Mild winters, which allow breeding late in the season, usually lead to severe outbreaks during the following spring and summer (Nel 1983). The moths usually fly at night and are attracted to light, but during epidemics they can be seen flying during the day, hovering around flowers in gardens (Annecke & Moran 1982; Nel 1983; Blomefield *et al*. 1986).

1.2.6.2. Damage

Most damage is caused early in the season when the larvae feed on buds, blossoms, leaves and berries (De Klerk 1981; Blomefield *et al*. 1986). Deep round holes are usually eaten into the berries and if the berries are still very small they may be consumed entirely (Blomefield *et al*. 1986). The fruit forms cork tissue over the injured places, which inhibits normal subsequent development of the fruit, leading to malformation (Blomefield *et al*. 1986). When mature or almost mature fruit is infested, the wounds remain as relatively large corky holes or depressions (Blomefield *et al*. 1986).

1.2.7. *Tetranychus urticae*

The increase in the use of nitrogen and potassium fertilisers and non-selective pesticides in viticulture favoured outbreaks of spider mites, which were previously only known as occasional grapevine pests (Rilling 1989). Along with the European red mite *Panonychus ulmi* Koch, the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae) is considered to be the most important pest of grapevines in Europe (Candolfi *et al*. 1992). It is also the most important spider mite pest of grapevines in dry summer regions of Europe (Schruft 1985), being especially important in Spain (Flaherty & Wilson 1988a).

Tetranychus urticae, also known as the glasshouse spider mite, attacks deciduous fruit, strawberry and approximately a hundred other plants (Pringle *et al*. 1986). The

carmine form of *T. urticae* was previously known as *Tetranychus cinnabarinus* (Boisd.), the common red spider mite, but they are now considered to be the same species (Smith Meyer 1987; Pringle & Giliomee 1992).

1.2.7.1. Biology and seasonal cycle

Tetranychus urticae passes the winter as fertilised female colonies under the bark of the trunk, on leaves on the ground and on winter weeds (Schruft 1985). In Europe, the foliage of grapevines is not colonised until summer (Schruft 1985). All the stages live in dense colonies on the undersurface of leaves (Schruft 1985). Outbreaks of this mite are unpredictable (Pringle *et al*. 1986). Infestation can take place from sources on other plants and generally occurs with the onset of warm, dry weather (Pringle *et al*. 1986).

1.2.7.2. Damage

When the mites feed on the undersurface of leaves, chlorotic spots are formed (Schruft 1985; Flaherty & Wilson 1988a). This is followed by yellowing or browning of whole leaves (Pringle *et al*. 1986) and eventually a high degree of defoliation, the latter influencing the maturation and quality of the berries (Schruft 1985; Flaherty & Wilson 1988a). Plant growth is retarded (Pringle *et al*. 1986) and there can be a reduction in yield (Prischmann *et al*. 2002). Fruit clusters may also be attacked, resulting in dark spots on the skin (Schruft 1985; Flaherty & Wilson 1988a). However, during a three-year study conducted by Schwartz (1990), no bunch infestation by *T. urticae* was observed in the Hex River Valley.

1.3. Present study

1.3.1. Main objectives and hypotheses

It is important that a monitoring system should be sufficiently easy to implement so that farmers can educate untrained workers to use the system. Farmers have agreed that the sampling system for monitoring population levels of *P. ficus*, in which 20

evenly spaced plots of five vines per plot in one hectare are inspected (Walton 2003), is feasible. In addition, the sampling error and precision of decision making for control intervention (Binns *et al*. 2000) has been determined for the monitoring protocol for *P. ficus* (Walton 2003). Therefore, one of the main objectives of the present study was to determine whether or not the sampling protocol developed for monitoring *P. ficus* population levels could be extended to include all the major pests of table grapes. Pests, in addition to *P. ficus*, specifically targeted in this study were *E. acerbella*, *P. callosus*, *Tetranychus* spp., *F. occidentalis* and *H. armigera*. An attempt was not made to develop a sampling system for vinegar flies, since they are still considered to be mainly a secondary pest. However, their presence may indicate damage caused by other pests, such as *E. acerbella*. Due to the importance of *E. acerbella* as a phytosanitary pest (Pryke 2005), vinegar fly activity levels were also monitored to see whether or not they could be used as indicators of *E. acerbella* bunch damage, which is more difficult to detect. The use of traps and bands, previously used by other researchers (see section 1.1), was also investigated since farmers were familiar with these systems.

Information on the temporal distribution (seasonal occurrence) is important for planning pest management systems, as it can be used to determine when monitoring should commence. In addition, Walton (2003) showed that there was a succession in the pattern of infestation of vines by *P. ficus*. First the stems were infested, then the leaves and finally the bunches. Therefore, stem infestation could be used as a warning for pending bunch infestations, which are responsible for economic losses (Walton 2003). The possibility of identifying warning systems for the other pests was investigated. However, these temporal patterns should also be linked to spatial association if they are to be of use in pest management systems. For example, if the bunch infestations do not occur in the same areas of the vineyard as stem infestations, then the latter cannot be used to plan spot treatments for preventing bunch infestations. Therefore, detailed studies on the spatial patterns of the pests were conducted.

The occurrence of weeds in plantings is important in the biological control of mites on a number of crops, including apples (Croft & McGroarty 1977; Pringle 1995), pears (Flexner *et al*. 1991) and citrus (Aucejo *et al*. 2003). The presence of certain cover

crop plants may enhance biological control of phytophagous mites by the predatory mites in that they provide food and shelter for the latter. It is therefore important to know which of these plants serve as hosts for both phytophagous and predatory mites. The spatial association between important cover crop plants and the presence of phytophagous and predatory mites on the vine leaves was also determined. Although such information will not be used in the development of a sampling plan as such, it will give insight on how the vineyard floor can be managed in order to create a potentially successful biological control system of the phytophagous mites.

Epichoristodes acerbella population levels build up early in the season, with moth activity increasing during May and infestation by the larvae starting during spring when leaves and flowers are formed (Blomefield & Du Plessis 2000). However, moth activity declines from September onwards (Blomefield & Du Plessis 2000). This moth is sensitive to temperatures above 25°C (Bolton 1979; Gabarra *et al*. 1986). Therefore, life table studies were conducted on the strain from the Hex River Valley to determine whether or not this was the case with this particular strain, as sensitivity to high temperatures could explain the mid-season decline in population levels. In addition, due to the importance of *E. acerbella* from a phytosanitary point of view (Pryke 2005), it is possible that a sterile insect technique (SIT) programme, as currently being developed to locally eradicate the Mediterranean fruitfly *Ceratitis capitata* (Wiedemann) in the Hex River Valley (Barnes 2000a, b) and to eradicate the codling moth *Cydia pomonella* (L.) in Canada (Dyck & Gardiner 1992; Judd & Gardiner 2005), will be developed in the future. Information on temperature requirements, mortality, fecundity and sex-ratio will be very valuable for such a programme, as it will provide a guide for release rates and breeding of the insect.

1.3.2. Layout of dissertation

Determining sampling errors and operational characteristic curves, seasonal occurrence and temporal and spatial distribution and associations of the main table grape pests, will each be discussed in separate chapters. The study sites used and experimental procedures followed were the same for these main objectives. Therefore, to prevent duplication, these are discussed first in Chapter 2. This will be followed by the studies on seasonal occurrence in Chapter 3, since these results

determined the pests or type of damage or infestation for which the sampling errors and operational characteristic curves need to be determined. The latter will be discussed in Chapter 4. Before the temporal and spatial distribution patterns and associations can be discussed, the cover crop plants of importance for phytophagous and predatory mites first need to be identified in Chapter 5, since this will be included in the spatial analysis. Chapter 6 on the spatial analyses will follow. Chapter 7 will contain the work on life table studies for *E. acerbella*. In the last chapter (8), the main findings will be summarized and a generic monitoring system for managing the pest complex in vines will be described.

1.4. References

Addison, P. 2002. Chemical stem barriers for the control of ants (Hymenoptera: Formicidae) in vineyards. *South African Journal of Enology and Viticulture* 23: 1-8.

Addison, P. & Samways, M.J. 2000. A survey of ants (Hymenoptera: Formicidae) that forage in vineyards in the Western Cape Province, South Africa. *African Entomology* 8: 251-260.

Annecke, D.P. & Moran, V.C. 1982. *Insects and Mites of Cultivated Plants in South Africa*. Butterworths, Pretoria.

Anonymous. 1997. Ou plaag met nuwe status. *Deciduous Fruit Grower* 47(7): 256-257.

Aucejo, S., Foo, M., Gimeno, E., Gomez-Cadenas, A., Monfort, R., Obiol, F., Prades, E., Ramis, M., Ripolles, J.L., Tirado, V., Zaragoza, L., Jacas, J.A. & Martinez-Ferrer, M.T. 2003. Management of *Tetranychus urticae* in citrus in Spain: acarofauna associated to weeds. *Bulletin OILB/SROP* 26(6): 213-220.

Barnes, B.N. 2000a. Fruit flies of economic importance in South Africa: an overview. In: Price, N.S. & Seewooruthun, I. (Ed.) *Proceedings of the Indian Ocean Commission, Regional Fruit Fly Symposium, Mauritius, 5-9 June 2000.* 101-107. Indian Ocean Commission, Flic en Flac, Mauritius.

Barnes, B.N. 2000b. Monitoring and control of fruit flies in South African fruit orchards. In: Price, N.S. & Seewooruthun, I. (Ed.) *Proceedings of the Indian Ocean Commission, Regional Fruit Fly Symposium, Mauritius, 5-9 June 2000.* 147-152. Indian Ocean Commission, Flic en Flac, Mauritius.

Barnes, B.N., Daiber, K.C. & Donaldson, J.M. 1986. Fruit-eating and leaf-eating beetles. In: Myburgh, A.C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 35-42. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Barnes, B.N., Knipe, M.C. & Calitz, F.J. 1994. Trunk barriers provide effective control of banded fruit-weevil on apples and nectarines. *Deciduous Fruit Grower* 44(9): 327-332.

Barnes, B.N., Knipe, M.C. & Calitz, F.J. 1995. Effective weevil control on apple trees with batting trunk barriers. *Deciduous Fruit Grower* 45(9): 376-378.

Bezert, J. 1999. *Tetranychus urticae* on processing tomatoes. How to reason cultural practices? *Acta Horticulturae* 487: 257-261.

Binns, M.R., Nyrop, J.P. & Van der Werf, W. 2000. *Sampling and Monitoring in Crop Protection: The Theoretical Basis for Developing Practical Decision Guides*. CAB International, Wallingford.

Blomefield, T. L., Daiber, K.C. & Bolton, M.C. 1986. Fruit-eating and leaf-eating caterpillars. In: Myburgh, A.C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 26-34. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Blomefield, T. & Du Plessis, N. 2000. Pear leafroller: a simple matter of weed control? *Deciduous Fruit Grower* 50(6): 12-13.

Blomefield, T., Du Plessis, N. & Knipe, M. 2004. Pear leafroller: a holistic approach is the key to the control of this pest. *South African Fruit Journal* 3(5): 30-32.

Blumberg, D., Klein, M. & Mendel, Z. 1995. Response by encapsulation of four mealybug species (Homoptera: Pseudococcidae) to parasitization by *Anagyrus pseudococci*. *Phytoparasitica* 23: 157-163.

Bolton, M.C. 1979. Some effects of temperature, humidity and larval diet on the life cycle of the South African carnation worm, *Epichoristodes acerbella* (Walker) (Lepidoptera: Tortricidae). *Journal of the Entomological Society of Southern Africa* 42: 129-135.

Botha, J.H., Du Plessis, D. & Calitz, F.J. 1994. Effect of acaricides on phytophagous mites and selected predators in apple orchards. *Journal of the Southern African Society for Horticultural Sciences* 4(1): 47-49.

Buchanan, G.A. & Amos, T.G. 1992. Grape pests. In: Coombe, B.G. & Dry, P.R. (Eds) *Viticulture*. 209-231. Winetitles, Adelaide.

Buhler, A. & Zohren, E. 1992. Blue sticky board traps for early recognition and monitoring of thrips damage – especially by *Frankliniella occidentalis* – in ornamental horticulture and nurseries. *Gesunde Pflanzen* 44: 268-270.

Candolfi, M.P., Boller, E.F. & Wermelinger, B. 1992. Spatio-temporal distribution of *Panonychus ulmi* Koch (Acari, Tetranychidae) on Guyot-trained grapevines. *Journal of Applied Entomology* 114: 244-250.

Childers, C.C. 1997. Feeding and oviposition injuries to plants. In: Lewis, T. (Ed.) *Thrips as Crop Pests*. 505-538. CAB International, New York.

Chu, C.-C., Pinter, P.J., Henneberry, T.J., Umeda, K., Natwick, E.T., Wei, Y.-A., Reddy, V.R. & Shrepatis, M. 2000. Use of CC traps with different trap base colors for silverleaf whiteflies (Homoptera: Aleyrodidae), thrips (Thysanoptera: Thripidae), and leafhoppers (Homoptera: Cicadellidae). *Journal of Economic Entomology* 93: 1329-1337.

Colombo, M. & Biondo, L. 1996. Monitoring of Thysanoptera in crops of cyclamen with azure blue sticky traps. *Informatore Agrario* 52(30): 70-72.

Croft, B.A. & McGroarty, D.L. 1977. The role of *Amlyseius fallacis* (Acarina: Phytoseiidae) in Michigan apple orchards. *Research report No. 333, Michigan State University, Agricultural Experiment Station, East Lansing*.

De Klerk, C.A. 1981. Wingerdplae. In: Burger, J. & Deist, J. (Reds.) *Wingerdbou in Suid-Afrika*. 433-462. Maskew Miller, Pretoria.

Dyck, V.A. & Gardiner, M.G.T. 1992. Sterile-insect release programme to control the codling moth *Cydia pomonella* (L.) (Lepidoptera: Olethreutidae) in British Columbia, Canada. *Acta Phytopathologica et Entomologica Hungarica* 27: 219-222.

Flaherty, D.L. 1992. Vinegar fly. In: Flaherty, D.L., Christensen, L.P., Lanini, W.T., Marois, J.J., Phillips, P.A. & Wilson, L.T. (Eds) *Grape Pest Management. Second Edition*. 258-259. Division of Agriculture and Natural Resources, University of California.

Flaherty, D.L. & Wilson, L.T. 1988a. Part II. Mites and insects that cause diseaselike symptoms in grapes: Mites. In: Pearson, R.C. & Goheen, A.C. (Eds) *Compendium of Grape Diseases.* 60-61. The American Phytopathological Society, Minnesota.

Flaherty, D.L. & Wilson, L.T. 1988b. Part II. Mites and insects that cause diseaselike symptoms in grapes: Thrips. In: Pearson, R.C. & Goheen, A.C. (Eds) *Compendium of Grape Diseases.* 61-62. The American Phytopathological Society, Minnesota.

Flexner, J.L., Westigard, P.H., Gonzalves, P. & Hilton, R. 1991. The effect of groundcover and herbicide treatment on twospotted spider mite density and dispersal in southern Oregon pear orchards. *Entomologia Experimentalis et Applicata* 60: 111-123.

Gabarra, R., Buisán, A., Avilla, J. & Albajes, R. 1986. Longevity, fecundity and egg hatching of *Epichoristodes acerbella* under constant temperatures (Lepidoptera: Tortricidae). *Entomologia Generalis* 12: 45-50.

Gaum, W.G. & Giliomee, J.H. 1994. Preference of western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae), and greenhouse whitefly, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae), for differently coloured sticky traps. *Journal of the Southern African Society for Horticultural Sciences* 4(2): 39-41.

Gilli, C., Farinet, R., Mittaz, C. & Carlen, C. 2005. Sampling of the two-spotted spider mite *Tetranychus urticae*, the predator *Neoseiulus californicus* and the whitefly *Trialeurodes vaporariorum* on roses in greenhouse. *Revue Suisse de Viticulture, Arboriculture et Holticulture* 37: 173-179.

Gonzalez Zamora, J.E. & Moreno Vazquez, R. 1996. Analysis of population trends of *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) in pepper under plastic. *Boletin de Sanidad Vegetal, Plagas* 22: 391-399.

Hluchy, M. & Pospisil, Z. 1991. Damage potential of the phytophagous Eriophyidae and Tetranychidae mites (Acari; Tetrapodili, Prostigmata) in grapevine. *Ochrana Rostlin* 27(3/4): 273-285.

Jacobs, S. 1995. Thrips damage and control in apple orchards. *Deciduous Fruit Grower* 45(8): 323-331.

Jensen, S.E. 2000. Insecticide resistance in the western flower thrips, *Frankliniella occidentalis*. *Integrated Pest Management Reviews* 5: 131-146.

Jensen, F.L., Flaherty, D.L. & Luvisi. D.A. 1992. Thrips. In: Flahery, D.L., Christensen, L.P., Lanini, W.T., Marois, J.J., Phillips, P.A. & Wilson, L.T. (Eds) *Grape Pest Management. Second Edition*. 193-201. Division of Agriculture and Natural Resources, University of California.

Joyce, A.L., Hoddle, M.S., Bellows, T.S. & González, D. 2001. Oviposition behaviour of *Coccidoxenoides peregrinus*, a parasitoid of *Planococcus ficus*. *Entomologia Experimentalis et Applicata* 98: 49-57.

Judd, G.J.R. & Gardiner, M.G.T. 2005. Towards eradication of codling moth in British Columbia by complimentary actions of mating disruption, tree banding and sterile insect technique: five-year study in organic orchards. *Crop Protection* 24: 718-733.

Katayama, H. 2005. Damage analysis of the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), on strawberry plants. *Japanese Journal of Applied Entomology and Zoology* 49: 51-56.

Kirk, W.D.J. 1997a. Feeding. In: Lewis, T. (Ed.) *Thrips as Crop Pests*. 119-174. CAB International, New York.

Kirk, W.D.J. 1997b. Distribution, abundance and population dynamics. In: Lewis, T. (Ed.) *Thrips as Crop Pests*. 217-258. CAB International, New York.

Koschier, E.H., De Kogel, W.J. & Visser, J.H. 2000. Assessing the attractiveness of volatile plant compounds to western flower thrips *Frankliniella occidentalis*. *Journal of Chemical Ecology* 26: 2643-2655.

Labanowska, B.H. & Gajek, D. 1999. Monitoring and control of the main pests of blackcurrant. *Progress in Plant Protection* 39(1): 305-311.

Louis, C., Girard, M., Kuhl, G. & Lopez-Ferber, M. 1996. Persistence of *Botrytis cinerea* in its vector *Drosophila melanogaster*. *Phytopathology* 86: 934-939.

Malais, M.H. & Ravensberg, W.J. 2003. *Knowing and Recognizing, the Biology of Glasshouse Pests and their Natural Enemies*. Reed Business Information, The Netherlands.

Millar, J.G., Daane, K.M., McElfresh, J.S., Moreira, J.A., Malakar-Kuenen, R., Guillén, M. & Bentley, W.J. 2002. Development and optimization of methods for using sex pheromone for monitoring the mealybug *Planococcus ficus* (Homoptera: Pseudococcidae) in California vineyards. *Journal of Economic Entomology* 95: 706-714.

Morishita, M. 2001. Toxicity of some insecticides to larvae of *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) evaluated by the petri dish-spraying tower method. *Applied Entomology and Zoology* 36: 137-141.

Morishita, M. 2002. Reflective plastic mulch as control measure for thrips in fig plant (*Ficus carica* L.). *Proceedings of the Kansai Plant Protection Society* 44: 21-25.

Myburgh, A.C., Barnes, B.N. & Rust, D.J. 1986a. Fruitflies and vinegar fly. In: Myburgh, A.C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 17-21. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Myburgh, A.C., Swart, P.L. & Urban, A.J. 1986b. Mealybugs and Australian bugs. In: Myburgh, A. C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 43-47. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Nel, P.J. 1983. *Deciduous Fruits and Vines. Pests and Diseases and their Control*. David Philip Publisher, Cape Town.

Nel, P.J. & Addison, M.F. 1993. The development of an integrated pest management programme in apple orchards in Elgin, South Africa and the implications for integrated fruit production. *Acta Horticulturae* 347: 323-326.

Opit, G.P., Chen, Y., Williams, K.A., Nechols, J.R. & Margolies, D.C. 2005. Plant age, fertilization, and biological control affect damage caused by twospotted spider mites on ivy geranium: development of an action threshold. *Journal of the American Society for Horticultural Science* 130: 159-166.

Perold, A.I. 1927. *A Treatise on Viticulture*. Macmillan and Co., Limited, London.

Phillips, P.A. 1989. Simple monitoring of black vine weevil in vineyards. *California Agriculture* 43(3): 12-13.

Pongrácz, D.P. 1978. *Practical Viticulture*. David Philip Publisher, Cape Town.

Pringle, K.L. 1987. *Development of a Sampling System for Monitoring Population Levels of Tetranychid Mites (Acarina: Tetranychidae) on Apple Trees in the Elgin Area*. PhD Dissertation, University of Stellenbosch.

Pringle, K.L. 1995. The role of the cover crop in biological control of mites using *Phytoseiulus persimilis* in apple orchards in South Africa. *European Journal of Plant Pathology. XIII International Plant Protection Congress, The Hague, The Netherlands, 2-7 July, 1995, Abstracts*: 859.

Pringle, K.L. & Giliomee, J.H. 1992. Dispersion statistics and sample size estimates for monitoring mite populations in commercial apple orchards. *Journal of Applied Ecology* 29: 143-149.

Pringle, K.L., Rust, D.J. & Meyer, M.P.K. 1986. Plant-eating mites. In: Myburgh, A.C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 62-68. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Prischmann, D.A., Croft, B.A. & Luh, H.-K. 2002. Biological control of spider mites on grape by phytoseiid mites (Acari: Tetranychidae, Phytoseiidae): emphasis on regional aspects. *Journal of Economic Entomology* 95: 340-347.

Pryke, J.S. 2005. *Insect Contaminants in Table Grapes*. MSc Thesis, University of Stellenbosch.

Rilling, G. 1989. Differential response of grapevine cultivars to European red mite (*Panonychus ulmi* KOCH) – elaboration of a screening method. *Vitis* 28: 97-110.

Romoser, W.S. & Stoffolano, J. G. 1998. *The Science of Entomology. Fourth Edition.* McGraw-Hill Companies, Inc., Boston.

Schruft, G.A. 1985. Grape. In: Helle, W. & Sabelis, M.W. (Eds) *Spider Mites. Their Biology, Natural Enemies and Control. World Crop Pests Vol1B.* 359-366. Elsevier, New York.

Schwartz, A. 1990. Pesticide effect on populations of *Tetranychus urticae* Koch (Acari: Tetranychidae) and a predaceous mite on table grapes in the Hex River Valley. *South African Journal of Enology and Viticulture* 11: 33-37.

Schwartz, A. 1993. Occurrence of natural enemies of phytophagous mites on grapevine leaves following application of fungicides for disease control. *South African Journal of Enology and Viticulture* 14: 16-17.

Shipp, J.L. & Zariffa, N. 1991. Spatial patterns of and sampling methods for western flower thrips (Thysanoptera: Thripidae) on greenhouse sweet pepper. *Canadian Entomologist* 123: 989-1000.

Smit, B. 1964. *Insects in Southern Africa, How to Control them*. Oxford University Press, Cape Town.

Smith Meyer, M.K.P. 1987. African Tetranychidae (Acari: Prostigmata) with reference to the world genera. *Republic of South Africa Department of Agriculture and Water Supply, Entomology Memoir* 69.

Speight, M.R., Hunter, M.D. & Watt, A.D. 1999. *Ecology of Insects. Concepts and Applications.* Blackwell Science Ltd, London.

Terry, L.I. 1997. Host selection, communication and reproductive behaviour. In: Lewis, T. (Ed.) *Thrips as Crop Pests*. 65-118. CAB International, New York.

Tommasini, M.G. & Burgio, G. 2004. The damage of thrips on nectarine: sampling methods of populations and injury level. *Bulletin OILB/SROP* 27(5): 35-47.

Tsitsipis, J.A., Roditakis, N., Michalopoulos, G., Palivos, N., Pappas, D., Zarpas, K.D., Jenser, G., Vaggelas, J. & Margaritopoulos, J.T. 2003. A novel scarring symptom on seedless grapes in the Corinth region (Peloponnese, southern Greece) caused by western flower thrips, *Frankliniella occidentalis*, and pest control tests. *Bulletin OILB/SROP* 26(8): 259-263.

Van de Vrie, M. 1991. Tortricids in ornamental crops and greenhouses. In: Van der Geest, L.P.S. & Evenhuis, H.H. (Eds) *Tortricid Pests. Their Biology, Natural Enemies and Control. World Crop Pests Vol. 5*. 515-533. Elsevier, New York.

Walton, V.M. 2003. *Development of an Integrated Pest Management System for Vine Mealybug,* Planococcus ficus *(Signoret), in Vineyards in the Western Cape Province, South Africa*. PhD Dissertation, University of Stellenbosch.

Walton, V.M., Daane, K.M. & Pringle, K.L. 2004. Monitoring *Planococcus ficus* in South African vineyards with sex pheromone-baited traps. *Crop Protection* 23: 1089-1096.

Walton, V.M. & Pringle, K.L. 2003. Evaluating effectiveness of mass releases of the vine mealybug (*Planococcus ficus*) parasitoid *Coccidoxenoides peregrinus* in Western Cape Province vineyards, South Africa. *Proceedings of the 1st International Symposium on Biological Control of Arthropods*: 524-532.

Walton, V.M. & Pringle, K.L. 2004. A survey of mealybugs and associated natural enemies in vineyards in the Western Cape Province, South Africa. *South African Journal of Enology and Viticulture* 25: 23-25.

Walton, V.M., Pringle, K.L. & Daane, K.M. 2003. Geïntegreerde beheer van wingerdwitluis (*Planococcus ficus*) met behulp van feromoonvalletjies in wingerde in Suid-Afrika. *Wynboer: 'n Tegniese Gids vir Wynprodusente* 168: 15-16.

Weaver, R.J. 1976. *Grape Growing*. John Wiley & Sons, New York.

Weihrauch, F. 2004. A new monitoring approach for the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), in hop culture. *Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz* 111(2): 197-205.

Witt, A.B.R., Little, R.M. & Crowe, T.M. 1995. The effectiveness of helmeted guineafowl *Numida meleagris* (Linnaeus 1766) in controlling the banded fruit weevil *Phlyctinus callosus* (Schönherr 1826), and their impact on other invertebrates in apple orchards in the Western Cape Province, South Africa. *Agriculture, Ecosystems and Environment* 55: 169-179.

CHAPTER 2

MONITORING: STUDY SITES AND PROCEDURES

2.1 Study sites

The study was conducted on three farms in the Hex River Valley in the Western Cape Province of South Africa, namely Klipheuwel (19°31'E, 33°30'S), Boplaas (19°36'E, 33°30'S) and De Vlei Boerdery (19°41'E, 33°26'S). At each farm two blocks of Barlinka, a late season black cultivar, and two blocks of Dauphine, a late season white cultivar, were used (Figure 2.1). Each block was approximately one to two hectares in size. Twenty evenly distributed plots, each consisting of five vines, were selected per block. Normal spray programmes were followed in all the blocks (see Appendix A for block names and exact sizes, plant dates, soil types and the pesticides that were sprayed).

2.2 Experimental design

2.2.1. Monitoring in vineyards

The top fork of each of the five vines per plot was examined for the presence of the grapevine mealybug *Planococcus ficus* to a distance of within 30 cm of the stem, as well as the distal 15 cm of one cane per vine for *P. ficus* and damage caused by the banded fruit weevil *Phlyctinus callosus* (Figures 2.1 & 2.2). For *P. callosus*, the leaves around the stems of five vines per plot were also examined for damage (Figure 2.2). One bunch per vine was examined for the presence of insects and damage caused by insects such as *P. ficus*, *P. callosus*, the western flower thrips *Frankliniella occidentalis*, pear leafroller *Epichoristodes acerbella*, African bollworm *Helicoverpa armigera* and the presence of vinegar flies (Drosophilidae) in the berries (Figure 2.2). One leaf per vine was examined for leaf feeding insects such as spider mites, *Tetranychus* spp., thrips and *P. ficus* (Figure 2.2). After examination in the field, the

leaves were placed in brown paper bags and transported, in cool bags, to the laboratory, where they were stored in a cool room prior to counting. The leaves were brushed with a brushing machine to dislodge the insects and mites (Sabelis 1985) and all the developmental stages of the mites, their predators and thrips were microscopically determined.

2.2.2. Monitoring using traps and bands

Fluted cardboard bands (Figure 2.1) were tied around the stems of one vine per plot to trap *P. callosus*. After inspection, the cardboard band was moved to the next plant in the plot. At Boplaas and Klipheuwel the activity levels of *F. occidentalis* were monitored using a blue sticky trap (Gaum & Giliomee 1994; Chu *et al*. 2000) in four of the 20 plots. At De Vlei Boerdery a blue sticky trap was used in either four or five of the 20 plots, depending on the structure of the block. The sticky traps were placed outside the canopy, as this is the position where most thrips are caught (E. Allsop, personal communication[*]) (Figure 2.1).

Pheromone capsules were placed in yellow delta traps, containing a white sticky pad (Figure 2.1), at a density of one trap per block of one to two hectares to monitor the activity levels of *E. acerbella*, *H. armigera* and *P. ficus* (Figure 2.2). Separate traps were used for these pests. The traps were placed at the height of the bunches for *E. acerbella* and *H. armigera* (T. Blomefield, personal communication[*]) and at the height of the cordon for *P. ficus* (Walton *et al*. 2003), with the openings parallel to the row direction to avoid chemicals from being sprayed into the trap.

[*] ARC Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599.

Figure 2.1. The cultivars used in the study, parts of the stems and shoots that were inspected and the traps, bands and handheld equipment that were used.

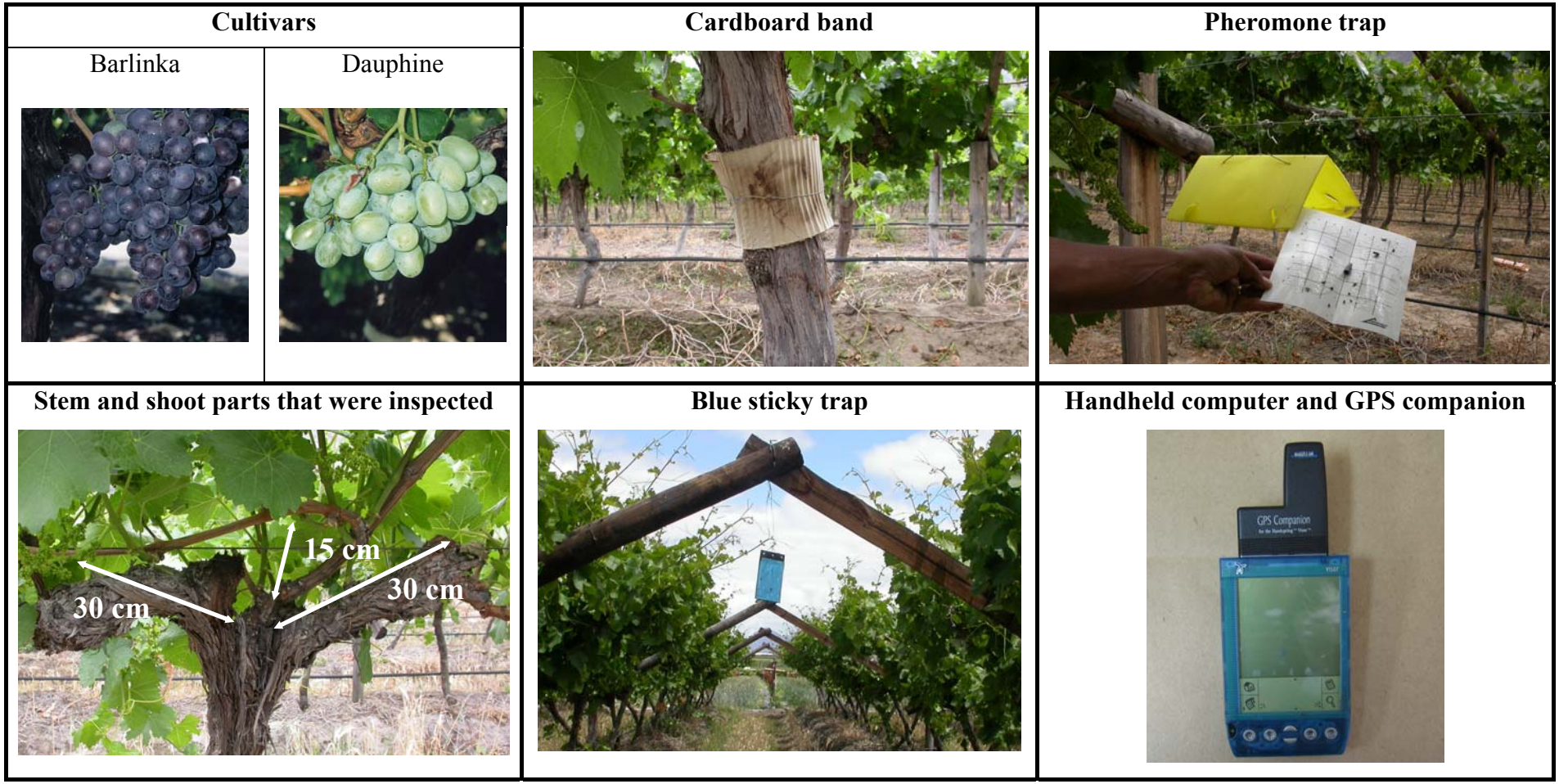
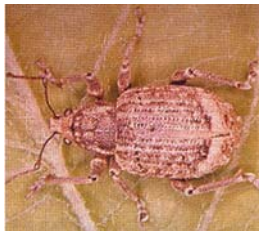


Figure 2.2. The main table grape pests and their damage.

Planococcus ficus	***Phlyctinus callosus***	***Frankliniella occidentalis***	***Epichoristodes acerbella***	***Helicoverpa armigera***
Female and male  ARC-Infruitec Nietvoorbij	Adult  ARC-Infruitec Nietvoorbij	Adult  ARC-Infruitec Nietvoorbij	Adult 	Adult  Blomefield *et al.* 1986
Bunch infestation  De Klerk 1981	Bunch damage  Ferreira & Venter 1996	Bunch damage (halo spot)  Jensen *et al.* 1992	Bunch damage with larva present  ARC-Infruitec Nietvoorbij	Larva  Blomefield *et al.* 1986
Stem infestation  Vaughn Walton	Shoot and leaf damage  ARC-Infruitec Nietvoorbij	**Drosophilidae** Adult  Flaherty 1992	 ARC-Infruitec Nietvoorbij	Bunch damage  ARC-Infruitec Nietvoorbij
				***Tetranychus* spp.** *T. urticae* female with egg 

2.2.3. Sampling frequencies

Monitoring was done over a period of just more than three years, from March 2002 until mid-April 2005. Leaf samples were taken only from October to the end of April, when the fruit season ended, during all the seasons. From April onwards the quality of the leaves rapidly decreased until leaf fall and it was too difficult to brush the brittle leaves with the brushing machine (see section 2.2.1). The cardboard bands and sticky traps were placed in the vineyards during March 2002. Monitoring of the plants and inspection of the cardboard bands and sticky traps were done at two-weekly intervals. *Planococcus ficus* traps were placed in the vineyards during July 2003, when the traps became commercially available. The first data were recorded during August 2003. These traps were inspected at two-weekly intervals during the fruit season (September to the end of April during 2003 and 2004) (Walton *et al*. 2003, 2004) and monthly during the rest of the year (Walton *et al*. 2003). The sampling dates of the 12 vineyard blocks were however not the same since the 12 blocks could not be sampled on one day. Therefore, six of the blocks were sampled on one day during a certain week, say week one, and the other six on one day during the next week, say week two. *Epichoristodes acerbella* and *H. armigera* traps were inspected at weekly intervals. The first data were recorded in May 2002, a week after placement. All the above-mentioned monitoring was occasionally postponed for a few days due to rain.

2.3. Additional equipment

A handheld computer with the Cybertracker software (http://www.cybertracker.co.za) was used to record the data obtained from vine inspections, trap catches and band monitoring in the field. These data were then downloaded to a computer, which saved the time of manually typing in the data. A GPS companion, connected to the handheld computer (Figure 2.1), was used to determine the geographic co-ordinates of all the sampling points. The data were imported into Access, a relational database (Dowling 2000).

2.4. Weather data

Weather data were obtained from the ARC - Institute of Soil, Climate and Water (AgroMet Section, Private Bag X79, Pretoria 0001).

2.5. References

Blomefield, T. L., Daiber, K.C. & Bolton, M.C. 1986. Fruit-eating and leaf-eating caterpillars. In: Myburgh, A.C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 26-34. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Chu, C.-C., Pinter, P.J., Henneberry, T.J., Umeda, K., Natwick, E.T., Wei, Y.-A., Reddy, V.R. & Shrepatis, M. 2000. Use of CC traps with different trap base colors for silverleaf whiteflies (Homoptera: Aleyrodidae), thrips (Thysanoptera: Thripidae), and leafhoppers (Homoptera: Cicadellidae). *Journal of Economic Entomology* 93: 1329-1337.

De Klerk, C.A. 1981. Wingerdplae. In: Burger, J. & Deist, J. (Reds.) *Wingerdbou in Suid-Afrika*. 433-462. Maskew Miller, Pretoria.

Dowling, N. 2000. *Database Design & Management using Access*. Continuum, London.

Ferreira, J.H.S. & Venter, E. 1996. *Grapevine Diseases & Pests in South Africa*. ARC-Nietvoorbij Institute for Viticulture and Oenology.

Flaherty, D.L. 1992. Vinegar fly. In: Flaherty, D.L., Christensen, L.P., Lanini, W.T., Marois, J.J., Phillips, P.A. & Wilson, L.T. (Eds) *Grape Pest Management. Second Edition*. 258-259. Division of Agriculture and Natural Resources, University of California.

Gaum, W.G. & Giliomee, J.H. 1994. Preference of western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae), and greenhouse whitefly, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae), for differently coloured sticky traps. *Journal of the Southern African Society for Horticultural Sciences* 4(2): 39-41.

Jensen, F.L., Flaherty, D.L. & Luvisi. D.A. 1992. Thrips. In: Flahery, D.L., Christensen, L.P., Lanini, W.T., Marois, J.J., Phillips, P.A. & Wilson, L.T. (Eds) *Grape Pest Management. Second Edition*. 193-201. Division of Agriculture and Natural Resources, University of California.

Sabelis, M.W. 1985. Sampling Techniques. In: Helle, W. & Sabelis, M.W. (Eds) *Spider Mites. Their Biology, Natural Enemies and Control. World Crop Pests Vol1A.* 337-350. Elsevier, New York.

Walton, V.M., Daane, K.M. & Pringle, K.L. 2004. Monitoring *Planococcus ficus* in South African vineyards with sex pheromone-baited traps. *Crop Protection* 23: 1089-1096.

Walton, V.M., Pringle, K.L. & Daane, K.M. 2003. Geïntegreerde beheer van wingerdwitluis (*Planococcus ficus*) met behulp van feromoonvalletjies in wingerde in Suid-Afrika. *Wynboer: 'n Tegniese Gids vir Wynprodusente* 168: 15-16.

CHAPTER 3

SEASONAL OCCURRENCE OF VINE PESTS IN THE HEX RIVER VALLEY IN THE WESTERN CAPE PROVINCE OF SOUTH AFRICA

3.1. Introduction

Information on the seasonal occurrence of pests is needed for planning the initiation of monitoring and for determining when damage can be expected. If damage by a pest is not expected until late in the fruit season, certain sampling procedures, aimed specifically at that pest, can be postponed. The foliage of grapevines in Europe is not colonised by *Tetranychus urticae* until summer (Schruft 1985). If this is also the case in South Africa, specifically the Hex River Valley, it would not be necessary to examine the leaves for *T. urticae* at the onset of the fruit season in September. In apple orchards adult *Phlyctinus callosus* emerged in spring (Barnes *et al*. 1986) or early summer (Annecke & Moran 1982; Nel 1983). This is therefore the time during which damage can be expected and monitoring population levels of these weevils should start early in the fruit season. Infestation by *Helicoverpa armigera* in deciduous fruit and grapes peaked in November to December and sometimes again in January to February (Blomefield *et al*. 1986). Again, this information provides an indication of when to inspect for damage caused by this pest. Grapevine stem infestation by the key pest, *Planococcus ficus*, preceded *P. ficus* bunch infestation. This information was used to develop a monitoring system for *P. ficus*, using stem infestation as an early warning for bunch infestation (Walton 2003).

Seasonal occurrence can be determined by monitoring pest populations directly on the plant itself (absolute sampling methods), as well as determining the number of insects caught in traps (relative sampling methods). Trapping includes some of the most important sampling techniques for insect surveys (Pedigo 1999). Traps collect insects either passively, by catching them incidentally, or by attraction, luring them using a physical or chemical stimulus (Pedigo 1999). Pest damage can be related to the number of insects found in a trap and management decisions can be made accordingly

(Romoser & Stoffolano 1998). Walton *et al*. (2004) correlated the abundance of *P. ficus* males in pheromone traps with *P. ficus* stem infestation, making it possible to use trap catch information to predict when stem inspections should commence. *Epichoristodes acerbella* moth activity in vineyards in the Hex River Valley drastically increased from May, staying high between June and August (Blomefield & Du Plessis 2000). Such an increase in moth activity may be followed by egg laying and an increase in damaging larval populations. If population levels of this moth are monitored with pheromone traps, one might be able to predict when damage may be expected.

The seasonal occurrence of vine pests, in terms of either their presence or the damage that they cause, was determined in the Hex River Valley of the Western Cape Province, South Africa, making use of plant inspections, traps and bands, to aid in the development of a suitable monitoring system for these pests. The importance of predatory mites in the family Phytoseiidae for controlling phytophagous mites in numerous agricultural ecosystems worldwide has been documented by a number of authors, including Helle & Sabelis (1985), Duso (1989), Duso & Pasqualetto (1993), McMurtry & Croft (1997), Stanyard *et al*. (1997), Jung & Croft (2001), Pringle (2001) and Prischmann *et al*. (2002). Several natural enemies, which have an impact on tetranychid and other phytophagous mites, occur in vineyards in the Western Cape Province of South Africa (Schwartz 1993). Of these, *Euseius addoensis* was considered to be the most important (Schwartz 1993). Therefore, the seasonal occurrence of the predatory mites was also determined.

3.2. Material and methods

3.2.1. Experimental design, study sites and weather data

See Chapter 2, sections 2.1, 2.2 and 2.4.

3.2.2. Temporal patterns of occurrence

The objectives were to determine when the vine pests were present and to identify possible trends in their abundance. Therefore, the data were presented graphically. Plant inspections were conducted at intervals of two weeks in each vineyard. They were conducted in six vineyards during one week and in the remaining six during the following week. The data (insects per sample unit and percent infestation) for each two-weekly cycle from the 12 vineyards were averaged and plotted against date, which was determined as the day that fell in the middle of the two-weekly cycle. These will be referred to as the combined data. The same was done for *P. ficus* males caught in sticky traps. *Epichoristodes arcebella* and *H. armigera* trap catches were recorded every week in all 12 vineyards. These weekly trap catches were averaged and plotted on date.

3.2.3. Synchrony between phytophagous mites and their predators

Cross correlation analysis (Chatfield 1984) was performed between the phytophagous mites and their predators to determine whether or not the population increase of predatory mites occurred after that of the phytophagous mites. This was performed on the combined data (see section 3.2.2) for each of the three seasons as well as on the data from each individual block for the three seasons.

3.2.4. Synchrony in abundance for different sampling methods for each pest

Cross correlations (Chatfield 1984) between the number of *Frankliniella occidentalis* caught on the sticky traps and bunch damage were performed on the combined data (see section 3.2.2) as well as on the data from the individual blocks. The same was done for *E. arcebella* caught in the pheromone traps and bunch damage and for *P. callosus* recorded under the cardboard bands and bunch damage. The objective was to determine whether or not there was a time lag between trap catches and bunch damage and to quantify any time lag.

3.2.5. Simplifying pheromone trapping for *Planococcus ficus*

Planococcus ficus stem inspections should start when more than 65 *P. ficus* males per pheromone trap per two weeks are recorded (Walton *et al*. 2003). The sticky pads used in the pheromone traps have a counting grid, consisting of 36 blocks. The amount of time spent counting *P. ficus* males on the sticky pads in the pheromone traps could be reduced by counting the number of grid blocks with *P. ficus* males in the field and relating it to the actual *P. ficus* counts. Therefore, for each pheromone trap and sampling date, the total number of *P. ficus* males found in the pheromone trap was regressed on the number of blocks in the grid on the sticky pad (grid blocks) in which *P. ficus* was recorded during physical inspection.

3.3. Results

3.3.1. Weather data

For all seasons, the temperatures in the Hex River Valley started to rise during spring, with mean monthly temperatures above 20°C usually recorded from November to March (Figure 3.1). Maximum temperatures were recorded during February during all three seasons, after which temperatures declined and reached a minimum during July to August (Figure 3.1).

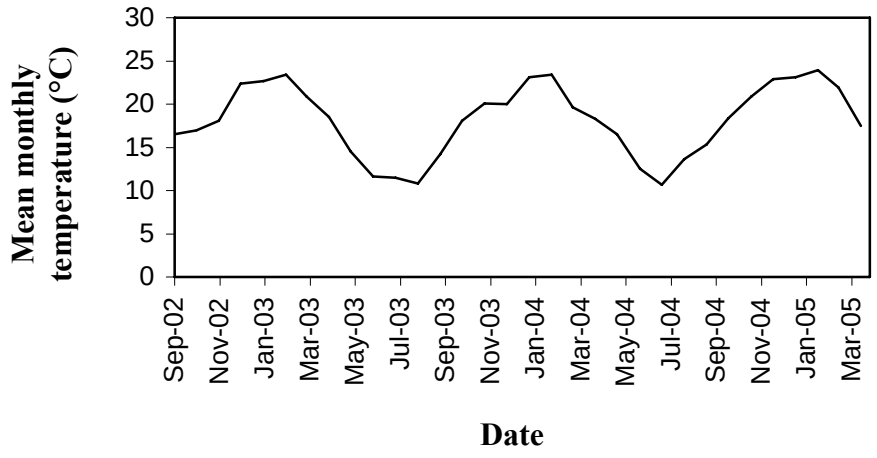


Figure 3.1. Mean monthly temperatures in the Hex River Valley from the onset of the 2002/2003 season until the end of the 2004/2005 season.

3.3.2. Phytophagous and predatory mites

The phytophagous mites on vine leaves were all two-spotted spider mite *Tetranychus urticae*. *Tetranychus urticae* was active from October to April, with the highest number recorded during the warmest part of the year (Figures 3.1 and 3.2). During the 2003/2004 and 2004/2005 seasons, the *T. urticae* population reached a peak during January. During the 2002/2003 season this peak occurred during February, but numbers were lower than during the following seasons (Figure 3.2).

The predatory mites were mostly *Euseius addoensis* (Van der Merwe & Ryke) (Mesostigmata: Phytoseiidae), which made up more than 85% of the predatory mite complex during all the seasons in the study (Table 3.1). The rest of the predatory mite complex consisted of *Neoseiulus californicus* (McGregor) (Mesostigmata: Phytoseiidae), *Tydeus grabouwi* (Meyer & Ryke) (Prostigmata: Phytoseiidae) and an undescribed phytoseiid in the genus *Typhlodromus* (Mesostigmata: Phytoseiidae) (Table 3.1). The latter was only found from the 2003/2004 season onwards. The predatory mites were active from mid-October, with numbers increasing towards the end of the season (Figure 3.2). *Tydeus grabouwi* is not an important predator (K.L. Pringle, personal communication[*]) and was therefore not included in the data used in Figure 3.2.

Table 3.1. Percentage occurrence of each predatory mite recorded on vine leaves in the Hex River Valley for the 2002/2003, 2003/2004 and 2004/2005 seasons.

Season	*Euseius addoensis*	*Neoseiulus californicus*	*Typhlodromus* species	*Tydeus grabouwi*
2002/2003	97.79	1.95	-	0.25
2003/2004	89.08	3.99	5.03	1.91
2004/2005	86.11	0.87	10.85	2.17

[*]Department of Conservation Ecology and Entomology, Faculty of AgriSciences, University of Stellenbosch, Private Bag X1, 7602 Matieland.

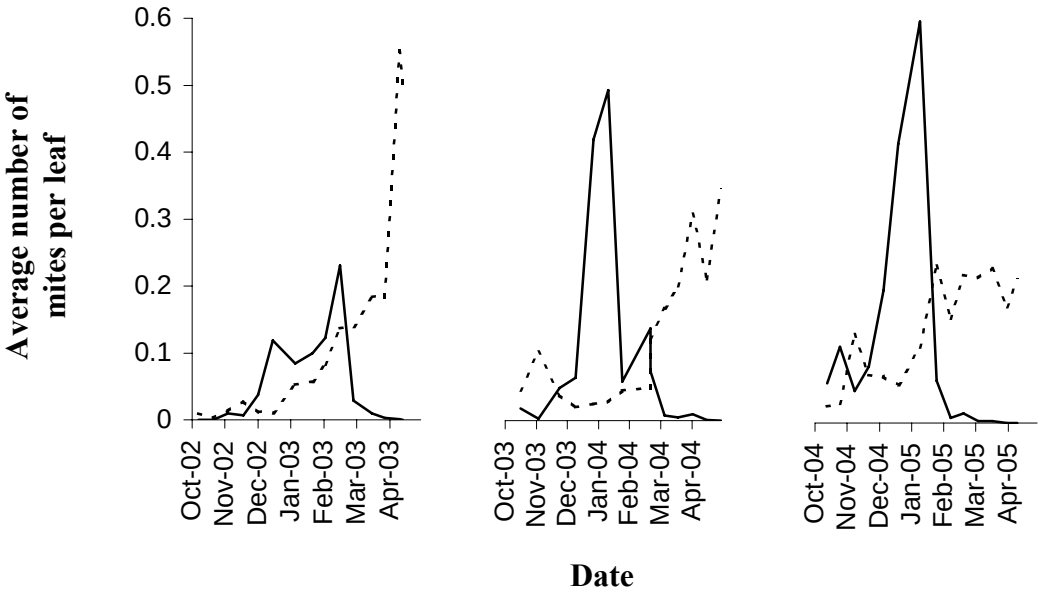


Figure 3.2. Seasonal occurrence of *Tetranychus urticae* and the predatory mite complex on vine leaves for the 2002/2003, 2003/2004 and 2004/2005 seasons. (—) *T. urticae*; (----) Predatory mites (see section 3.2.2 for calculation of the average number of mites per leaf).

There was a time lag between the occurrence of *T. urticae* and the predatory mites on the vine leaves (Figure 3.2). A cross correlation analysis on the combined data indicated that this lag was five to six sampling cycles or 10 to 12 weeks. These correlations were r = 0.71, 0.52 and 0.35 for the 2002/2003, 2003/2004 and 2004/2005 seasons respectively (Figure 3.3). This was however only significant during the 2002/2003 season (P = 0.020, 0.185 and 0.363 for the 2002/2003, 2003/2004 and 2004/2005 seasons respectively). Significant time lag correlations were only observed during the 2002/2003 and 2003/2004 seasons using cross correlations on data from the individual blocks. During the 2002/2003 season, a significant correlation was observed in four of the 12 blocks (see Appendix A for the blocks that were used during every season), with the time lag varying between 10 weeks (with correlations ranging from r = 0.74 (P = 0.014) to r = 0.76 (P = 0.011)) and 14 weeks (in one block: r = 0.79; P = 0.021). During the 2003/2004 season, a significant correlation was observed in two of the 12 blocks, with the time lag varying between six weeks (r = 0.66; P = 0.037) and eight weeks (r = 0.70; P = 0.034).

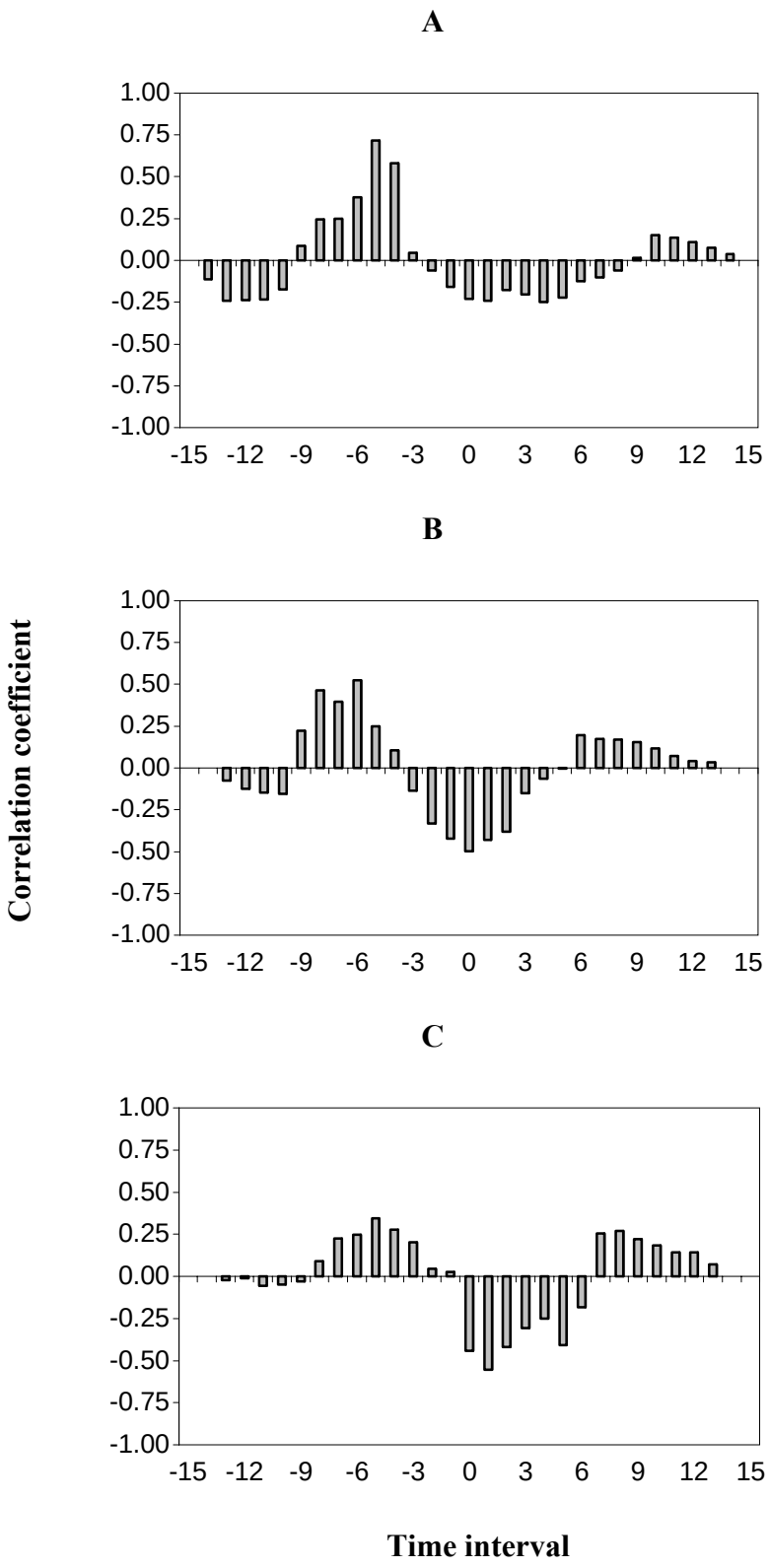


Figure 3.3. Cross correlation between *Tetranychus urticae* and the predatory mites on vine leaves for the combined data during the (A) 2002/2003, (B) 2003/2004 and (C) 2004/2005 seasons (see section 3.2.3 for calculation). One time interval = two weeks.

3.3.3. *Planococcus ficus*

Planococcus ficus stem infestation preceded bunch infestation during all the seasons (Figure 3.4). The time between bunch and stem infestation was four months during the 2002/2003 season, five months during the 2003/2004 season and three months during the 2004/2005 season (Figure 3.4). The first bunch infestation was observed in January during the 2002/2003 and 2004/2005 season and February during the 2003/2004 season (Figure 3.4). *Planococcus ficus* leaf infestation occurred more or less at the same time as bunch infestation (Figure 3.4). Shoot infestation occurred later than bunch infestation during the 2002/2003 season, earlier during the 2003/2004 season and was absent during the 2004/2005 season (Figure 3.4).

The presence of *P. ficus* males in the pheromone traps preceded bunch infestation by four months during the 2003/2004 season and four and a half months during the 2004/2005 season (Figure 3.4). During both seasons, numbers of *P. ficus* males in the pheromone traps increased during December and peaked towards the end of February (Figure 3.4), which was always the warmest month of the year (Figure 3.1). Bunch and stem infestation were highest during the 2002/2003 season. Bunch infestation was lowest during the 2003/2004 season, while stem infestation was lowest during the 2004/2005 season (Figure 3.4).

There was a good non-linear relationship between the actual number of *P. ficus* males found in the pheromone traps and the number of blocks in the grid in which *P. ficus* was recorded ($r = 0.91$; $P < 0.001$) (Figure 3.5). When *P. ficus* males were present in 27 and 28 grid blocks, the number of males counted in the pheromone traps was 63 and 73 respectively.

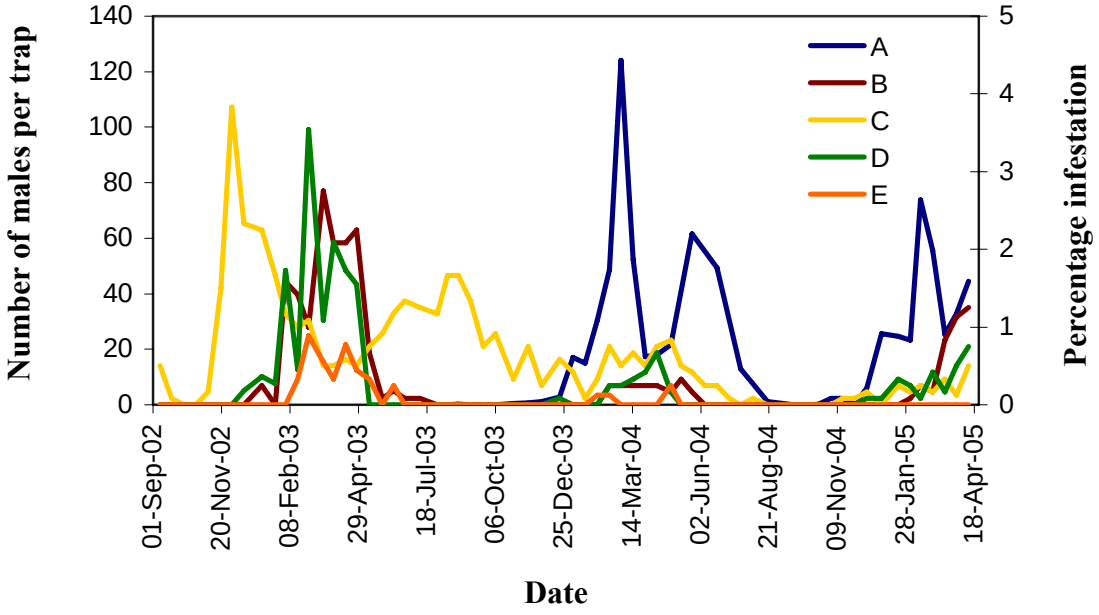


Figure 3.4. Seasonal occurrence of *Planococcus ficus* from the onset of the 2002/2003 season until the end of the 2004/2005 season. (A) Pheromone trap catches; (B) Bunch infestation; (C) Stem infestation; (D) Leaf infestation; (E) Shoot infestation (see section 3.2.2 for calculation of the number of males per trap and the percentage infestation).

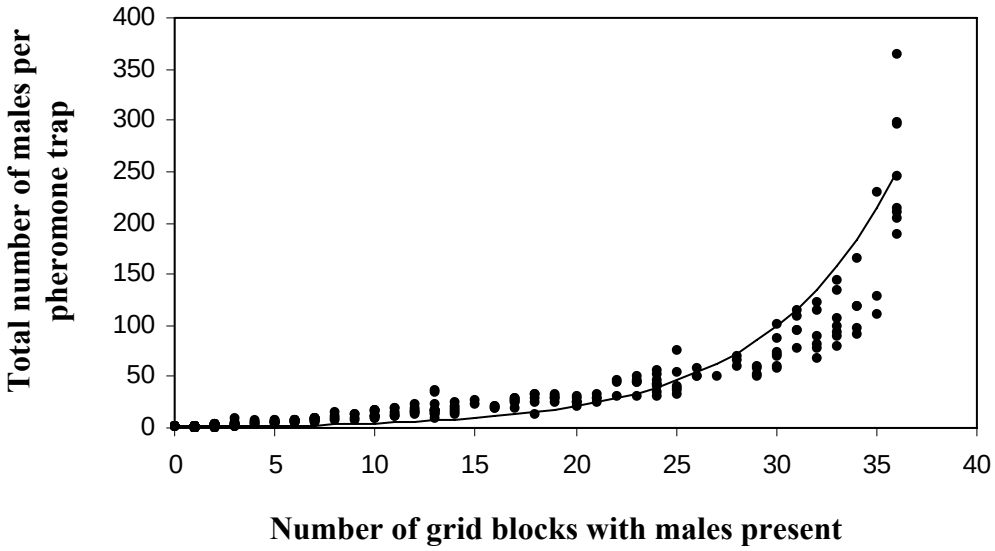


Figure 3.5. Relationship between the total number of *Planococcus ficus* males per pheromone trap and the number of grid blocks on the sticky pad on which *P. ficus* males were present (see section 3.2.5 for calculations). $y = e^{(0.1533)x}$; $r = 0.91$; $P < 0.001$.

3.3.4. *Frankliniella occidentalis*

Not all of the thrips that were found on the sticky traps were *F. occidentalis*. The thrips complex included both phygophagous and predatory thrips. It was very difficult to identify the thrips on the sticky traps, since they could not be suitably prepared for microscopic examination necessary for identification. In addition, if the insect was on a specific side (for example dorsal), the other side (for example ventral) could not be seen, since it was stuck to the glue. Therefore, only thrips that could be easily distinguished from *F. occidentalis* due to apparent differences in size, abdominal shape and colour were not counted. Thrips were active mainly during spring and summer (Figure 3.6). During all seasons, thrips numbers on the traps (the thrips complex, not only *F. occidentalis*) started to increase from about September or October, reaching a peak during November (Figure 3.6). The presence of thrips on the blue sticky traps preceded halo spot damage caused by *F. occidentalis* during all the seasons (Figure 3.6). The latter was found from mid-November onwards. Thrips activity (number of thrips found on the sticky traps) as well as halo spot damage was lowest during the 2002/2003 season and highest during the 2004/2005 season (Figure 3.6).

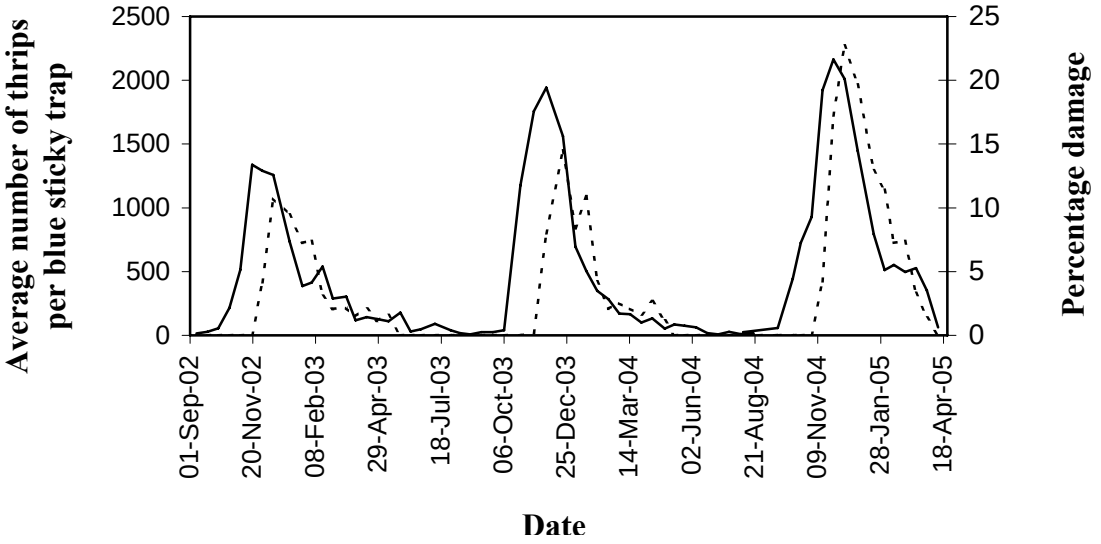


Figure 3.6. Seasonal occurrence of *Frankliniella occidentalis* from the onset of the 2002/2003 season until the end of the 2004/2005 season. (—) Sticky trap catches; (----) Bunch damage (see section 3.2.2 for calculation of the average number of thrips per trap and the percentage damage).

It appeared as if the population peaks of the thrips on the traps were correlated with the peaks of the halo spot damage (Figure 3.6). The cross correlation on the combined data indicated a high correlation with a time lag of four weeks between trap catches and bunch damage ($r = 0.90$; $P < 0.001$) (Figure 3.7). There was a significant time lag correlation in all but one block (see Appendix A for the blocks that were used), using cross correlations on data from the individual blocks. The time lag was usually four weeks with correlations varying between $r = 0.56$ ($P < 0.001$) and $r = 0.94$ ($P < 0.001$). In two blocks, a time lag of two weeks was recorded, with correlations varying between $r = 0.69$ ($P < 0.001$) and $r = 0.80$ ($P < 0.001$).

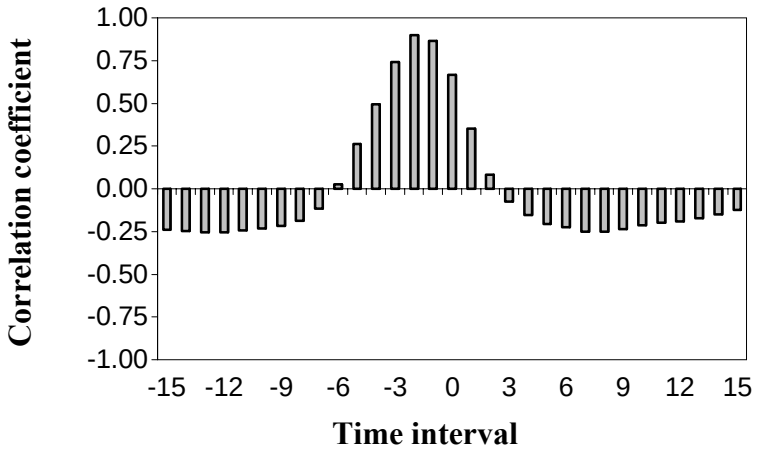


Figure 3.7. Cross correlation between the average number of thrips on the blue sticky traps and halo spot damage caused by *Frankliniella occidentalis* for the combined data (see section 3.2.4 for calculation). One time interval = two weeks.

3.3.5. *Epichoristodes acerbella*

Epichoristodes acerbella moth activity (average number of moths per pheromone trap) peaked during spring (Figure 3.8). During all seasons this preceded bunch damage caused by the larvae, which occurred when moth activity was low. The first damage was recorded during the end of November (Figure 3.8). *Epichoristodes acerbella* moths were more active during the cooler times of the year (May to November) than during the warmer months (December to April) (Figures 3.1 and 3.8). During the 2003/2004 and 2004/2005 seasons, moth activity started to decline from the end of October onwards (Figure 3.8). This decline was earlier during the 2001/2002 season than during the subsequent two seasons. There was a decline in

bunch infestation by the larvae towards January and February, after which the incidence of larvae in the bunches again increased (Figure 3.8). Bunch damage was highest during the 2002/2003 season, but during this season, moth activity during the preceding cooler months (May to November 2002) was lowest (Figure 3.8). Therefore, high moth activity did not necessarily result in high bunch damage.

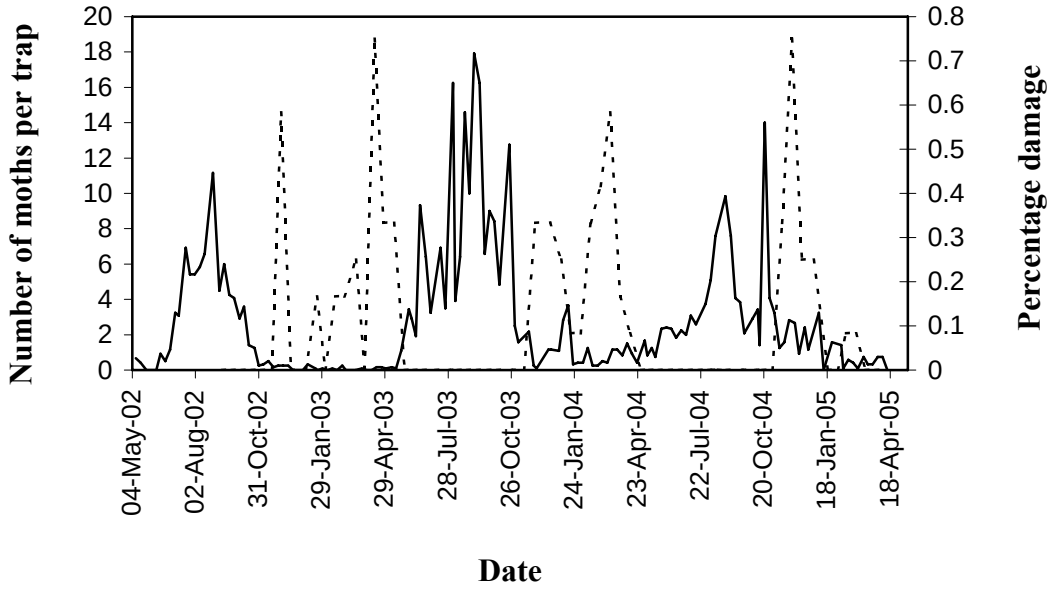


Figure 3.8. Seasonal occurrence of *Epichoristodes acerbella* from May 2002 until the end of the 2004/2005 season. (—) Pheromone trap catches; (----) Bunch damage (see section 3.2.2 for calculation of the number of moths per trap and the percentage damage).

As mentioned previously, bunch damage occurred at a later stage than the presence of moths in the traps. However, the correlations between moth counts and larval damage were weak, although significant ($r = 0.30$; $P = 0.020$ at a time lag of 24 weeks for the combined data; Figure 3.9). This was especially the case for data from the individual blocks, for which a significant time lag correlation was recorded in only six of the 13 blocks analyzed (see Appendix A for the blocks that were used), with the time lag varying between 10 weeks ($r = 0.63$, $P = 0.002$) and 22 weeks ($r = 0.27$; $P = 0.037$). This supported the notion that high moth activity did not necessarily result in high levels of bunch damage.

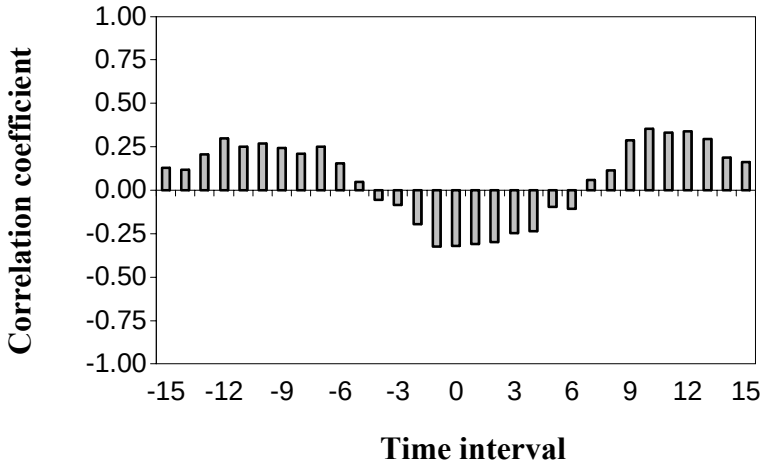


Figure 3.9. Cross correlation between *Epichoristodes acerbella* bunch damage and the number of moths found per pheromone trap for the combined data (see section 3.2.4 for calculation). One time interval = two weeks.

3.3.6. *Helicoverpa armigera*

During the 2002/2003 and 2004/2005 seasons *H. armigera* numbers in pheromone traps peaked during spring and early summer (Figure 3.10A). This was not the case during the 2003/2004 season when numbers in traps were fairly low throughout the season (Figure 3.10A). No bunch, bud or foliage damage, caused by the larvae, was observed.

3.3.7. *Phlyctinus callosus*

The seasonal occurrence of *P. callosus* during the 2002/2003 season was not included in Figure 3.10B since almost no damage and very little weevil activity was recorded during this season. *Phlyctinus callosus* was found under the cardboard bands from the beginning of October (Figure 3.10B). During both the 2003/2004 and 2004/2005 seasons, this preceded bunch damage, which was first recorded towards the end of October and the beginning of November (Figure 3.10B). *Phlyctinus callosus* shoot and bunch damage were recorded at the same time. Peak damage levels occurred from November to January in both cases (Figure 3.10B), when the mean monthly temperatures started to increase above 20°C (Figure 3.1). *Phlyctinus callosus* activity

(average number of weevils found per cardboard band) peaked during November (Figure 3.10B).

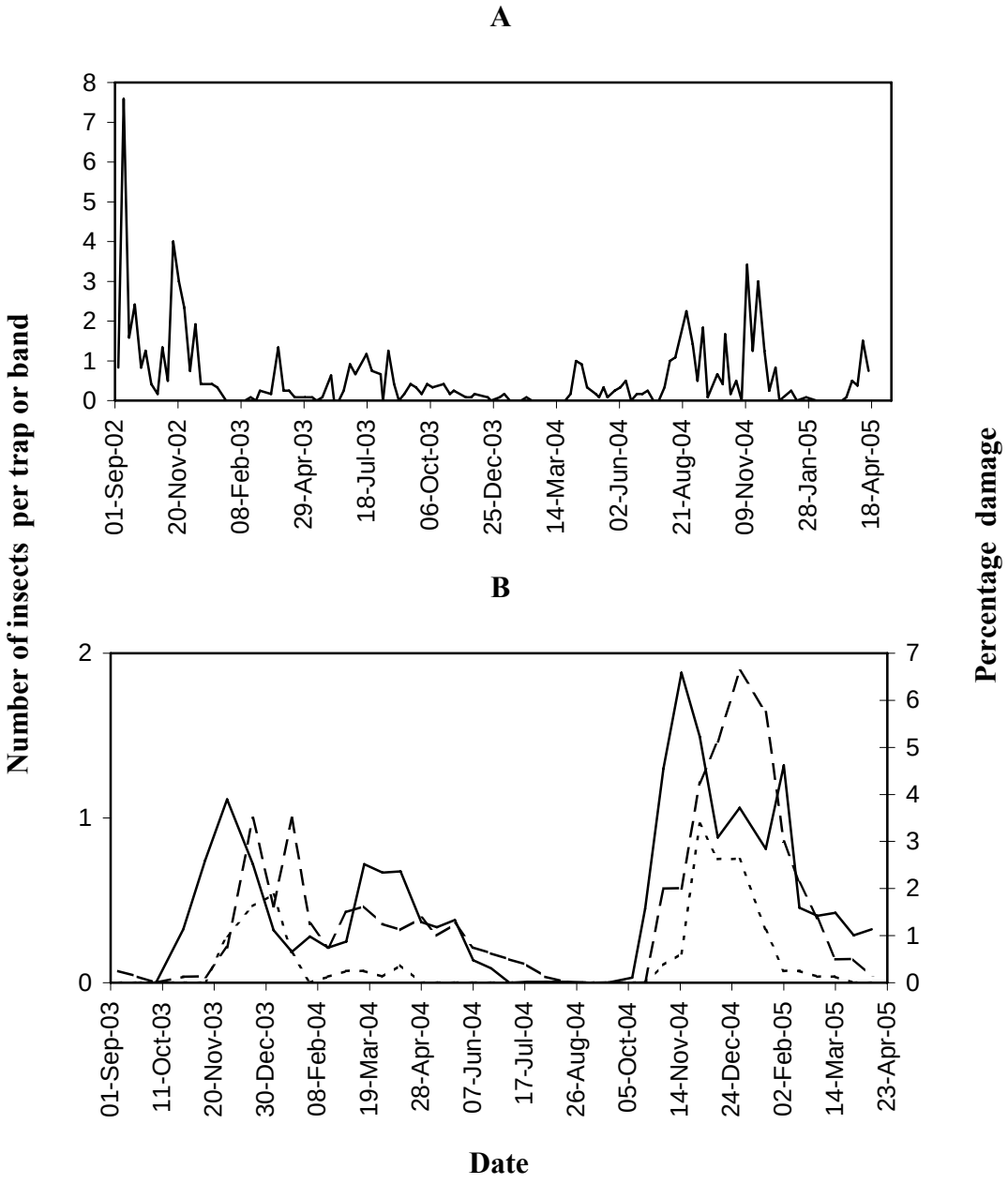


Figure 3.10. Seasonal occurrence of (A) *Helicoverpa armigera* from the onset of the 2002/2003 season until the end of the 2004/2005 season and (B) *Phlyctinus callosus* from the onset of the 2003/2004 season until the end of the 2004/2005 season. (—) Trap or band catches (average number of insects per trap or band); (----) Bunch damage; (– –) Shoot damage (see section 3.2.2 for calculation of the number of insects per trap or band and the percentage damage).

Cross correlation between the number of weevils under cardboard bands and weevil bunch damage was strong at a time lag of two weeks ($r = 0.76$, $P < 0.001$) for the combined data (Figure 3.11). When this analysis was performed on data for the separate blocks, a significant time lag correlation was observed in only two of the eight blocks for which data were analyzed (data from the blocks at Klipheuwel and vineyard Nr 3 were not analyzed due to the absence of weevils and weevil damage in these blocks). This time lag varied between four weeks ($r = 0.42$; $P = 0.011$) and eight weeks ($r = 0.69$; $P < 0.001$). In three of the blocks, a significant time lag of zero weeks (in other words no time lag) was recorded with correlations varying from $r = 0.44$ ($P = 0.005$) to $r = 0.68$ ($P < 0.001$).

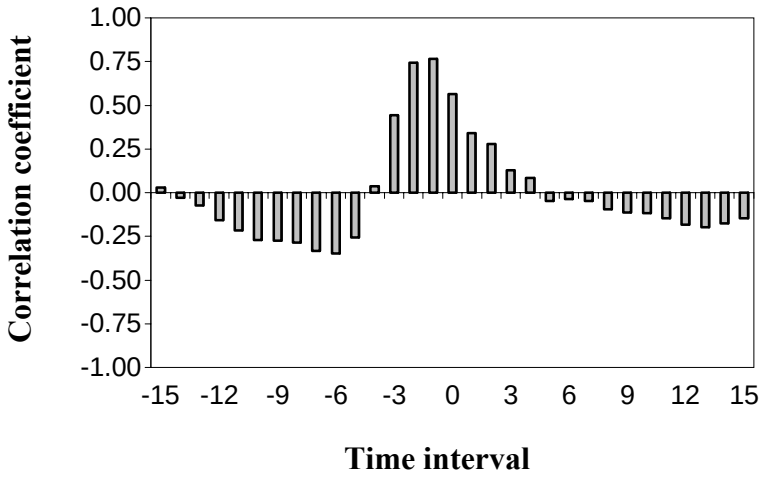


Figure 3.11. Cross correlation between *Phlyctinus callosus* bunch damage and the number of weevils found under the cardboard for the combined data (see section 3.2.4 for calculation). One time interval = two weeks.

3.4. Discussion

An important, yet not unexpected, observation was that, for all the pests or damage caused by these pests, there were differences in occurrence between the three seasons. Many producers follow a set recommended spray programme without making use of a monitoring system. The fact that there were differences between seasons showed that such a predetermined spray programme may lead to either unnecessary sprays or

under spraying. This emphasized the need for monitoring for these pests during every season in order to determine whether or not they need to be controlled.

Tetranychus urticae, the only phytophagous mite found on the vine leaves in the Hex River Valley, was present from as early as October. This was earlier than in Europe where these mites did not colonise the foliage prior to summer (Schruft 1985). In the present study, population levels of *T. urticae* in the Hex River Valley during October were very low. The highest mite counts were recorded during the warm summer months of January and February. However, Schwartz (1990) recorded high numbers of *T. urticae* on vine leaves in the Hex River Valley during October. Sabelis (1985) recommended initiating sampling for phytophagous mites within about a month of the new leaves unfolding. Therefore, sampling for *T. urticae* should be initiated during October, which is about a month after budbreak.

The most abundant predatory mite found in this study, *E. addoensis*, is a specialised pollen feeder or generalist predator (type IV phytoseiid) (McMurtry & Croft 1997) and is able to keep *T. urticae* below economically damaging levels in undisturbed vineyards (Schwartz 1993). Because *E. addoensis* is a type IV phytoseiid, it is not dependent on the presence of *T. urticae* for survival and has therefore the advantage of being able to survive when *T. urticae* populations are low, or even when they are absent. *Neoseiulus californicus* is rated between a type II and a type III phytoseiid, with type II being selective predators of Tetranychid mites and type III generalist predators (McMurtry & Croft 1997; Croft *et al*. 1998; Jung & Croft 2001). Therefore, it can feed on arthropods other than spider mites and it may also feed on pollen (Croft *et al*. 1998). Tydeid mites will feed on various plant and animal food sources (Gerson *et al*. 2003). Although *T. grabouwi* (Tydeidae) is not an important predator (see section 3.3.2), it may serve as a food source for some of the other predatory mites (Gerson *et al*. 2003). The predatory mites were present throughout the fruit season, as was the case with *T. urticae*. However, they only started to increase in numbers after an increase in *T. urticae* was observed. The predatory mites may have contributed to the reduction of *T. urticae* populations towards the end of the season. This aspect will be explored further in Chapter 6.

Planococcus ficus stem infestation preceded bunch infestation by three to five months in the present study, confirming the findings of Walton (2003) that stem infestation can be used as an early warning for bunch infestation. Leaf and shoot infestation did not precede bunch infestation. Therefore, they cannot be used as an early warning for bunch infestation and it would not be necessary to include leaf and shoot inspections in a monitoring system. Walton *et al*. (2003) recommended the use of pheromone traps for *P. ficus*, starting trap inspections during October. Instead of counting all *P. ficus* males found in the pheromone traps as Walton *et al*. (2003) did, the number of grid blocks with males present can be counted, thereby saving time. The presence of *P. ficus* males in 27 grid blocks on the sticky pad correlated with the threshold of 65 males per trap determined by Walton *et al*. (2003). In the present study, *P. ficus* counts in the pheromone traps started to increase during December. However, trap inspections should start during October to make sure the threshold is not exceeded prior to sampling. When males are found in 27 grid blocks, stem inspections should commence.

The number of thrips found per blue sticky trap gave a good indication of the amount of bunch damage that could be expected four weeks later. This was however not always the case for data from the individual blocks, indicating that bunch damage predictions can only be made in general, but not for individual blocks. However, despite this time laged correlation between thrips on sticky traps and bunch damage, the use of the sticky traps for predicting damage is not recommended, as it was very difficult to identify thrips on the sticky traps (see section 3.3.4). Identification will be even more difficult for farmers who do not have the equipment (good microscopes) or training. Halo spot damage by thrips on the berries occurs early in the season, from the onset of bloom until fruit set (Jensen *et al*. 1992). However, in the present study it was detected only from the middle of November onwards. Therefore, by the time the damage was observed, it was too late to apply control measures. Bunch inspections should however not be excluded, since they can provide the producer with information on the infestation status of the vineyard. Bunch inspections for thrips damage should start during November.

Although *E. acerbella* moths were found in the pheromone traps before bunch damage by the larvae was recorded, the number of *E. acerbella* moths found in the

pheromone traps did not provide an indication of the amount of bunch damage that could be expected. Thus, the pheromone traps could only be used to identify vineyards where this pest was present and therefore where phytosanitary problems may arise. Adult *E. acerbella* activity recorded in the present study was similar to previous findings (Blomefield & Du Plessis 2000) in that it also increased from May onwards. However, in the present study it did not remain at a high level only until August as observed by Blomefield & Du Plessis (2000). High moth counts were recorded until October. Trap inspections for *E. acerbella* moths should start during May, since high moth activity during winter months prior to the fruit season may lead to larval activity later in the fruit season. Although bunch damage caused by *E. acerbella* was observed only from the end of November onwards, bunch inspections should commence during the beginning of November to make sure that the infestation level at which control measures are recommended (see Chapter 4, section 4.4) is not exceeded prior to sampling.

Helicoverpa armigera were caught in the pheromone traps, but no damage was observed. The pheromone traps can only be used to identify vineyards where this pest is present and therefore where phytosanitary problems may arise if larvae are found in the bunches. Although this was not the case in the present study, larvae have been found in bunches in other grape producing areas in South Africa. Trap inspections for *H. armigera* moths should start during September, with the onset of the fruit season.

Phlyctinus callosus shoot and bunch damage occurred simultaneously, thus shoot damage cannot be used as an early warning system for bunch damage. Therefore, it would be unnecessary to include shoot inspections for *P. callosus* damage during monitoring. The number of *P. callosus* under the cardboard bands gave a good indication of the amount of *P. callosus* bunch damage that could be expected two weeks later. However, this was not the case in the individual blocks, indicating that bunch damage predictions based on band counts cannot be made in individual blocks. This was similar to observations in apple orchards (Nel 1983). However, the presence of weevils under the cardboard bands could be used to identify vineyards where *P. callosus* was present and therefore where phytosanitary problems may arise for the USA and Israeli markets. During the present study, *P. callosus* adults were first recorded under the bands during October. This supported findings in apple orchards

where *P. callosus* adults emerged in spring (Barnes *et al*. 1986). Monitoring using bands should start during the middle of September in order to ensure that the onset of weevil activity is recorded. The first bunch damage was recorded towards the end of October. Therefore, monitoring bunch damage should be initiated during the beginning of October to make sure that the infestation level at which control measures are applied (see Chapter 4, section 4.4) is not exceeded before the onset of sampling.

Recommendations made here regarding the time at which sampling for bunch damage or infestation caused by the various pests should start, is based on the occurrence of this damage or infestation on the late-season varieties, Barlinka and Dauphine. For early-season varieties, which bloom and set fruit earlier in the season, the onset of sampling should be advanced by about one month.

3.5. References

Annecke, D.P. & Moran, V.C. 1982. *Insects and Mites of Cultivated Plants in South Africa*. Butterworths, Pretoria.

Barnes, B.N., Daiber, K.C. & Donaldson, J.M. 1986. Fruit-eating and leaf-eating beetles. In: Myburgh, A.C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 35-42. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Blomefield, T. L., Daiber, K.C. & Bolton, M.C. 1986. Fruit-eating and leaf-eating caterpillars. In: Myburgh, A.C. (Ed.) *Crop Pests in Southern Africa Vol. 1. Deciduous Fruit, Grapes and Berries*. 26-34. Plant Protection Research Institute, Department of Agriculture and Water Supply, Pretoria.

Blomefield, T. & Du Plessis, N. 2000. Pear leafroller: a simple matter of weed control? *Deciduous Fruit Grower* 50(6): 12-13.

Chatfield, C. 1984. *The analysis of time series: an introduction. Third Edition.* Chapman and Hall, London.

Croft, B.A., Monetti, L.N. & Pratt, P.D. 1998. Comparative life histories and predation types: are *Neoseiulus californicus* and *N. fallacis* (Acari: Phytoseiidae) similar type II selective predators of spider mites? *Environmental Entomology* 27: 531-538.

Duso, C. 1989. Role of the predatory mites *Amblyseius aberrans* (Oud.), *Typhlodromus pyri* Scheuten and *Amblyseius andersoni* (Chant) (Acari, Phytoseiidae) in vineyards. I. The effects of single or mixed phytoseiid population releases on spider mite densities (Acari: Tetranychidae). *Journal of Applied Entomology* 107: 474-492.

Duso, C. & Pasqualetto, C. 1993. Factors affecting the potential of phytoseiid mites (Acari: Phytoseiidae) as biocontrol agents in North-Italian vineyards. *Experimental and Applied Acarology* 17: 241-258.

Gerson, U., Smiley, R.L. & Ochoa, R. 2003. *Mites (Acari) for Pest Control*. Blackwell Science Ltd, Oxford.

Helle, W. & Sabelis, M.W. 1985. *Spider Mites. Their Biology, Natural Enemies and Control. World Crop Pests Vol1B.* Elsevier, New York.

Jensen, F.L., Flaherty, D.L. & Luvisi. D.A. 1992. Thrips. In: Flahery, D.L., Christensen, L.P., Lanini, W.T., Marois, J.J., Phillips, P.A. & Wilson, L.T. (Eds) *Grape Pest Management. Second Edition*. 193-201. Division of Agriculture and Natural Resources, University of California.

Jung, C. & Croft, B.A. 2001. Ambulatory and aerial dispersal among specialist and generalist predatory mites (Acari: Phytoseiidae). *Environmental Entomology* 30: 1112-1118.

McMurtry, J.A. & Croft, B.A. 1997. Life-styles of phytoseiid mites and their roles in biological control. *Annual Review of Entomology* 42: 291-321.

Nel, P.J. 1983. *Deciduous Fruits and Vines. Pests and Diseases and their Control*. David Philip Publisher, Cape Town.

Pedigo, L.P. 1999. *Entomology and Pest Management. Third Edition.* Prentice-Hall, Inc., New Jersey.

Pringle, K.L. 2001. Biological control of tetranychid mites in South African apple orchards. *Acarology:* In: Haliday, R.B., Walter, D.E., Proctor, H.C., Norton, R.A. & Colloff, M.J. (Eds) *Proceedings of the 10th International Congress*. 429-435. CSRIO Publishing, Australia.

Prischmann, D.A., Croft, B.A. & Luh, H.-K. 2002. Biological control of spider mites on grape by phytoseiid mites (Acari: Tetranychidae, Phytoseiidae): emphasis on regional aspects. *Journal of Economic Entomology* 95: 340-347.

Romoser, W.S. & Stoffolano, J.G. 1998. *The Science of Entomology. Fourth Edition.* McGraw-Hill Companies, Inc., Boston.

Sabelis, M.W. 1985. Sampling Techniques. In: Helle, W. & Sabelis, M.W. (Eds) *Spider Mites. Their Biology, Natural Enemies and Control. World Crop Pests Vol1A.* 337-350. Elsevier, New York.

Schruft, G.A. 1985. Grape. In: Helle, W. & Sabelis, M.W. (Eds) *Spider Mites. Their Biology, Natural Enemies and Control. World Crop Pests Vol1B.* 359-366. Elsevier, New York.

Schwartz, A. 1990. Pesticide effect on populations of *Tetranychus urticae* Koch (Acari: Tetranychidae) and a predaceous mite on table grapes in the Hex River Valley. *South African Journal of Enology and Viticulture* 11: 33-37.

Schwartz, A. 1993. Occurrence of natural enemies of phytophagous mites on grapevine leaves following application of fungicides for disease control. *South African Journal of Enology and Viticulture* 14: 16-17.

Stanyard, M.J. Foster, R.E. & Gibb, T.J. 1997. Effects of orchard ground cover and mite management options on the population dynamics of European red mite (Acari: Tetranychidae) and *Amblyseius fallacis* (Acari: Phytoseiidae) in apple. *Journal of Economic Entomology* 90: 595-603.

Walton, V.M. 2003. *Development of an Integrated Pest Management System for Vine Mealybug,* Planococcus ficus *(Signoret), in Vineyards in the Western Cape Province, South Africa*. PhD Dissertation, University of Stellenbosch.

Walton, V.M., Daane, K.M. & Pringle, K.L. 2004. Monitoring *Planococcus ficus* in South African vineyards with sex pheromone-baited traps. *Crop Protection* 23: 1089-1096.

Walton, V.M., Pringle, K.L. & Daane, K.M. 2003. Geïntegreerde beheer van wingerdwitluis (*Planococcus ficus*) met behulp van feromoonvalletjies in wingerde in Suid-Afrika. *Wynboer: 'n Tegniese Gids vir Wynprodusente* 168: 15-16.

CHAPTER 4

DETERMINING SAMPLING ERRORS AND DECISION CURVES FOR DEVELOPING A SYSTEM FOR MONITORING INSECT AND MITE PEST POPULATION LEVELS IN THE HEX RIVER VALLEY, WESTERN CAPE PROVINCE, SOUTH AFRICA

4.1. Introduction

Producers are forced to minimize chemical sprays due to the negative impact they have on the environment and the increasing requirements by consumers to have food products free of chemicals. In order to achieve this without risking economic losses, accurate pest monitoring is vital. Romoser & Stoffolano (1998) stressed the importance of knowledge of the relationship between pest densities and pest damage.

Knowledge of economic threshold levels is of importance in insect pest management programmes (Pedigo 1999; Speight *et al*. 1999). The economic threshold was defined by Stern *et al*. (1959) as the density at which control measures should be initiated to prevent an increasing pest population from reaching the economic-injury level. The latter was defined as the lowest population density that will cause economic damage (Stern *et al*. 1959). When pest numbers in a crop are sampled, the actual density in the field is compared with the acceptable threshold, making it possible to recommend a management decision (Binns *et al*. 2000). Over spraying, which is not only an unnecessary expense but can cause unnecessary environmental contamination, and under spraying, which may lead to crop losses, can thus be avoided.

It is important that the information obtained from a monitoring system is reliable since it will be used for making management decisions. In order to determine the reliability of a monitoring system, the sampling precision should first be determined. A sampling error of 20% or less is acceptable for pest management purposes (Reusink & Kogan 1994). The second step in determining the reliability of a monitoring system is to determine operational characteristic curves, which can be used to estimate the probability that the correct decision is made when deciding not to intervene with a

control measure (Binns *et al*. 2000). Using these operational characteristic curves, decisions regarding the application of control measures can be made even if the sampling error exceeds 20%. Heunis (2001) developed a sampling system for monitoring population levels of the woolly apple aphid *Eriosoma lanigerum* (Hausmann) in apple orchards. In her study, the sampling error when 25 trees were sampled per two hectares was just over 40%. The sampling system was however not rejected because of this high sampling error. The operational characteristic curve was used to determine the risk of not intervening using a spray (Heunis 2001). The sampling error of *Planococcus ficus* on vines also exceeded 20% (Walton 2003). However, the operational characteristic curve was used to determine the precision of deciding not to intervene and a recommendation was made accordingly.

This study was performed to determine sampling errors and operational characteristic curves for the main table grape pests in vineyards in the Hex River Valley in the Western Cape Province of South Africa, using the protocol developed by Walton (2003) for *P. ficus*. This was done to determine how this protocol could be extended to include the rest of the table grape pest complex. Where possible, recommendations regarding the timing of control will also be made.

4.2. Material and methods

4.2.1. Experimental design and study sites

See Chapter two, sections 2.1, 2.2.1 and 2.2.3.

4.2.2. Sampling statistics

4.2.2.1. Counts of pests

To assess the reliability of a sampling system an index of precision is required. The following index of precision was used (Iwao & Kuno 1971; Binns *et al*. 2000):

$$D = \left(1/\bar{x}\right)\left(\sqrt{S^2/n}\right) \qquad (1),$$

where n is the number of sample units, $\bar{x}$ is the average number of insects per sample and S^2 is the variance. This function can only be used if the variance remains constant. However, in the case of statistically clumped dispersion patterns, as is the case with insect and mite populations, the variance usually increases with the average. The relationship between these two parameters is given by the linear regression:

$$Log\left(S^2\right) = Log(a) + (b)Log\left(\bar{x}\right) \qquad (2),$$

where *Log(a)* and *b* are regression constants, estimated from linear regression. By taking the antilogs of (2), the following expression can be obtained:

$$S^2 = a\left(\bar{x}\right)^b \qquad (3).$$

This expression is known as Taylor's power law (Taylor 1961, 1965, 1971; Binns *et al*. 2000). The variance in (1) can be substituted with (3) to give the following expression:

$$D = \left(1/\bar{x}\right)\left[\sqrt{a\left(\bar{x}\right)^b/n}\right] \qquad (4).$$

Expression (4) was used to determine the level of precision, D, for a given average number of insects or mites per sampling unit, $\bar{x}$ (taken as the economic threshold value) and different numbers of sampling units, n, as well as for a given number of sampling units (n = 20) and different population levels. Multiplying D by 100, gave an estimate of the percentage sampling error (Davis 1994; Binns *et al*. 2000).

Dummy variable regression (Gujarati 1970a, b) was used to determine whether or not there were differences in the regressions between the three seasons and between the two cultivars.

Operational characteristic (OC) curves were calculated to determine the probability of making the correct decision when deciding not to intervene (Binns *et al*. 2000):

$$z = \frac{\bar{x} - ET}{\sqrt{\frac{S^2}{n}}} \qquad (5).$$

Expression (3) was substituted into (5) and the economic threshold value (*ET*) was substituted for $\bar{x}$ in (3) to obtain the following expression (Binns *et al*. 2000):

$$z = \frac{\bar{x} - ET}{\sqrt{\frac{a(ET)^b}{n}}} \qquad (6).$$

Values for *z* were determined for a range of population levels, $\bar{x}$. The probability levels for making a correct decision not to intervene at various population levels were obtained from one-tailed normal probability tables (Binns *et al*. 2000).

4.2.2.2. Presence-absence sampling

Instead of counting all the insects or mites on the leaves, the leaves can simply be classified as infested or uninfested, therefore saving time. This is called presence-absence sampling. This type of sampling has been developed for several pests, including citrus red mite, spider mites on cotton and almonds and aphids on brussels sprouts (Flaherty *et al*. 1992). Binns *et al*. (2000) gives the following expression for the relationship between actual counts and presence-absence data:

$$\ln(-\ln(1-p)) = a + b\ln(\bar{x}) \qquad (7),$$

where ln is the base of the natural logarithm, *p* is the proportion of infested leaves, *a* and *b* are regression constants and $\bar{x}$ is the average number of insects or mites per sampling unit. Linear regression was used, with $\ln(\bar{x})$ as the independent variable and ln(-ln(1-*p*)) as the dependent variable.

Binns *et al*. (2000) showed that the proportion of infested samples, *p*, can be determined for any value of $\bar{x}$, using the following expression:

$$p = 1 - \exp[-\{e^{a}(\bar{x})^{b}\}] \qquad (8).$$

In order to link the threshold value with the presence-absence data, $\bar{x}$ was substituted with the economic threshold (*ET*). Dummy variable regression was again used to determine whether or not there were differences in the regressions between the three seasons and between the two cultivars.

OC-curves can be used to evaluate the presence-absence sampling plan. The general expression for estimating OC-curves is given by (5). To solve this, (8) was used to provide an estimate of the range of proportions of infested units and *ET* was replaced by an estimate of the proportion of infested units at the *ET* in the numerator. In the denominator an estimate of the standard error of the average is required. The following expression was used for the standard error (*SE*) of the average in the binomial distribution (Binns *et al*. 2000):

$$SE(\bar{x}) = \sqrt{\frac{p(1-p)}{n}} \qquad (9).$$

In (9) *p* was substituted with (8) and $\bar{x}$ was substituted with *ET*, giving the following expression for *z*:

$$z = \frac{[1-\exp\{-(e^{a}(\bar{x})^{b})\}] - [1-\exp\{-(e^{a}(ET)^{b})\}]}{\sqrt{\frac{[1-\exp\{-(e^{a}(ET)^{b})\}][\exp\{-(e^{a}(ET)^{b})\}]}{n}}} \qquad (10).$$

Again, values for *z* were obtained for a range of population levels and the probability levels of making a correct decision not to intervene were obtained from one-tailed normal probability tables.

4.2.2.3. Presence-absence cluster sampling

The initial sampling can also be conducted by classifying the unit, like a fruit or bunch of grapes, as infested or uninfested. In cases like these, it is convenient to take a number of secondary units, like grape bunches, from one primary unit, like a vine, or a plot of five vines in the case of the present study. This type of sampling, or presence-absence cluster sampling (Binns *et al*. 2000), was used for sampling pests on various parts of the vine. Such data are described by the beta-nomial distribution (Binns *et al*. 2000). The binomial distribution describes presence-absence data when there is no clustering. The proportion, p, of infested units in the binomial distribution is the equivalent of the average in count data. The variance of the proportion for the binomial distribution is given by (Binns *et al*. 2000):

$$Var(Bin) = \frac{p(1-p)}{n} \qquad (11),$$

where n is the total number of units examined.

In cluster sampling, the proportion of infested units, p, is first estimated using (Madden *et al*. 1996; Madden & Hughes 1999):

$$p = \frac{\sum_{i=1}^{n}\sum_{j=1}^{N} X_{ij}}{nN} \qquad (12),$$

where N are the primary units, for example a plot of five vines, and n the secondary units, for example bunches. Thus, p is the total number of infested bunches divided by the total number of bunches inspected.

The proportion of infested bunches in the sample from each individual plot of vines is estimated to produce p_j for the j^{th} plot. The variance of these proportions is estimated using (Madden & Hughes 1999):

$$Var(Obs) = \frac{\sum_{j=1}^{N}(p_j - p)^2}{N-1} = S_O^2 \qquad (13).$$

This is the observed variance. The following linear regression is fitted (Binns *et al*. 2000):

$$\ln(S_O^2) = \ln(a) + b\ln(S_B^2) \qquad (14).$$

Taking the antilogs results in the following expression (Binns *et al*. 2000):

$$S_O^2 = a(S_B^2)^b \qquad (15).$$

If infested bunches conform to the binomial distribution, the proportion of infested bunches in each plot will be the same as the proportion of infested bunches in the whole sample, because, if the binomial distribution is assumed, infestation will occur at random. Every bunch will thus have an equal chance of being infested. If the binomial variance (11) is substituted into (15), the following expression, similar to Taylor's power law, is obtained (Binns *et al*. 2000):

$$S_O^2 = a\left\{\frac{p(1-p)}{n}\right\}^b \qquad (16).$$

Here the variance, S_O^2, is expressed in terms of the proportion infested bunches, p. From (16) the sampling error can be estimated using (Binns *et al*. 2000):

$$D = \frac{1}{p}\sqrt{\frac{a}{N}\left\{\frac{p(1-p)}{n}\right\}^b} \qquad (17).$$

For bunch and stem infestation, the sampling error was determined for a constant infestation level (taken as the economic threshold value) and different numbers of sampling units, as well as a range of infestation levels and a constant number of sampling units (N = 20, n = 5). Dummy variable regression was again used to

determine whether or not there were differences in the regressions between the three seasons and between the two cultivars. Where the number of observations for some of the combinations of season and cultivar were too few, dummy variable regression was used only to determine whether or not there were differences between the regressions of the two cultivars. OC-curves were also calculated for a particular *ET* value, using expression (17) as the standard error and substituting *p* in (17) with the *ET*:

$$z = \frac{p - ET}{\sqrt{\frac{a}{N}\left\{\frac{ET(1-ET)}{n}\right\}^{b}}} \qquad (18).$$

4.2.2.4. Dummy variable regression models

In most of the cases the full model used was:

$$Y = A0 + B1D1 + B2D2 + B3D3 + B4D4 + B5D5 + (B0)X + (B6D1)X + (B7D2)X + (B8D3)X + (B9D4)X + (B10D5)X \qquad (19),$$

where

A0 = Basic intercept (2004/2005 season, Dauphine)
B0 = Basic slope (2004/2005 season, Dauphine)
B1-B5 = Change in intercept
B6-B10 = Change in slope,

and

D1 = 2002/2003 season; Barlinka
D2 = 2002/2003 season; Dauphine
D3 = 2003/2004 season; Barlinka
D4 = 2003/2004 season; Dauphine
D5 = 2004/2005 season; Barlinka.

For *Tetranychus urticae*, actual counts (number of mites on the vine leaves) were obtained. Presence-absence sampling was also used for *T. urticae*. Presence-absence cluster sampling was used for *P. ficus* bunch and stem infestation, as well as for *Frankliniella occidentalis*, *Epichoristodes acerbella* and *Phlyctinus callosus* bunch damage.

Therefore,

Y = $Log\left(S^2\right)$ for *T. urticae* counts on the vine leaves

Y = $\ln(-\ln(1-p))$ for *T. urticae* presence-absence sampling

Y = $\ln(S_O^2)$ for *P. ficus* stem infestation, *F. occidentalis* and *P. callosus* bunch damage

X = $Log\left(\bar{x}\right)$ for *T. urticae* counts on the vine leaves,

X = $\ln(\bar{x})$ for *T. urticae* presence-absence sampling,

X = $\ln(S_B^2)$ for *P. ficus* stem infestation, *F. occidentalis* and *P. callosus* bunch damage.

Almost no *P. callosus* bunch damage was observed during the 2002/2003 season. D1 and D2 were therefore equal to zero.

The exceptions to this full model (19) were for *E. acerbella* and *P. ficus* bunch infestation. In these cases there were insufficient data during individual seasons to assign dummy variables separating the seasons. Therefore the full model was:

$$\ln(S_O^2) = A0 + B1D1 + (B0)\ln(S_B^2) + (B2D1)\ln(S_B^2) \qquad (20),$$

where

A0 = Basic intercept (Dauphine, all seasons)

B0 = Basic slope (Dauphine, all seasons)

B1 = Change in intercept

B2 = Change in slope

and

D1 = Barlinka, all seasons

In each case the reduced model was selected by inspecting the regression coefficients of the full model (Gujarati 1970a, b). A F-test was used to determine whether or not the reduced models differed from the full model. In the case of a difference between a reduced model and the full model, the reduced model cannot be used and will therefore be rejected.

4.2.2.5. Economic thresholds

According to the guidelines for Integrated Production of Wines in South Africa (IPW), expert advice should be obtained when an average of more than five *T. urticae* per leaf are found (ARC Infruitec-Nietvoorbij 2004). This is similar to the threshold of six *T. urticae* per leaf used in Arkansas (Johnson *et al*. 2003). An average of six *T. urticae* per leaf was therefore used as the economic threshold.

For *P. ficus*, an infestation level of 5% stem and bunch infestation was taken as the economic threshold, as farmers agreed that they would accept a bunch infestation level of up to 5% (Walton 2003). No economic thresholds have been determined for *F. occidentalis*, *E. acerbella* and *P. callosus*. Therefore, it was assumed that a 5% bunch infestation level of these pests would also be acceptable and the same economic threshold as for *P. ficus* was therefore used. In the case of the phytosanitary pests *E. acerbella* and *P. callosus*, this threshold of 5% damage is only applicable if the grape crop is to be exported to markets for which the presence of these pests are allowed.

4.2.2.6. Sampling for phytosanitary pests

In the case of phytosanitary pests most, if not all, of the sample units should be pest free. In such cases it would be valuable to determine, with a specified degree of certainty, the number of pest free primary sampling units (plots of five vines), that is needed to conclude that the proportion of infested units is equal to or less than a specified level. The following expression can be used (Madden *et al*. 1996):

$$N = \frac{(-\theta)[Log(P)]}{p_u[Log(1+n\theta)]} \qquad (21),$$

where N is the number of primary sampling units or plots (plots of five vines in this case), n is the number of secondary units (number of vines per plot in this case), P is the significance level for a one-sided confidence interval, p_u is the upper limit of a one-sided confidence interval for p (p is the proportion of infested units) and θ is the degree of aggregation. The following expression was used to determine θ (Madden *et al*. 1996):

$$\theta = \frac{\rho}{1-\rho} \qquad (22),$$

where ρ is the intra-cluster correlation. The following expression can be used to determine ρ (Hughes *et al*. 1996):

$$\rho = \frac{n}{n-1}\left(\frac{a'}{f(p)} - \frac{1}{n}\right) \qquad (23),$$

where

$$a' = an^{-b} \qquad (24)$$

and

$$f(p) = \left[p(1-p)\right]^{1-b} \qquad (25),$$

with a and b being the regression constants determined in (14), p is the proportion of infested units and n is the number of secondary units or the number of bunches per plot. Substituting (24) and (25) into (23) gives the following expression:

$$\rho = \frac{a\left[\frac{p(1-p)}{n}\right]^{b-1} - 1}{n-1} \qquad (26).$$

The USDA phytosanitary standards require that a 10% infestation level of cartons of grapes can be detected with a 99% degree of certainty. However, the 10% infestation level is based on cartons of grapes (4.5 kg/carton) and not individual bunches. Therefore, the number of bunches that need to be sampled will depend on the bunch size, as this will influence the number of bunches that are packed per carton. The number of plots of five vines (one bunch per vine) that need to be inspected to comply with USDA phytosanitary requirements was estimated for bunch sizes of 100 to 900 gram. This was determined for *E. acerbella*, a phytosanitary pest responsible for a lot of the rejections to the USA (Pryke 2005).

4.3. Results

4.3.1. General

The regression coefficients in the full models for *T. urticae* counts and presence-absence data, *P. ficus* stem and bunch infestation, as well as *F. occidentalis*, *E. acerbella* and *P. callosus* bunch damage are given in Table 4.1. Inspection of the regression coefficients suggested that for *T. urticae* counts on leaves and presence-absence data, the full model (expression 19, page 61) could be reduced to the following model:

Y = (A0.1) + (B1.1)(D1+D3+D5) + (B0.1)X + (B2.1)(D1+D3+D5)X,

where

A0.1 = Basic intercept (Dauphine, all seasons)
B0.1 = Basic slope (Dauphine, all seasons)
B1.1 = Change in intercept (Barlinka, all seasons)
B2.1 = Change in slope (Barlinka, all seasons).

Therefore, the following hypotheses were tested:

H0: $B1 = B3 = B5$ and
$B6 = B8 = B10$ and
$B_i = 0$ for all i = 2, 4, 7 and 9 in the full model (expression 19).

Ha: $B_j \neq B_k$ for at least one pair of j and k, with j, k = 1, 3, 5, 6, 8 and 10, and $j \neq k$, or $B_i \neq 0$ for at least one i = 2, 4, 7 and 9 in the full model (expression 19).

The regression coefficients are given in Table 4.2. Inspection of the regression coefficients in the full model (Table 4.1) suggested that the full model for *P. ficus* bunch (expression 20, page 62) and stem infestation (expression 19), as well as for *F. occidentalis* and *E. acerbella* bunch damage (expressions 19 and 20 respectively), could be reduced to the following model:

$$\ln(S_O^2) = (A0.1) + (B0.1)\ln(S_B^2),$$

and the following hypothesis were tested:

H0: $B_i = 0$ for all i = 1, 2, …, 10 in the full model.
Ha: $B_i \neq 0$ for at least one i = 1, 2, …, 10 in the full model.

The regression coefficients are given in Table 4.2. Inspection of the regression coefficients in the full model (Table 4.1) suggested that for *P. callosus* bunch damage, the full model (expression 19) could be reduced to the following model:

$$\ln(S_O^2) = (A0.1) + (B1.1)(D3+D4) + (B0.1)\ln(S_B^2) + (B2.1)(D3+D4)\ln(S_B^2),$$

where

A0.1 = Basic intercept (2004/2005 season, both cultivars)
B0.1 = Basic slope (2004/2005 season, both cultivars)
B1.1 = Change in intercept (2003/2004 season, both cultivars)

B2.1 = Change in slope (2003/2004 season, both cultivars).

The following hypotheses were tested:

H0: $B3 = B4$ and
$B8 = B9$ and
$B_i = 0$ for all i = 5 and 10 in the full model (expression 19).

Ha: $B_j \neq B_k$ for at least one pair of j and k, with j, k = 3, 4, 8 and 9, and $j \neq k$,
or $B_i \neq 0$ for at least one i = 5 and 10 in the full model (expression 19).

The regression coefficients are given in Table 4.2. In neither case did the reduced model differ from the full model (Table 4.3). In addition, the correlation coefficients of all the linear regressions were good (Table 4.4). The regression relationships are shown in Figures 4.1 to 4.4.

Table 4.1. Regression coefficients (RC) with their standard errors (SE) and probability levels (P) for the full model for *Tetranychus urticae* counts on vine leaves and presence-absence data, *Planococcus ficus* bunch and stem infestation, as well as *Frankliniella occidentalis*, *Epichoristodes acerbella* and *Phlyctinus callosus* bunch damage. A0 = Basic intercept (2004/2005 season, Dauphine); B0 = Basic slope (2004/2005 season, Dauphine); B1-B5 = Change in intercept; B6-B10 = Change in slope (B1 & B6 = 2002/2003 season, Barlinka; B2 & B7 = 2002/2003 season, Dauphine; B3 & B8 = 2003/2004 season, Barlinka; B4 & B9 = 2003/2004 season, Dauphine; B5 & B10 = 2004/2005 season, Barlinka).

Pest	d.f.		A0	B0	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
T. urticae actual counts	182	RC	0.665	1.706	-0.374	-0.462	-0.485	-0.027	-0.422	-0.202	-0.243	-0.250	-0.019	-0.163
		SE	0.068	0.048	0.100	0.207	0.099	0.100	0.104	0.073	0.132	0.069	0.070	0.072
		P	<0.001	<0.001	<0.001	0.027	<0.001	0.785	<0.001	0.006	0.067	<0.001	0.785	0.025
T. urticae presence-absence data	95	RC	-3.073	0.321	0.719	-1.214	1.299	0.414	1.111	0.257	-0.334	0.223	0.195	0.316
		SE	0.223	0.097	0.325	1.445	0.320	0.334	0.336	0.132	0.533	0.123	0.136	0.147
		P	<0.001	0.001	0.029	0.403	<0.001	0.218	0.001	0.055	0.532	0.074	0.156	0.034
P. ficus bunch infestation*	57	RC	0.439	1.068	0.093	0.020								
		SE	0.208	0.038	0.511	0.091								
		P	0.040	<0.001	0.857	0.826								
P. ficus stem infestation	91	RC	-0.390	0.936	0.873	1.608	<0.001	0.716	<0.001	0.144	0.259	<0.001	0.127	<0.001
		SE	2.299	0.375	2.394	2.310	2.714	2.342	3.207	0.393	0.377	0.445	0.385	0.521
		P	0.866	0.014	0.716	0.488	1.000	0.761	1.000	0.716	0.494	1.000	0.741	1.000
F. occidentalis bunch damage	212	RC	0.349	1.055	-0.103	-0.034	-0.152	0.188	0.061	-0.020	0.001	-0.030	0.025	0.015
		SE	0.169	0.039	0.316	0.259	0.351	0.254	0.364	0.069	0.056	0.081	0.056	0.095
		P	0.040	<0.001	0.744	0.897	0.666	0.460	0.867	0.769	0.987	0.714	0.660	0.873
E. acerbella bunch damage*	52	RC	-0.549	0.910	0.026	0.004								
		SE	0.027	0.005	0.042	0.007								
		P	<0.001	<0.001	0.537	0.535								
P. callosus bunch damage	45	RC	0.330	1.050			0.875	3.820	-0.568			0.142	0.615	-0.092
		SE	0.432	0.076			0.605	1.351	0.572			0.107	0.225	0.104
		P	0.449	<0.001			0.155	0.007	0.326			0.192	0.009	0.383

*A0 = Basic intercept (Dauphine, all seasons); B0 = Basic slope (Dauphine, all seasons); B1 = Change in intercept (Barlinka, all seasons); B2 = Change in slope (Barlinka, all seasons).

Table 4.2. Regression coefficients (RC) with their standard errors (SE) and probability levels (P) for the reduced model for *Tetranychus urticae* counts on vine leaves and presence-absence data (A0.1 = Basic intercept: Dauphine, all seasons; B0.1 = Basic slope: Dauphine, all seasons; B1.1 = Change in intercept: Barlinka, all seasons; B2.1 = Change in slope: Barlinka, all seasons), *Planococcus ficus* bunch and stem infestation and *Frankliniella occidentalis* and *Epichoristodes acerbella* bunch damage (A0.1 = Basic intercept: all seasons and cultivars; B0.1 = Basic slope: all seasons and cultivars), as well as *Phlyctinus callosus* bunch damage (A0.1 = Basic intercept: 2004/2005 season, both cultivars; B0.1 = Basic slope: 2004/2005 season, both cultivars; B1.1 = Change in intercept: 2003/2004 season, both cultivars; B2.1 = Change in slope: 2003/2004 season, both cultivars).

Pest	d.f.		A0.1	B0.1	B1.1	B2.1
T. urticae actual counts	190	RC	0.625	1.689	-0.384	-0.189
		SE	0.049	0.033	0.065	0.045
		P	<0.001	<0.001	<0.001	<0.001
T. urticae presence-absence data	103	RC	-2.905	0.419	0.840	0.138
		SE	0.170	0.069	0.222	0.086
		P	<0.001	<0.001	<0.001	0.112
P. ficus bunch infestation	59	RC	0.463	1.074		
		SE	0.186	0.034		
		P	0.016	<0.001		
P. ficus stem infestation	101	RC	0.905	1.151		
		SE	0.169	0.031		
		P	<0.001	<0.001		
F. occidentalis bunch damage	222	RC	0.357	1.056		
		SE	0.084	0.018		
		P	<0.001	<0.001		
E. acerbella bunch damage	54	RC	-0.538	0.911		
		SE	0.021	0.003		
		P	<0.001	<0.001		
P. callosus bunch damage	49	RC	-0.042	0.988	1.416	0.226
		SE	0.283	0.051	0.491	0.086
		P	0.883	<0.001	0.006	0.011

Table 4.3. Pests, sample units, description of the reduced model, F-values with their degrees of freedom for comparing the reduced model with the full model [F (d.f.)] and the probability levels for accepting the reduced models when they were compared with the full models (P).

Pest	Sample unit	Model description	F (d.f.)	P
Tetranychus urticae	Counts on leaves	Separate slopes and intercepts for Barlinka and Dauphine	1.380 (8, 182)	0.208
	Presence-absence	Separate slopes and intercepts for Barlinka and Dauphine	1.966 (8, 95)	0.059
Planococcus ficus	Bunch infestation	Common slope and intercept for all seasons and both cultivars	0.075 (2, 57)	0.928
	Stem infestation	Common slope and intercept for all seasons and both cultivars	1.734 (10, 91)	0.085
Frankliniella occidentalis	Bunch damage	Common slope and intercept for all seasons and both cultivars	0.587 (10, 212)	0.823
Epichoristodes acerbella	Bunch damage	Common slope and intercept for all seasons and both cultivars	0.197 (2, 52)	0.822
Phlyctinus callosus	Bunch damage	Separate slopes and intercepts for the 2003/2004 and 2004/2005 seasons	1.865 (4, 45)	0.133

Table 4.4. Pests, sample units, cultivars, seasons, intercepts, slopes, multiple correlation coefficients (R) and the probability levels for goodness of fit of the reduced regression models (P).

Pest	Sample unit	Cultivar	Season	Intercept	Slope	R	P
Tetranychus urticae	Counts on leaves	Barlinka	All	0.24	1.50	0.98	<0.001
		Dauphine	All	0.62	1.69		
	Presence-absence	Barlinka	All	-2.06	0.56	0.79	<0.001
		Dauphine	All	-2.90	0.42		
Planococcus ficus	Bunch infestation	Both	All	0.46	1.07	0.97	<0.001
	Stem infestation	Both	All	0.90	1.15	0.97	<0.001
Frankliniella occidentalis	Bunch damage	Both	All	0.36	1.06	0.97	<0.001
Epichoristodes acerbella	Bunch damage	Both	All	-0.54	0.91	≈1.00	<0.001
Phlyctinus callosus	Bunch damage	Both	03/04	1.37	1.21	0.97	<0.001
		Both	04/05	-0.04	0.99		

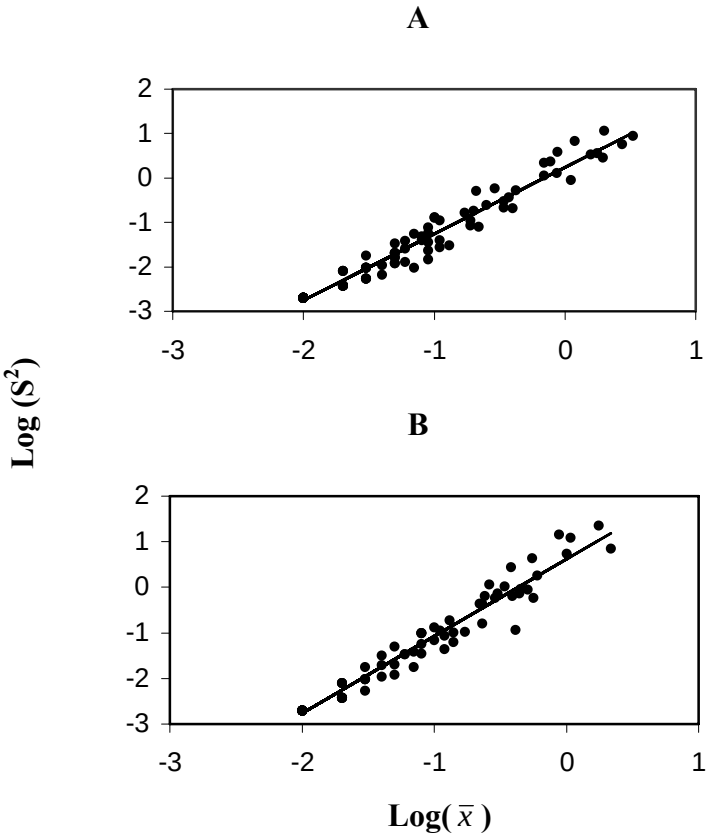


Figure 4.1. Log(S^2) plotted against Log($\bar{x}$) for *Tetranychus urticae* counts on (A) Barlinka leaves and (B) Dauphine leaves. (•) observed Log(S^2); (—) estimated Log(S^2).

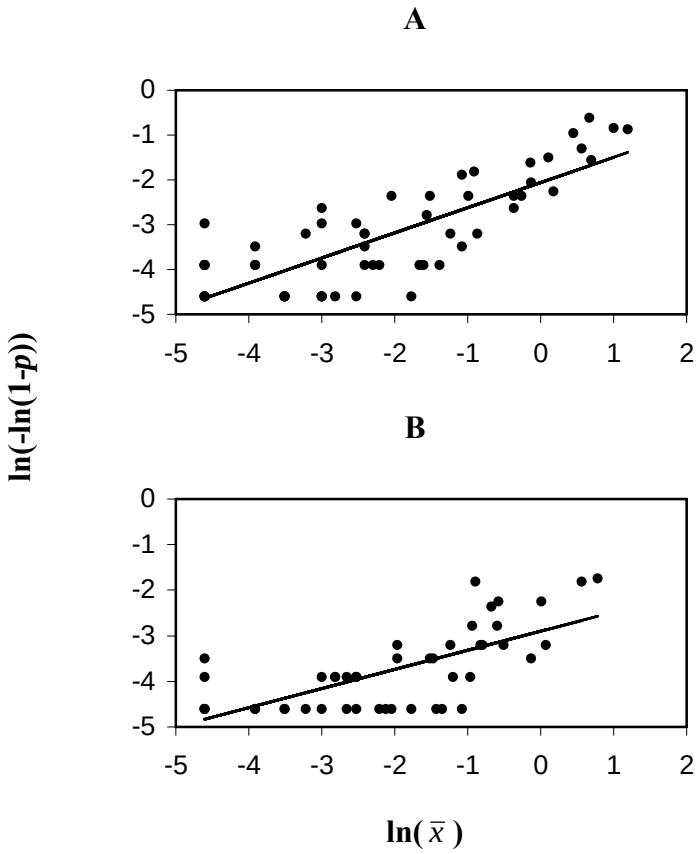


Figure 4.2. ln(-ln(1-*p*)) plotted against ln($\bar{x}$) for the proportion of (A) Barlinka and (B) Dauphine leaves infested with *Tetranychus urticae*. (•) observed ln(-ln(1-*p*)); (—) estimated ln(-ln(1-*p*)).

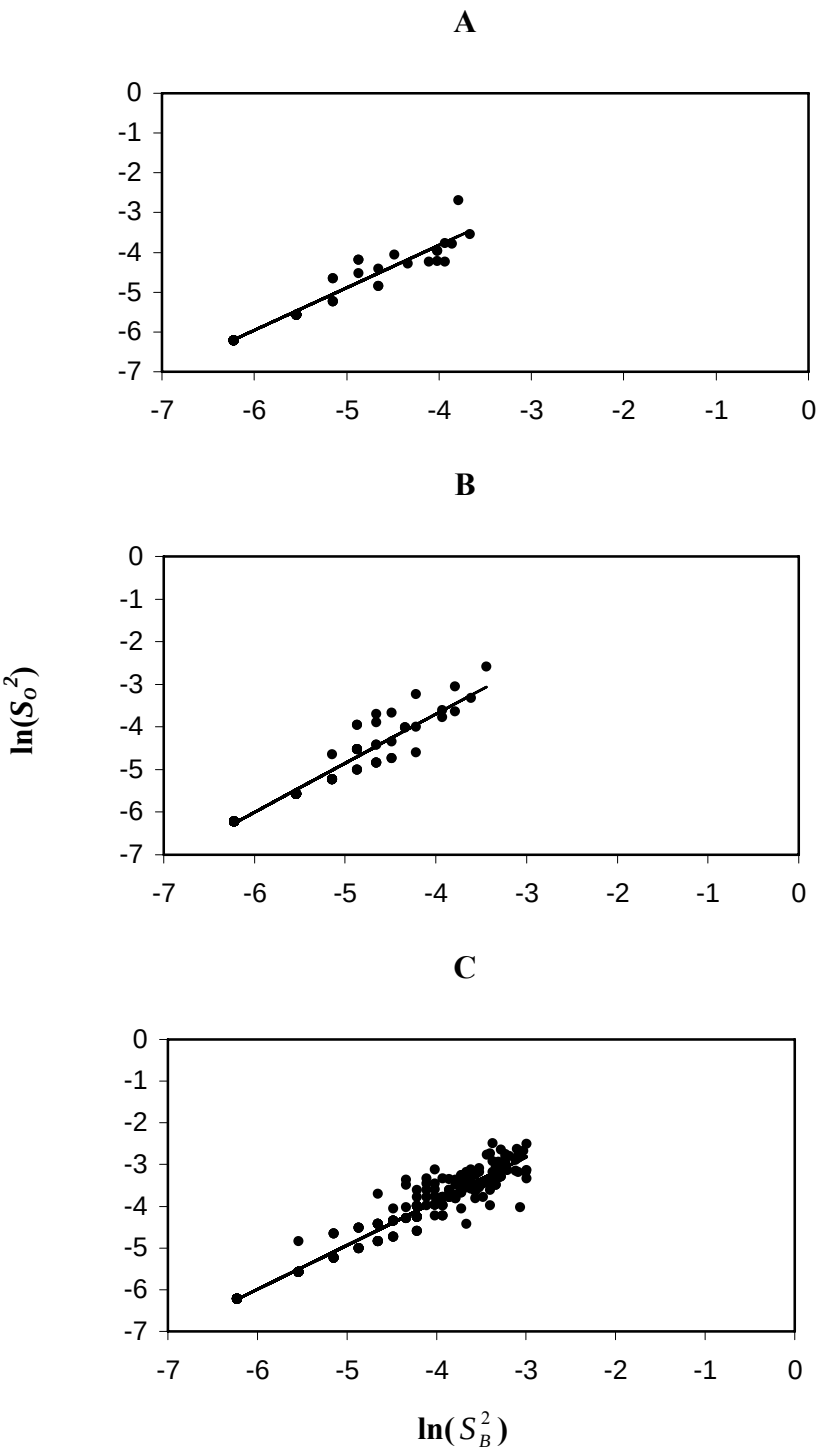


Figure 4.3. **ln(S_O^2) plotted against ln(S_B^2) for (A) *Planococcus ficus* bunch infestation, (B) *P. ficus* stem infestation and (C) *Frankliniella occidentalis* bunch damage. (•) observed ln(S_O^2); (—) estimated ln(S_O^2).**

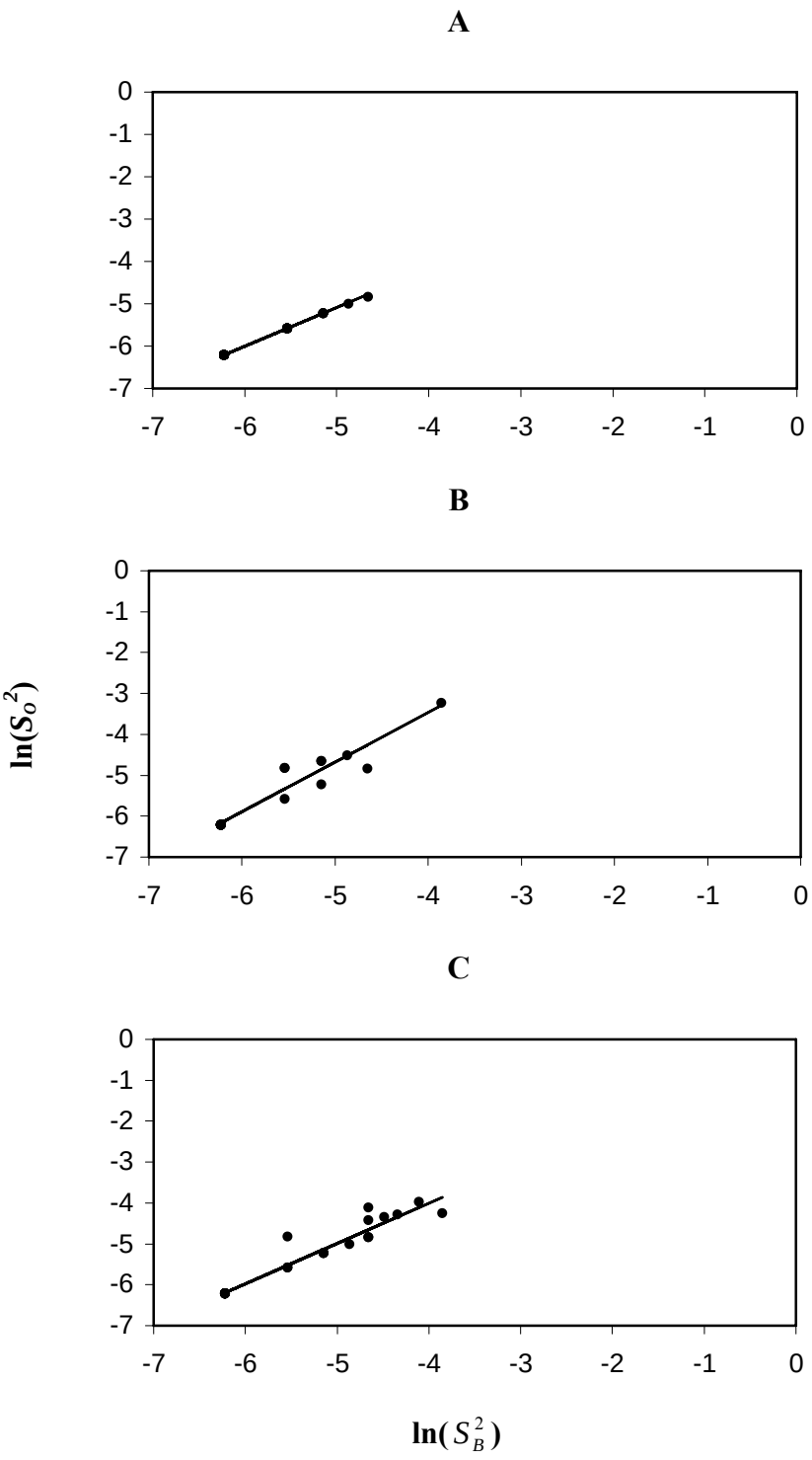


Figure 4.4. ln(S_O^2) plotted against ln(S_B^2) for (A) *Epichoristodes acerbella* bunch damage, (B) *Phlyctinus callosus* bunch damage, the 2003/2004 season and (C) *P. callosus* bunch damage, the 2004/2005 season. (•) observed ln(S_O^2); (—) estimated ln(S_O^2).

4.3.2. Sampling error

When 20 plots were sampled and the population or infestation level was set at the economic threshold, the sampling error varied between 18.85%, for *T. urticae* counts on Barlinka leaves, and 53.03%, for *P. callosus* bunch damage during the 2003/2004 season (Table 4.5, Figures 4.5 to 4.7). In no instance did the sampling error decline dramatically when more than 20 plots were used (Figures 4.5B and 4.7).

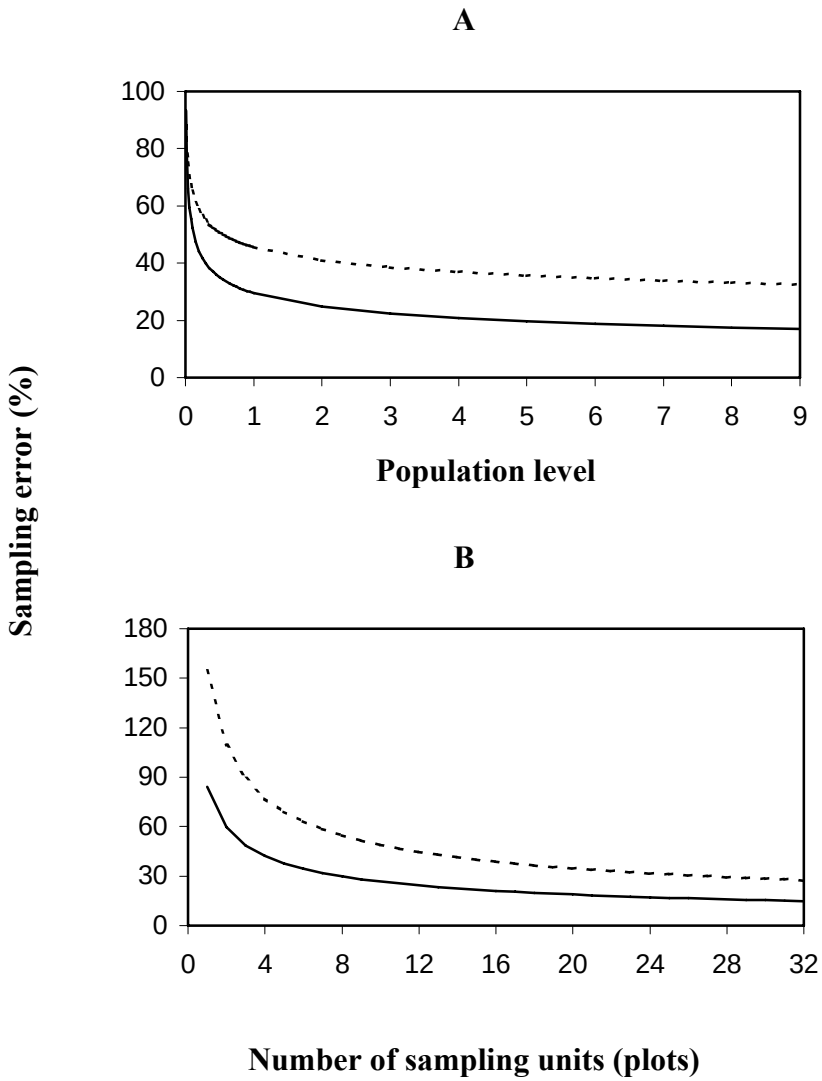


Figure 4.5. Percentage sampling error for *Tetranychus urticae* on (—) Barlinka and (----) Dauphine vine leaves at (A) a constant number of sampling units (*n* = 20) and a range of population levels and (B) a constant population level, set at the economic threshold (six mites per leaf), and various numbers of sampling units.

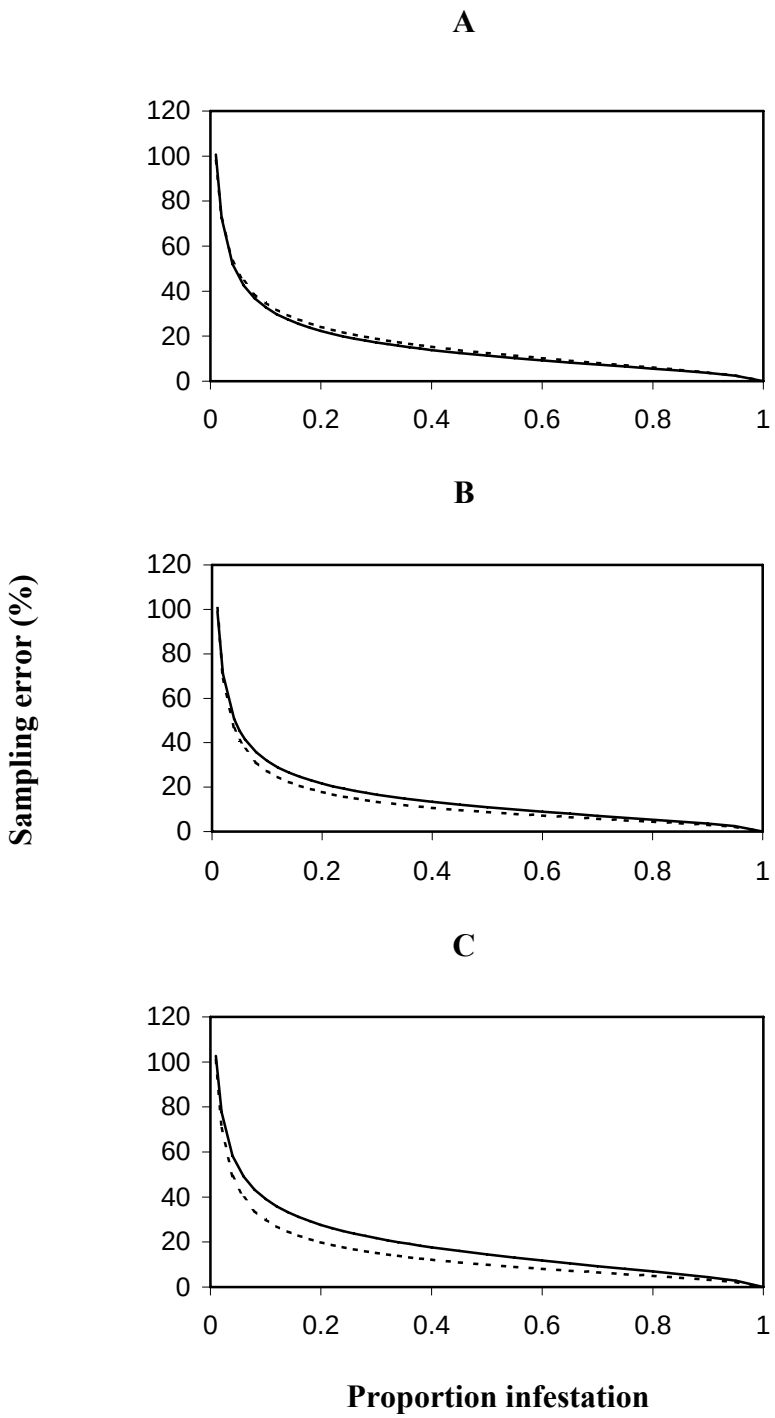


Figure 4.6. Percentage sampling error for (A) *Planococcus ficus* bunch (—) and stem (----) infestation, (B) *Frankliniella occidentalis* (—) and *Epichoristodes acerbella* (----) bunch damage and (C) *Phlyctinus callosus* bunch damage during the (—) 2003/2004 season and (----) 2004/2005 season at different infestation levels and a constant number of sampling units (*N* = 20, *n* = five).

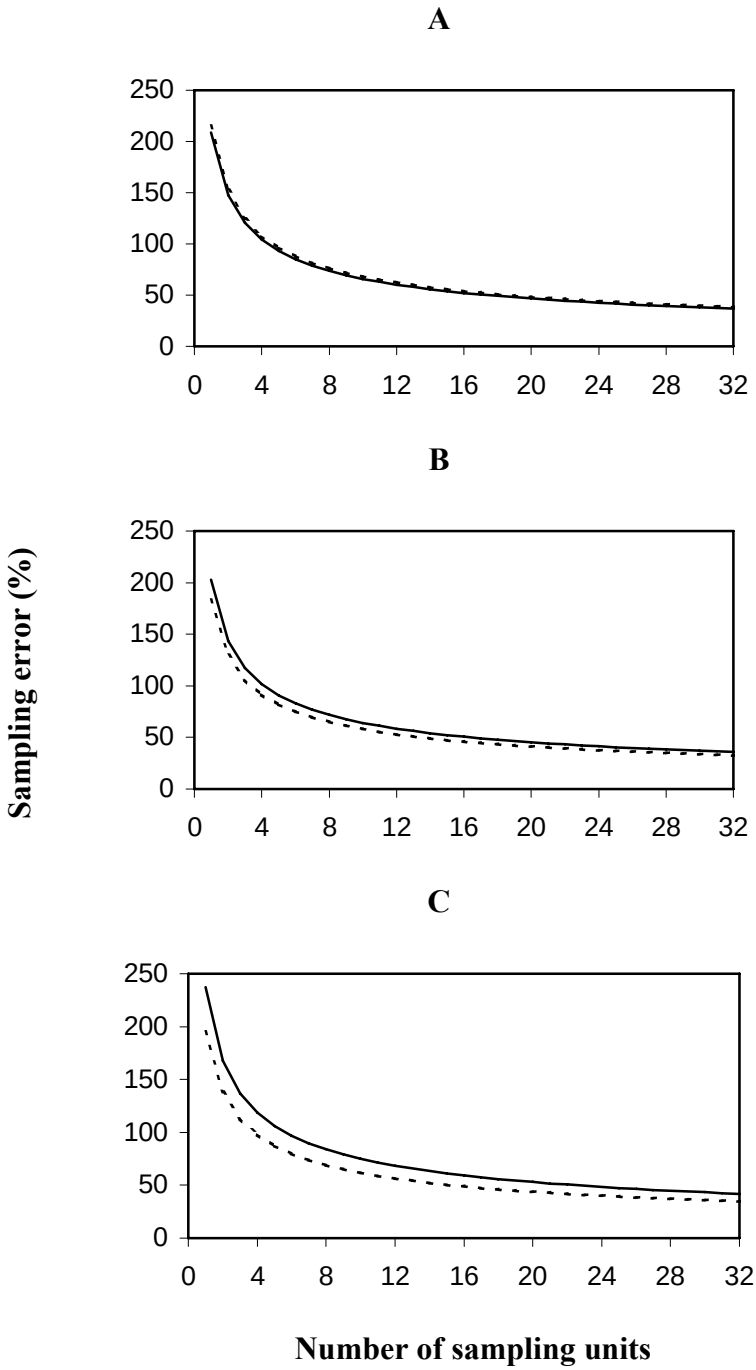


Figure 4.7. Percentage sampling error for (A) *Planococcus ficus* bunch (—) and stem (----) infestation, (B) *Frankliniella occidentalis* (—) and *Epichoristodes acerbella* (----) bunch damage and (C) *Phlyctinus callosus* bunch damage during the (—) 2003/2004 season and (----) 2004/2005 season at a constant infestation level ($p = 0.05$) and a range of sampling units (plots of five vines).

Table 4.5. The percentage sampling error (*D*) and economic threshold (*ET*) for *Tetranychus urticae* on vine leaves (*n* = 20 plots), *Planococcus ficus* bunch and stem infestation, as well as *Frankliniella occidentalis*, *Epichoristodes acerbella* and *Phlyctinus callosus* bunch damage (*N* = 20 plots; *n* = five vines).

Pest	Cultivar	Season	*ET*	*D* (%)
T. urticae (actual counts)	Barlinka	All	six mites per leaf	18.85
	Dauphine	All	six mites per leaf	34.59
P. ficus bunch infestation	Both	All	5% infestation	46.61
P. ficus stem infestation	Both	All	5% infestation	48.21
F. occidentalis bunch damage	Both	All	5% infestation	45.38
E. acerbella bunch damage	Both	All	5% infestation	41.03
P. callosus bunch damage	Both	03/04	5% infestation	53.03
	Both	04/05	5% infestation	43.73

4.3.3. Operational characteristic curves

4.3.3.1. *Tetranychus urticae*

Seperate operational characteristic (OC) curves were drawn for the Barlinka and Dauphine leaves, using actual mite counts and using presence-absence data (Figure 4.8). For the presence-absence data, expression (8) (page 58) was used to determine the proportion infested leaves for the threshold value of six mites per leaf. This gave a threshold of 29% infested leaves for Barlinka and 11% infested leaves for Dauphine.

When an average of 4.5 (Barlinka) and 3.3 (Dauphine) mites per leaf (actual mite counts) was observed, the decision not to intervene was correct in 90% of the cases (Figure 4.8). The presence-absence data was not as reliable as using the actual counts. Both the Barlinka and Dauphine OC-curves were flatter for the presence-absence data than for the actual counts (Figure 4.8). The decision not to intervene, when making use of presence-absence sampling, was correct in 90% of the cases when an average of 1.8 mites per leaf (an infestation of 16%) were found for Barlinka and 0.08 mites per leaf (an infestation of 1.9%) for Dauphine.

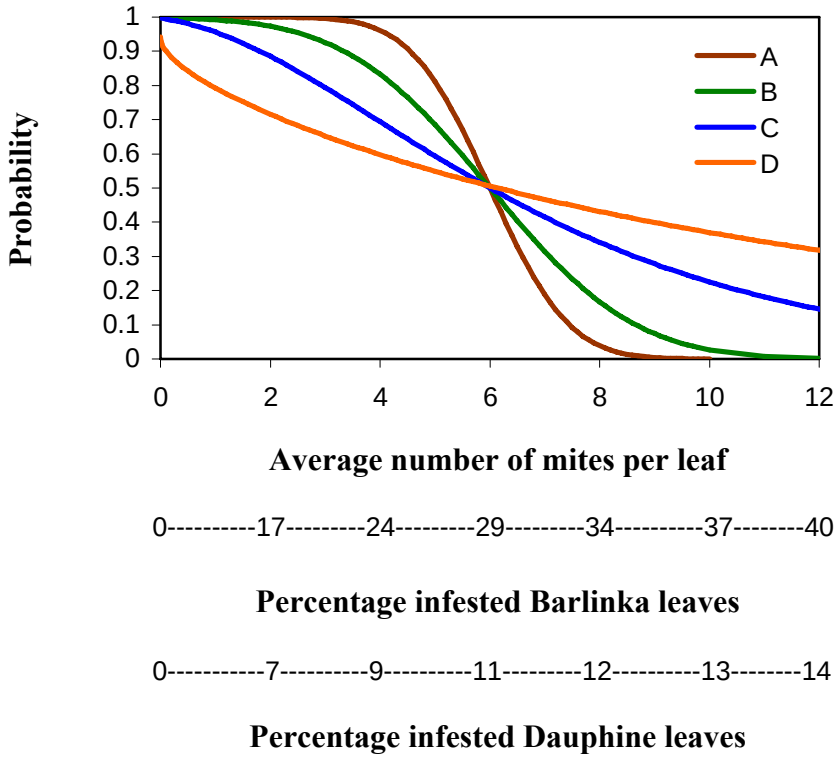


Figure 4.8. Operational characteristic curves for monitoring *Tetranychus urticae* on vine leaves. (A) Barlinka, actual counts (first X-axis); (B) Dauphine, actual counts (first X-axis); (C) Barlinka, presence-absence data (first and second X-axis); (D) Dauphine, presence-absence data (first and third X-axis). Threshold value = six mites per leaf.

4.3.3.2. *Planococcus ficus*

The OC-curves for *P. ficus* bunch and stem infestation were very similar (Figure 4.9A). At an economic threshold of 5%, the decision not to intervene with a control measure when 2% of either the stems or the bunches were infested, did not lead to under reacting in 89% and 90% of the cases respectively (Figure 4.9A).

4.3.3.3. *Frankliniella occidentalis*

It was not meaningful to draw an OC-curve for *F. occidentalis*, because the halo spots were formed early in the season during bloom and up to fruit set or shortly thereafter

(Jensen *et al*. 1992). During scouting, this damage was first seen later in the season, when the berries were larger. Intervening with a control measure at this later stage would therefore not prevent damage.

4.3.3.4. *Epichoristodes acerbella*

At an economic threshold of 5% bunch damage by *E. acerbella*, the decision not to intervene when 1% and 2% bunches were damaged was correct in 97% and 93% of the cases respectively (Figure 4.9B).

4.3.3.5. *Phlyctinus callosus*

The OC-curves for *P. callosus* fruit damage during the 2003/2004 and 2004/2005 seasons were similar, but the precision was higher for data from the 2004/2005 season. At an economic threshold of 5%, the decision not to intervene with a control measure when 1% of the bunches were infested, was correct in 93% of the cases for the 2003/2004 season and 97% of the cases for the 2004/2005 season (Figure 4.9C). Not intervening when 2% infestation occurred was correct in 87% of the cases for the 2003/2004 season and 91% of the cases for the 2004/2005 season (Figure 4.9C).

4.3.4. Phytosanitary pests

Table 4.6 gives the infestation levels in the field for a 10% infestation in the pack shed for various bunch sizes. The number of primary units (plots of five bunches), all pest free, that is needed to meet the USDA standard, was 45 (225 bunches) for bunches of 900 grams for *E. acerbella* (Table 4.6). For bunches of 100 grams, the number of sampling units needed was 463 (2315 bunches) (Table 4.6).

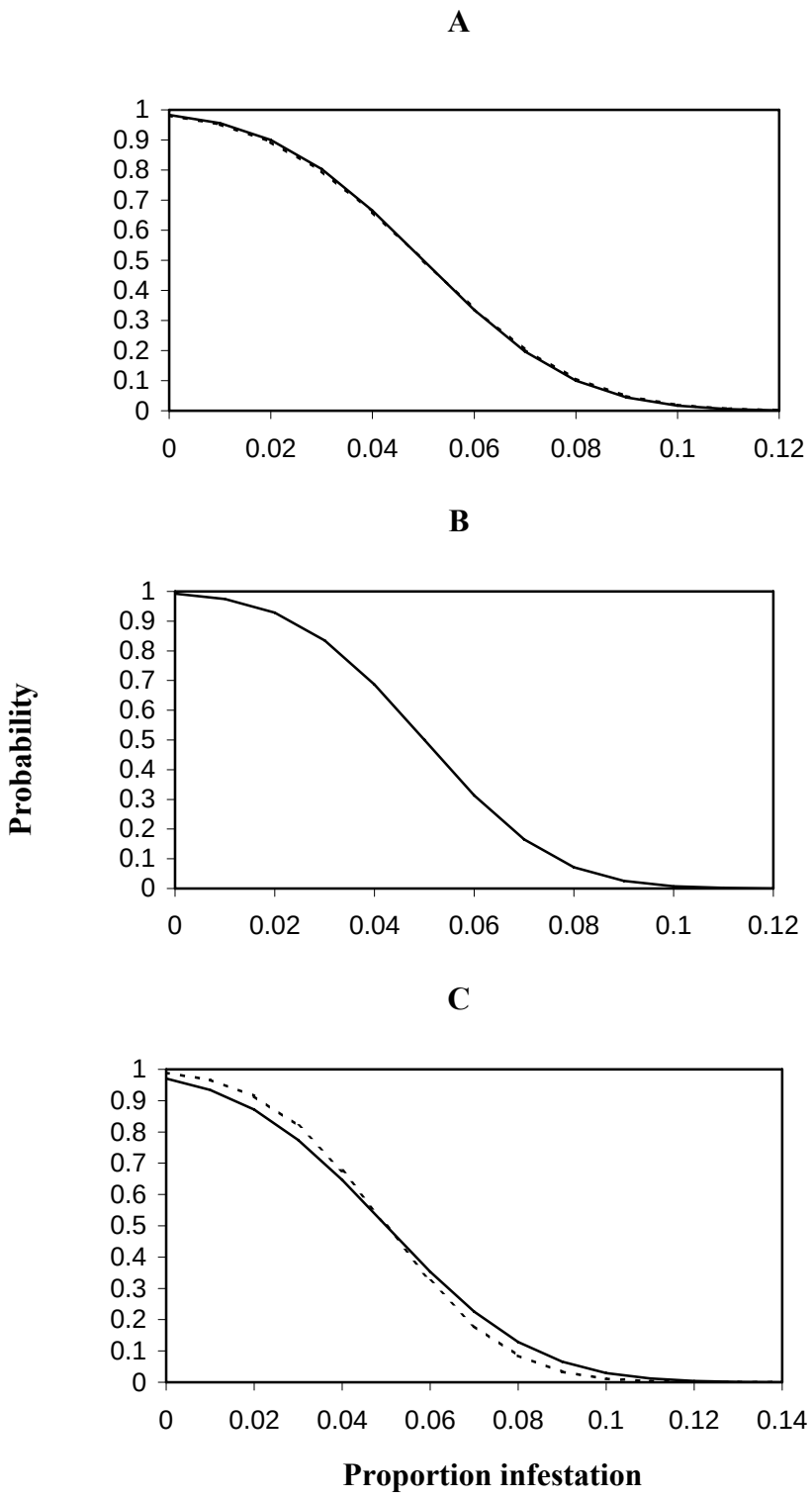


Figure 4.9. Operational characteristic curves for monitoring (A) *Planococcus ficus* (—) bunch and (----) stem infestation, (B) *Epichoristodes acerbella* bunch damage and (C) *Phlyctinus callosus* bunch damage during the (—) 2003/2004 season and (----) 2004/2005 season. Threshold value = 5% infestation or damage.

Table 4.6. The proportion infested bunches when 10% of the cartons are infested (with no more than one infested bunch per carton) and the corresponding number of sampling units (plots of five vines), all pest free, that need to be inspected in the field in order to conclude, with a 99% degree of certainty, that infestation levels showed in column three, will be detected.

Bunch size (gram)	Bunches per box	Proportion infested bunches when 10% of the boxes are infested*	Number of sampling units (pest free) needed for *Epichoristodes acerbella*
100	45.00	0.0022	463
200	22.50	0.0044	222
300	15.00	0.0067	142
400	11.25	0.0089	106
500	9.00	0.0111	84
600	7.50	0.0133	69
700	6.43	0.0156	58
800	5.63	0.0178	51
900	5.00	0.0200	45

* Pringle (unpublished report)

4.4. Discussion

When *T. urticae* was sampled, using 20 plots per one to two hectares, the sampling error when six mites per leaf (economic threshold) were found was less than the acceptable value of 20% for Barlinka, but exceeded 20% for Dauphine. For *P. ficus* bunch and stem infestation and *F. occidentalis*, *E. acerbella* and *P. callosus* bunch damage, the sampling error when 20 plots of five vines per plot were inspected, also exceeded 20%. These high sampling errors do not mean that this monitoring system cannot be used, because the OC-curves give an indication of the degree of precision for decision making based on the monitoring system. For *T. urticae*, which is not a direct pest, a high degree of precision (for example 90% and more) is not necessary, since under reacting will not lead to direct crop losses. Therefore, even though the level of precision using presence-absence sampling of the mites was far less than when using actual counts, it can still be used to sample the mites. Different threshold

values were obtained for presence-absence sampling of *T. urticae* on Barlinka and Dauphine leaves. In practice, it would be better to use only one threshold value for all cultivars. Control measures should therefore be applied when 11 to 29% of the leaves are infested, depending on factors such as leaf quality.

Planococcus ficus stem infestation can be used as an early warning for bunch infestation (see Chapter 3). In the present study, it was found that the decision not to intervene with a control measure when 2% stem infestation was observed, was correct in 89% of the cases. Walton (2003) however found this decision to be correct in 95% of the cases. The main reason for this higher precision is that a different expression for *z* was used. Walton (2003) used the following expression for *z*:

$$z = \frac{p - ET}{\sqrt{\frac{a}{N}\left\{\frac{p(1-p)}{\bar{n}}\right\}^{b}}}$$

Using the above expression and the data from the present study, the decision not to intervene when 2% stem infestation was observed produced a 98% probability of under reacting. This was similar to that found by Walton (2003) who recommended that control measures should be applied at 2% stem infestation.

A suitable sampling method for *F. occidentalis* still needs to be developed. The monitoring system used in the present study only provided information on the infestation status of the vineyard. Jensen *et al*. (1992) suggested that thrips should be sampled by striking bunches of the blossoms or small grapes three times against the flat surface of a cardboard, 8½ x 11 inch. The dislodged thrips are then counted on the cardboard. This can be very time-consuming, especially if it forms part of a generic monitoring system, where sampling of all pests, not only *F. occidentalis* is included. It can therefore only form part of a monitoring system if it is done only once or twice during the fruit season. However, it will be difficult to decide when this should be done and the timing of this procedure could influence the number of thrips recorded per bunch. In addition, it may also be difficult for farmers to distinguish between *F. occidentalis* and other thrips (see Chapter 3, section 3.3.4).

At a threshold of 5% bunch damage for *E. acerbella* and *P. callosus*, the chance of not under spraying when control measures were applied at 1% bunch damage would be good (between 93 and 97%). It is therefore recommended that control measures be applied against these two pests at 1% bunch damage if grapes are exported to markets where the presence of these pests in the bunches will not lead to rejections.

It should not be necessary to sample more than 20 plots, of five vines per plot, per one to two hectares for *T. urticae* on the vine leaves, *P. ficus* bunch and stem infestation and *F. occidentalis*, *E. acerbella* and *P. callosus* bunch damage. However, in the case of phytosanitary pests, the number of sampling units required to conclude with a 99% degree of certainty that infestation levels in the pack shed will be 10% or less, exceeded 20 plots. This was especially the case for bunches of 100 grams for which 463 plots (of five bunches per plot) would be required for *E. acerbella*. Sampling such a large number of plots in the field will be very time consuming. Prior to the present study, the recommendation was that fruit should not be exported to the USA from a vineyard if infestation was detected while sampling 20 plots. If no infestation is detected, more extensive pre-inspection sampling should be done in the pack shed.

Pringle (unpublished report) suggested a pre-inspection sampling plan for pack sheds. The number of bunches that needed to be inspected to detect a 10% infestation of boxes of grapes at a binomial probability of 99% was calculated. For 100 g bunches 2070 bunches would have to be inspected and for 900 g bunches, 228 bunches. In the present study 2315 bunches of 100 g would need to be inspected for detecting *E. acerbella*, while in the case of 900 g bunches 225 bunches would have to be inspected. These figures are similar to those of Pringle (unpublished report). Therefore, either of the two methods can be used.

The sampling protocol developed for *P. ficus* (Walton 2003) has now been extended to include all the major table grape pests. Information gained here, regarding the number of sampling units needed and recommendations on when to apply control measures, can now be used in a monitoring system for the table grape pest complex.

4.5. References

ARC Infruitec-Nietvoorbij, in consultation with the vine and wine industry. 2004 July. Guidelines for integrated production of wine in South Africa. IPW homepage. <http://www.ipw.co.za> Accessed 13 June 2005.

Binns, M.R., Nyrop, J.P. & Van der Werf, W. 2000. *Sampling and Monitoring in Crop Protection: The Theoretical Basis for Developing Practical Decision Guides*. CAB International, Wallingford.

Davis, P.M. 1994. Statistics for describing populations. In: Pedigo, L.P. & Buntin, G.D. (Eds) *CRC Handbook of Sampling Methods for Arthropods in Agriculture*. 33-54. CRC Press, Boca Raton.

Flaherty, D.L., Wilson, L.T., Welter, S.C., Lynn, C.D. & Hanna, R. 1992. Spider Mites. In: Flaherty, D.L., Christensen, L.P., Lanini, W.T., Marois, J.J., Phillips, P.A. & Wilson, L.T. (Eds) *Grape Pest Management. Second Edition*. 180-192. Division of Agriculture and Natural Resources, University of California.

Gujarati, D. 1970a. Use of dummy variables in testing for equality between sets of coefficients in two linear regressions: a note. *American Statistician* 24(1): 50-53.

Gujarati, D. 1970b. Use of dummy variables in testing between sets of coefficients in linear regression: a generalization. *American Statistician* 24(5): 18-22.

Heunis, J.M. 2001. *The Biology and Management of Aerial Populations of Woolly Apple Aphid,* Eriosoma Lanigerum *(Hausmann) (Homoptera: Aphididae)*. PhD Dissertation, University of Stellenbosch.

Hughes, G., Madden, L.V. & Munkvold, G.P. 1996. Cluster sampling for disease incidence data. *Phytopahology* 86: 132-137.

Iwao, S. & Kuno, E. 1971. An approach to the analysis of aggregation pattern in biological populations. In: Patil, G.P., Pielou, E.C. & Waters, W.E. (Eds) *Spatial Patterns and Statistical Distributions. Vol. I. Statistical Ecology*. 461-513. Pennsylvania State University Press, University Park.

Jensen, F.L., Flaherty, D.L. & Luvisi. D.A. 1992. Thrips. In: Flaherty, D.L., Christensen, L.P., Lanini, W.T., Marois, J.J., Phillips, P.A. & Wilson, L.T. (Eds) *Grape Pest Management. Second Edition*. 193-201. Division of Agriculture and Natural Resources, University of California.

Johnson, D., Striegler, R.K., Lewis, B.A. & Lake, C. 2003 June. Crop profile for grapes in Arkansas. <http://pestdata.ncsu.edu/cropprofiles/docs/ARgrapes.html> Accessed 13 June 2005.

Madden, L.V. & Hughes, G. 1999. Sampling for plant disease incidence. *Phytopathology* 89: 1088-1103.

Madden, L.V., Hughes, G. & Munkvold, G.P. 1996. Plant disease incidence: inverse sampling, sequential sampling, and confidence intervals when observed mean incidence is zero. *Crop Protection* 15: 621-632.

Pedigo, L.P. 1999. *Entomology and Pest Management. Third Edition.* Prentice-Hall, Inc., New Jersey.

Pryke, J.S. 2005. *Insect Contaminants in Table Grapes*. MSc Thesis, University of Stellenbosch.

Reusink, W.G. & Kogan, M. 1994. The quantitative basis of pest management: Sampling and measuring. In: Metcalf, R.L. & Luckman, W.H. (Eds) *Introduction to Insect Pest Management, Third Edition*. 355-391. John Wiley and Sons, Inc., New York.

Romoser, W.S. & Stoffolano, J.G. 1998. *The Science of Entomology. Fourth Edition.* McGraw-Hill Companies, Inc., Boston.

Speight, M.R., Hunter, M.D. & Watt, A.D. 1999. *Ecology of Insects. Concepts and Applications.* Blackwell Science Ltd, London.

Stern, V.M., Smith, R.F., Van den Bosch, R. & Hagen, K.S. 1959. The integrated control concept. *Hilgardia* 29: 81-101.

Taylor, L.R. 1961. Aggregation, variance and the mean. *Nature* 189: 732-735.

Taylor, L.R. 1965. A natural law for the spatial disposition of insects. *Proceedings of the XIIth International Congress of Entomology (London 1964)*: 396-397.

Taylor, L.R. 1971. Aggregation as a species characteristic. In: Patil, G.P., Pielou, E.C. & Waters, W.E. (Eds). *Spatial Patterns and Statistical Distributions. Vol. I. Statistical Ecology*. 357-377. Pennsylvania State University Press, University Park.

Walton, V.M. 2003. *Development of an Integrated Pest Management System for Vine Mealybug,* Planococcus ficus *(Signoret), in Vineyards in the Western Cape Province, South Africa*. PhD Dissertation, University of Stellenbosch.

CHAPTER 5

INFLUENCE OF COVER CROP PLANTS ON THE BIOLOGICAL CONTROL OF *TETRANYCHUS URTICAE* KOCH (ACARI: TETRANYCHIDAE) BY ITS PREDATORS IN VINEYARDS

5.1. Introduction

Natural enemies can be increased through environmental manipulation (Pedigo 1999). Attempts have been made to enhance the persistence of natural enemies by making their requirements, like alternate food sources, nesting habitats and overwintering sites, more available (Pedigo 1999). In Californian apple orchards, maintaining a cover crop, periodically mowing it and leaving the mulch, resulted in lower infestations of aphids, leafhoppers and codling moth, as well as an increase in surface-dwelling arthropod predators (Pedigo 1999). This was because maintaining a cover crop and related practices, such as mowing, interfered with the ability of the pests to find their hosts and provided alternate food sources and habitats for natural enemies (Pedigo 1999). In cotton plantings in Georgia, USA, predator numbers were higher and insecticide use lower where cover crop plants were grown as apposed to an absence of these plants (Tillman *et al*. 2002). Pesticide use was also decreased in almond orchards in California, USA, with the use of various grower practices, including management of cover crop plants between rows of trees to provide a continuous habitat for natural enemies (Hendricks 1995). The latter was obtained by mowing half of the strips at a time and planting mixed wild plants along the orchard borders (Hendricks 1995). Lucerne, planted between the rows of apple trees in China, increased the number of natural enemies and decreased the number of *Panonychus ulmi*, a phytophagous mite (Du & Yan 1994).

Cover crop plants on the vineyard floor may enhance biological control of *Tetranychus urticae* by predatory mites. *Tetranychus urticae* host plants may be of particular importance in this regard in that they provide a source of prey for the predatory mites during the winter when there is no foliage on the vines. The

management and diversification of cover crop plants in apple orchards in Elgin (Western Cape Province, South Africa), as well as orchard margin manipulation, contributed to the conservation of beneficial insects and mites (Nel & Addison 1993). In pear orchards in Oregon, USA, herbicide treatment of cover crop plants significantly increased the dispersal of *T. urticae* into orchard trees (Flexner *et al*. 1991). A variety of mite species have been found on weeds in citrus orchards in Spain (Aucejo *et al*. 2003). Although a relationship between the phytoseiid and tetranychid mite densities could not be established, it was argued that the weeds colonized mainly by *Tetranychus evansi* could serve as a reservoir for phytoseiids that preyed on *T. urticae* infesting the citrus trees (Aucejo *et al*. 2003). It is therefore important to identify the cover crop plants on the vineyard floor and those plants that harbour both phytophagous and predatory mites. This study was undertaken to identify plants in the cover crop that may be of importance for biological control of *T. urticae* in vineyards in the Hex River Valley in the Western Cape Province of South Africa.

5.2. Material and methods

5.2.1. Experimental design and study sites

In each of the rows in which the sample plots were situated (see Chapter 2, section 2.1), one leaf of each of the cover crop plant species was taken on a monthly basis and placed into brown paper bags. These were transported, in a cool bag, to the laboratory and microscopically examined. All the developmental stages of mites and their predators were recorded on every plant species. Only plants on which all stages of *T. urticae* were found were considered possible host plants. The host plants were divided into four categories, namely those that hosted high numbers (more than 250 mites recorded on the plants per season), moderate numbers (between 90 and 250 mites recorded per season), low numbers (between 30 and 90 mites recorded per season) and insignificantly low numbers (less than 30 mites recorded per season). The plants that harboured predatory mites were divided into two categories, namely those that harboured high numbers (more than 45 mites and/or eggs recorded per

season) and those that harboured low numbers (less than 45 mites and/or eggs recorded per season).

The total number of plant species which hosted *T. urticae* during the study was determined. The number of *T. urticae* host plants present during a particular month was divided by the total number of *T. urticae* host plants recorded during the study to estimate the proportion of *T. urticae* host plants present during a particular month. In addition, the proportion of host plants that harboured *T. urticae* was calculated as the number of host plants on which *T. urticae* was present during a specific month divided by the number of potential host plants available during that month. These proportions were multiplied by 100 to convert them to percentages. This was also done for the predatory mites.

The abundance and distribution of the plants were determined using a co-ordinate sampling system (Heunis 1992). A stick, 2.51 m long, with ten evenly spaced nails (Figure 5.1A) was placed at the bases of one of the five vines per plot (randomly chosen), at a right angle to the row direction (Figure 5.1B). The plant or habitat first touched by a nail was noted. Besides the plants, four habitats or categories were defined, namely bare ground, dead weeds, litter (plant material originating from the vines) and straw mulch. This was done at monthly intervals.

The cover crop plants were identified with the help of P.J. Pieterse (personal communication[*]), Grabandt (1985), Bromilow (1995) and Botha (2001). A few plant species were also sent to the Compton Herbarium at Kirstenbosch (Western Cape Province, South Africa) for identification.

---

[*] Department of Agronomy, Faculty of AgriSciences, University of Stellenbosch, Private Bag X1, 7602 Matieland

A

B

Figure 5.1. (A) The stick with ten evenly spaced nails that were used to determine the abundance and distribution of the cover crop plants and (B) the placement of the stick at the basis of a vine and subsequent documentation of the plants at each nail.

5.2.2. Statistical analysis

Four periods of the year, each consisting of three months (Heunis 1992), were defined. However, these periods differed from those defined by Heunis (1992). In the present study the periods were defined according to the fruit season, with the first period starting with the three winter months just after the end of the fruit season, namely May to July (period A), followed by August to October (period B), November to January (period C) and February to April (period D), which was the last three months of the fruit season. Simple correspondence analysis (Greenacre 1984) was used to analyse the data. The data were arranged in a two-way table of periods (columns) and weeds (rows). The farms (Klipheuwel, Boplaas and De Vlei Boerdery), cultivars (Barlinka and Dauphine) and seasons (2002/2003, 2003/2004 and 2004/2005 seasons) were entered as supplementary column variables. The percentage cover of the vineyard floor for each cover crop plant species included in the analysis was determined. This was calculated as the number of nails that touched the plant divided by the total number of nails that were put down, multiplied by 100. Percentages were used in the analysis because the number of samples was not the same for each period. All percentages were rounded up, since only whole numbers could be used in the correspondence analysis. Only plants that were considered as host plants for *T. urticae* or that harboured predatory mites were included in the analysis. Some of the plants that hosted *T. urticae* or had predatory mites present were not included because the number of mites that was found on these plants was very low or because the plants were not detected using the co-ordinate sampling system.

5.3. Results

Various cover crop plants were found in the vineyards (Table 5.1). Due to difficulty of identifying some of these in the field, especially in the absence of flowers, some were only identified to genus level. In addition *Coronopus didymus* and *Cotula australis* were listed together, as they could not be separated in the field during the rosette stage (Botha 2001). *Triticum aestivum* and an *Avena* species were also listed together, since they could not be seperated during the pre-flowering stages.

Most of the plants were detected using the co-ordinate sampling system (Table 5.1). However, not all of these plants were of importance to phytophagous and predatory mites. The phytophagous mites that were found on the cover crop plants were mostly *T. urticae*, with the exception of a few tetranychid mites that could not be identified due to a lack of males. The predatory mites were *Euseius addoensis*, *Neoseiulus californicus*, *Tydeus grabouwi* and an undescribed phytoseiid in the genus *Typhlodromus*. Of these mites, *E. addoensis* was the most abundant and made up almost 70% of the predatory mite complex (Table 5.2). This was also the most abundant predatory mite on the vine leaves (see Chapter 3, section 3.3.2).

The plants that hosted *T. urticae* and on which predatory mites (*T. grabouwi* excluded) were found are given in Table 5.3. Plants on which *T. grabouwi* were found, but none of the other predatory mites (or *T. urticae*), were not included in this table, as *T. grabouwi* is not an important predator (see Chapter 3, section 3.3.2).

Plants that hosted *T. urticae* throughout the year and in high numbers were *Medicago polymorpha* (Fabaceae), *Lamium amplexicaule* (Lamiaceae) and *Malva parviflora* (Malvaceae) (Table 5.3). The latter hosted the highest mite numbers (not shown in the table, but observed during the study). Predatory mites were present on *M. parviflora* (Malvaceae) and *Raphanus raphanistrum* (Brassicaceae) throughout the year (Table 5.3). These were also the only two plants on which predatory mites were found in high numbers (Table 5.3). Therefore, they were considered to be the most important host plants for predatory mites.

Table 5.1. Cover crop plants identified in vineyards in the Hex River Valley from May 2002 until the end of April 2005. Those that were recorded using the co-ordinate sampling system are indicated by an asterisk (*).

Cover crop plants identified in vineyards	
MONOCOTYLEDONAE	
Family: Commelinaceae	
Commelina benghalensis L.	*
Family: Cyperaceae	
Cyperus esculentus L.	*
Family: Poaceae	
Bromus L. spp. (*B. pectinatus* Thunb., *B. catharticus* Vahl., *B. diandrus* Roth.)	*
Chloris virgata Swartz.	*
Digitaria sanquinalis (L.) Scop.	*
Ehrharta longiflora Sm.	*
Eleusine coracana (L.) Gaertn. subsp. *africana* (K.-O'Byrne) Hilu & De Wet.	*
Eragrostis Wolf spp. (including *E. aspera* (Jacq.) Nees)	*
Hordeum murinum L.	*
Lolium L. spp.	*
Poa annua L.	*
Setaria Beauv. spp. (including *S. verticillata* (L.) Beauv. and *S. pallide-fusca* (Schumach.) Stapf & C.E. Hubb.)	*
Triticum aestivum L. and *Avena* L. sp.	*
Vulpia myuros (L.) C.C.Gmel.	
DICOTYLEDONAE	
Family: Aizoaceae	
Tetragonia echinata Aiton.	*
Family: Amaranthaceae	
Amaranthus L. spp. (including *A. hybridus* L. subsp. *hybridus* var. hybridus)	*
Family: Asteraceae	
Arctotheca calendula (L.) Levyns.	*
Bidens bipinnata L.	*
Bidens pilosa L.	*
Conyza Less. spp. (including *C. bonariensis* (L.) Cronq.)	*
Galingsoga parviflora Cav.	*
Hypochoeris radicata L.	*
Lactuca serriola L.	*
Picris echioides L.	*
Pseudognaphalium luteo-album (L.) Hilliard & Burtt.	*
Schkuhria pinnata (Lam.) Cabr.	
Senecio L. spp. (including *S. consanquineus* DC., *S. glutinosus* Thunb. and *S. pinnatifidus* (P.J.Bergius) Less.)	*

Table 5.1. Continued

Cover crop plants identified in vineyards	
Sonchus L. spp. (*S. asper* (L.) Hill subsp. *asper* and *S. oleraceus* L.)	*
Tagetes minuta L.	*
Taraxacum officinale Weber. Sens lat	*
Verbesina encelioides (Cav.) Benth. & Hook.	
Family: Boraginaceae	
Amsinckia menziesii (Lehm.) Nels. & Macbride	*
Family: Brassicaceae	
Capsella bursa-pastoris (L.) Medik.	*
Coronopus didymus (L.) Sm. and *Cotula australis* (Spreng.) Hook. F.**	*
Lepidium africanum (Burm.f.) DC. subsp. *africanum*	
Lepidium bonariense L.	
Raphanus raphanistrum L.	*
Sisymbrium capense Thunb.	
Family: Caryophyllaceae	
Spergula arvensis L.	
Stellaria media (L.) Vill.	*
Family: Chenopodiaceae	
Chenopodium album L.	*
Family: Convolvulaceae	
Convolvulus arvensis L.	*
Ipomoea purpurea (L.) Roth.	
Family: Cucurbitaceae	
Citrullus lanatus (Thunb.) Matsum. & Nakai.	
Family: Euphorbiaceae	
Chamaesyce inaequilatera (Sond.) Soják	*
*Chamaesyce prostrata (*Aiton) Small	*
Family: Fabaceae	
Medicago polymorpha L.	*
Melilotus indica (L.) All.	*
Trifolium repens L. var repens	*
Vicia L. spp. (including *V. hirsuta* (L.) S. F. Gray and *V. benghalensis* L.)	*
Family: Fumariaceae	
Fumaria muralis Sond. Ex Koch. subsp. *muralis*	*
Family: Geraniaceae	
Erodium moschatum (L.) L'Hérit.	*
Geranium molle L.	*
Pelargonium L'Herit sp.	
Family: Lamiaceae	
Lamium amplexicaule L.	*

** *Cotula australis* belongs to the family Asteraceae

Table 5.1. Continued

Cover crop plants identified in vineyards	
Family: Malvaceae	
Hibiscus trionum L.	
Malva parviflora L.	*
Family: Onagraceae	
Oenothera parodiana Munz	*
Family: Oxalidaceae	
Oxalis L. spp. (including *O. pes-caprae* L. var. pes-caprae (most abundant) and *O. latifolia* Humb., Bonpl. & Kunth)	*
Family: Plantaginaceae	
Plantago lanceolata L.	
Family: Polygonaceae	
Emex australis Steinh.	*
Polygonum aviculare L.	*
Family: Portulacaceae	
Portulaca oleracea L.	*
Family: Primulaceae	
Anagallis arvensis L.	
Family: Scrophulariaceae	
Veronica persica Poir.	*
Family: Solanaceae	
Datura L. sp. (*Datura ferox* L. or *Datura stramonium* L.)	
Solanum nigrum L.	*
Family: Urticaceae	
Urtica urens L.	
Family: Zygophyllaceae	
Tribulus terrestris L.	*

Table 5.2. Predatory mites found on cover crop plants in vineyards in the Hex River Valley from May 2002 until the end of April 2005.

Predatory mite	Percentage
Euseius addoensis	69.67
Neoseiulus californicus	8.21
Typhlodromus species	2.85
Tydeus grabouwi	19.27

A total of 89.2% of the inertia was explained by the first and second dimensions (Figure 5.2) in the correspondence analysis. The four periods of the year were in different quadrants (Figure 5.2), indicating that different plants dominated during the different periods. *Amaranthus* spp. (Amaranthaceae), *Bidens bipinnata*, *Bidens pilosa*, *Galingsoga parviflora*, *Lactuca serriola*, *Senecio* spp. and *Sonchus* spp. (Asteraceae), *Chenopodium album* (Chenopodiaceae), *Cyperus esculentus* (Cyperaceae), *M. polymorpha*, *Trifolium repens* and *Vicia* spp. (Fabaceae), *Geranium molle* (Geraniaceae), *M. parviflora* (Malvaceae), *Lolium* spp. (Poaceae), *Veronica persica* (Scrophulariaceae), *Solanum nigrum* (Solanaceae) and *Tribulus terrestris* (Zygophyllaceae) were close to the origin, indicating that these plants were present during all four periods of the year (Figure 5.2). However, not all of these plants were present during every month of the year. *Bidens bipinnata* was absent during September, *C. esculentus* and *T. terrestris* during June to August, *G. parviflora* during July and August and *Lolium* spp. during January (Table 5.3). Most of these plants hosted moderate to high numbers of *T. urticae* and, with the exception of *B. bipinnata*, *C. esculentus*, *Lolium* spp., *V. persica* and *Vicia* spp., during all four periods of the year (Table 5.3). All these plants hosted predatory mites during period D (February to April) with the exception of *C. esculentus*, *Lolium* spp. and *Vicia* spp. (Table 5.3). This was also the time of the year when predatory mite populations peaked on the vine leaves (see Chapter 3, section 3.3.2).

The plants that dominated during the four periods of the year, identified in the correspondence analysis (Figure 5.2) and that hosted *T. urticae* and predatory mites during these periods, are given in Table 5.4. Most of these plants hosted moderate to high numbers of *T. urticae* (Table 5.3). The only exceptions were *Oxalis* spp. (Oxalidaceae), which hosted insignificantly low numbers of *T. urticae*, and *Stellaria media* (Caryophyllaceae) and *Picris echioides* (Asteraceae), which hosted low numbers of *T. urticae* (Table 5.3).

Table 5.3. Cover crop plants in vineyards in the Hex River Valley that hosted *Tetranychus urticae* (a = high numbers; b = moderate numbers; c = low numbers; d = insignificantly low numbers) and on which predatory mites and/or eggs were found (e = high numbers) from May 2002 until the end of April 2005. (-----) Cover crop plants present; (— —) *T. urticae* present; (--x--) Predatory mites present.

Cover crop plants	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Commelinaceae												
Commelina benghalensis[a]	--x-- — — -----	— — -----		-----	— — -----	— — -----	--x-- — — -----	— — -----	--x-- — — -----	--x-- — — -----	--x-- — — -----	--x-- — — -----
Cyperaceae												
Cyperus esculentus[c]	-----				-----	-----	— — -----	— — -----	— — -----	— — -----	-----	-----
Poaceae												
Bromus spp.[d]	-----	--x-- -----	-----	-----	-----	— — -----	— — -----	— — -----	— — -----	-----	-----	--x-- -----
Digitaria sanquinalis[a]	-----	-----	-----	-----	-----	— — -----	--x-- — — -----	— — -----	--x-- — — -----	--x-- — — -----	--x-- — — -----	— — -----
Eleusine coracana[b]	--x-- -----	--x-- -----	-----			— — -----	— — -----	--x-- — — -----	--x-- — — -----	— — -----	--x-- — — -----	--x-- — — -----
Eragrostis spp.[d]	-----	— — -----		-----	-----	-----	— — -----	— — -----	— — -----	— — -----	— — -----	-----
Lolium spp.[d]	-----	--x-- -----	-----	— — -----	-----	— — -----	— — -----	— — -----		-----	-----	— — -----
Setaria spp.	-----	--x-- -----						-----	-----	-----	--x-- -----	-----
Triticum & Avena spp.	--x-- -----	--x-- -----	-----	-----	-----	-----	-----	-----	-----		-----	-----
Aizoaceae												
Tetragonia echinata	-----	-----	-----	-----	-----	-----			--x-- -----	-----	-----	-----
Amaranthaceae												
Amaranthus spp.[b]	-----	— — -----	-----	-----	-----	— — -----	--x-- — — -----	— — -----	--x-- — — -----	— — -----	--x-- — — -----	--x-- -----
Asteraceae												
Arcthotheca calendula[d]	--x-- -----	--x-- — — -----	--x-- — — -----	--x-- -----	— — -----	— — -----	— — -----	— — -----	-----	-----	— — -----	-----
Bidens bipinnata[a]	-----	-----	— — -----	-----		-----	— — -----	— — -----	— — -----	--x-- — — -----	— — -----	— — -----
Bidens pilosa[b]	— — -----	--x-- — — -----	— — -----	-----	-----	— — -----	— — -----	— — -----	--x-- — — -----	--x-- — — -----	--x-- — — -----	-----
Conyza spp.[a]	--x-- — — -----	--x-- — — -----	-----	— — -----	-----	— — -----	— — -----	--x-- — — -----	— — -----	--x-- — — -----	--x-- — — -----	--x-- — — -----
Galingsoga parviflora[b]	--x-- — — -----	-----			-----	— — -----	— — -----	— — -----	— — -----	--x-- — — -----	— — -----	--x-- — — -----
Lactuca serriola[b]	--x-- — — -----	--x-- — — -----	--x-- -----	— — -----	-----	— — -----	— — -----	— — -----	— — -----	-----	--x-- — — -----	--x-- — — -----
Picris echioides[c]	-----	-----		--x-- -----		— — -----	-----	— — -----	-----	--x-- -----	-----	-----
Pseudognaphalium lutuo-album[d]	— — -----	--x-- -----	-----	-----	-----	— — -----	— — -----	-----	— — -----		-----	-----

Table 5.3. Continued

Cover crop plants	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Schkuhria pinnata[d]	——								——			
Senecio spp.[b]	--x-- ——	--x-- ——	--x-- ——	--x--	--x--	——	——		——	——	--x-- ——	--x-- ——
Sonchus spp.[a]	--x-- ——	--x-- ——	--x-- ——	--x--	——	——	——	--x-- ——	--x-- ——	——	--x-- ——	--x-- ——
Tagetes minuta[d]		--x--					——	——	--x-- ——	——		--x--
Taraxacum officinale[d]		--x--				——	——	——	——	——		
Brassicaceae												
Coronopus didymus/ Cotula australis[d] *	——		——								——	
Lepidium bonariense			--x--									
Raphanus raphanistrum[be]	--x--	--x-- ——	--x-- ——	--x--	--x-- ——	--x-- ——	--x-- ——	--x-- ——	--x-- ——	--x-- ——	--x-- ——	--x-- ——
Caryophyllaceae												
Stellaria media[c]		——		——	——	——	——		——	——	——	——
Chenopodiaceae												
Chenopodium album[b]	--x-- ——			——	——	——	——	——	——	--x-- ——	——	--x-- ——
Convolvulaceae												
Convolvulus arvensis[a]						——	——	——	——		——	
Ipomoea purpurea[b]	--x-- ——	--x--					--x-- ——	--x-- ——	--x-- ——	--x-- ——	——	--x-- ——
Cucurbitaceae												
Citrullus lanatus[a]							——		--x--	--x--		
Fabaceae												
Medicago polymorpha[a]	--x-- ——	--x-- ——	——	——	——	——	——	——	--x-- ——	——	--x-- ——	——
Melilotus indica[a]					——	——	——	——	——	——		
Trifolium repens[a]		--x-- ——		——	——	--x-- ——	——	——	--x-- ——	--x-- ——	——	--x-- ——
Vicia spp.[a]		--x--			——	——	——	——	——		——	——
Fumariaceae												
Fumaria muralis	--x--											
Geraniaceae												
Erodium moschatum[b]		--x--	——	--x-- ——		——	——	——	——	——	——	——
Geranium molle[c]	--x--	--x-- ——	--x-- ——	--x-- ——	--x-- ——	——	——	——	——	--x-- ——	--x-- ——	——

* *Cotula australis* belongs to the family Asteraceae

Table 5.3. Continued

Cover crop plants	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Lamiaceae												
Lamium amplexicaule[a]	– –	--x-- – –	--x-- – –	--x-- – –	– –	– –	– –	– –	– –	– –	– –	– –
Malvaceae												
Hibiscus trionum[d]							--x--			--x-- – –	--x-- – –	
Malva parviflora[ae]	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –	--x-- – –
Onagraceae												
Oenothera parodiana[d]	– –			--x-- – –	– –	– –	– –	– –	– –			– –
Oxalidaceae												
Oxalis spp.[d]	--x--	--x-- – –		– –			– –	– –	– –	– –	--x-- – –	
Polygonaceae												
Emex australis[a]	--x--	– –		– –	– –	– –	– –	– –	– –	--x-- – –	– –	--x-- – –
Polygonum aviculare[a]					– –	– –	– –	– –	– –	– –	– –	
Portulacaceae												
Portulaca oleracea[d]								– –	– –			--x--
Scrophulariaceae												
Veronica persica[c]		--x--						– –			--x-- – –	--x-- – –
Solanaceae												
Solanum nigrum[a]	--x-- – –	--x-- – –	--x-- – –	– –	– –	– –	– –	– –	--x-- – –	– –	--x-- – –	--x--
Urticaceae												
Urtica erens						--x--						
Zygophyllaceae												
Tribulus terrestris[a]	– –					– –	– –	– –	– –	--x-- – –	--x-- – –	--x-- – –

Citrullus lanatus (Curcurbitaceae) also hosted high numbers of *T. urticae* (Table 5.3), but this plant was only found from November 2004 to March 2005 and was not very abundant. Another plant that hosted moderate numbers of *T. urticae* was *Ipomoea purpurea* (Convulvulaceae) (Table 5.3).

The 2002/2003 (S1) and 2003/2004 (S2) seasons coincided with each other in the correspondence analysis and they were closely associated with the 2004/2005 season (S3) (Figure 5.2), indicating that, in terms of cover crop plant occurrence, there was not much difference between the three seasons.

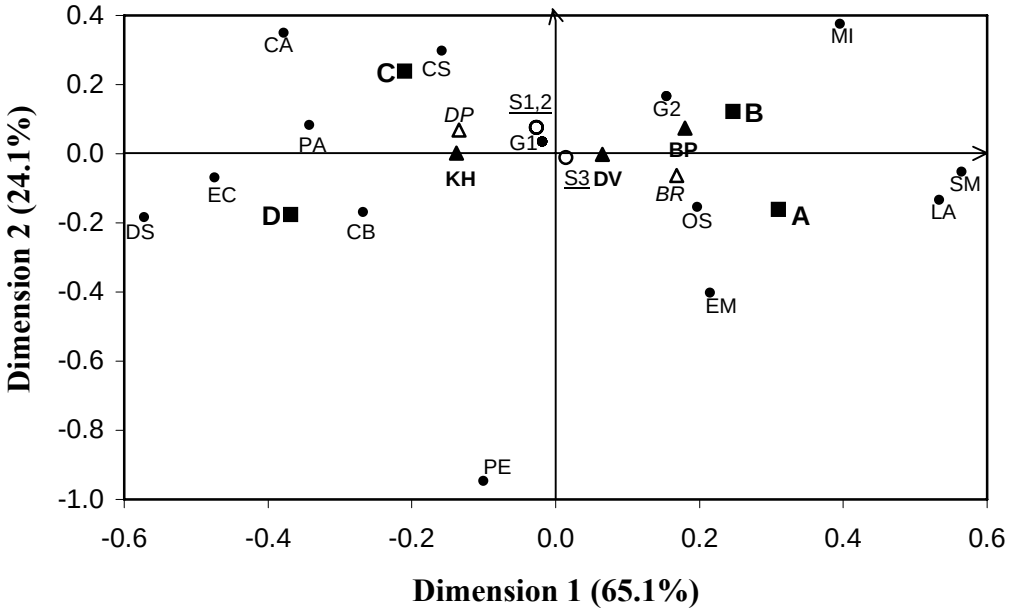


Figure 5.2. Correspondence analysis of the four periods of the year (■) and the cover crop plants which hosted *Tetranychus urticae* and on which predatory mites were present (●), with the cultivars (∆), farms (▲) and seasons (○) as supplementary column variables. Period: A = May to July; B = August to October; C = November to January; D = February to April. Cultivar: BR = Barlinka; DP = Dauphine. Farm: BP = Boplaas; DV = De Vlei Boerdery; KH = Klipheuwel. Seasons: S1 = 2002/2003; S2 = 2003/2004; S3 = 2004/2005. Cover crop plants: CA = *Convolvulus arvensis*; CB = *Commelina benghalensis*; CS = *Conyza* spp.; DS = *Digitaria sanquinalis*; EC = *Eleusine coracana*; EM = *Erodium moschatum*; G1 = group 1, consisting of the following plants that coincided with each other in the correspondence analysis: *Amaranthus* spp., *Bidens bipinnata*, *Bidens pilosa*, *Chenopodium album*, *Cyperus esculentus*, *Galingsoga parviflora*, *Geranium molle*, *Lactuca serriola*, *Lolium* spp., *Malva parviflora*, *Medicago polymorpha*, *Senecio* spp., *Solanum nigrum*, *Sonchus* spp., *Tribulus terrestris*, *Trifolium repens*, *Veronica persica* and *Vicia* spp.; G2 = group 2, consisting of *Emex australis* and *Raphanus raphanistrum*, which coincided with each other in the correspondence analysis; LA = *Lamium amplexicaule*; MI = *Melilotus indica*; OS = *Oxalis* spp.; SM = *Stellaria media*; PA = *Polygonum aviculare*; PE = *Picris echioides*.

Table 5.4. Cover crop plants that were dominant and hosted *Tetranychus urticae* and predatory mites during different times of the year in vineyards in the Hex River Valley. A = May to July; B = August to October; C = November to January; D = February to April.

Period	Dominant plants	Months during which mites were present	
		Tetranychus urticae	**Predatory mites**
A	*Erodium moschatum*	July	June
	Lamium amplexicaule	May to July	June, July
	Oxalis spp.	June	May, June
	Stellaria media	June	-
B	*Emex australis*	August to October	-
	Melilotus indica	September, October	-
	Raphanis raphanistrum	September, October	August to October
C	*Convolvulus arvensis*	November to January	-
	Conyza spp.	November to January	December
	Polygonum aviculare	November to January	-
D	*Commelina benghalensis*	February to April	February to April
	Digitaria sanquinalis	February to April	February, March
	Eleusine coracana	February to April	March, April
	Picris echioides	-	February

There was a difference in the cover crop flora between the Barlinka and Dauphine vineyards. The plants to the right of the origin dominated in the Barlinka vineyards and those to the left of the origin dominated in the Dauphine vineyards (Figure 5.2). The reasons for this are not known.

Klipheuwel was to the left of the origin and Boplaas and De Vlei Boerdery to the right (Figure 5.2), suggesting that the cover crop plants to the left of the origin dominated at Klipheuwel and those to the right dominated at Boplaas and De Vlei Boerdery. In terms of geographic position, Klipheuwel was more towards the western side of the Hex River Valley than Boplaas and De Vlei Boerdery (see Chapter 2, section 2.1), suggesting that the western side of the valley had a different cover crop flora from the eastern side.

Tetranychus urticae hosts were abundant throughout the year. Their numbers were especially high during October to May, when between 90% and 100% of the hosts were present (Figure 5.3). Plants on which predatory mites were found were also abundant throughout the year. This varied from 90% to 100% during November to June (Figure 5.3).

Although *T. urticae* host plants were found throughout the year, not all of them harboured *T. urticae* throughout the year (Table 5.3). This was also the case for the predatory mites (Table 5.3).

The percentage of *T. urticae* host plants that was colonised by *T. urticae* was highest during October to March (Figure 5.3), which was also the period during which *T. urticae* was active on the vine leaves (see Chapter 3, section 3.3.2). The percentage of plants that harboured predatory mites increased from October to June (Figure 5.3). Predatory mites increased on vine leaves from October to May, where after no leaf samples were taken (see Chapter 3, section 3.3.2).

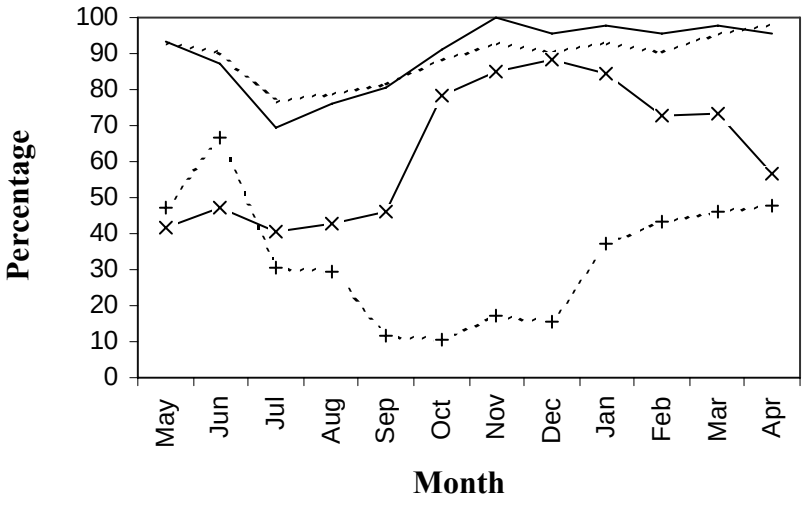


Figure 5.3. Percentage of *Tetranychus urticae* (——) and predatory mite (-----) host plants present during every month of the year, as well as the percentage of available host plants on which *T. urticae* (—x—) and predatory mites (--+--) were found (see section 5.2.1 for explanation)

5.4. Discussion

A wide variety of plant species was found on the vineyard floor and the co-ordinate sampling system was effective in detecting most of these plants. Many of these cover crop plants served as hosts for *T. urticae*. Cover crop plants in the families Commelinaceae, Poaceae, Amaranthaceae, Asteraceae, Brassicaceae, Chenopodiaceae, Convolvulaceae, Cucurbitaceae, Fabaceae, Geraniaceae, Lamiaceae, Malvaceae, Polygonaceae, Solanaceae and Zygophyllaceae hosted moderate to high numbers of *T. urticae*. Most of the host plants that dominated during different periods of the year also hosted moderate to high numbers of *T. urticae*. This resulted in the presence of *T. urticae* in the cover crop throughout the year, thereby providing a source of prey for the predatory mites, although the latter were not dependent on *T. urticae* for their survival (see Chapter 3, section 3.4).

Although *T. urticae* host plants were present throughout the year, their frequency of occurrence was particularly high from October to May. Colonisation of host plants by *T. urticae* was highest during the period that *T. urticae* was active on the vine leaves (October to March). *Tetranychus urticae* seasonal activity on cover crop plants was therefore similar to that on the vine leaves. The same was true for the predatory mites. This was also observed in apple orchards in South Africa by Pringle (1995), who recorded *T. urticae* and it's predator *Phytoseiulus persimilis* on the cover crop mostly from January to April, which was the time during which these mites were found in high numbers in the apple trees. The most important cover crop host plants for the predatory mites were *M. parviflora* (Malvaceae) and *R. raphanistrum* (Brassicaceae). These were the only plants on which they were frequently recorded and on which they were recorded throughout the year.

In this study plants that may be of importance in this biological control system were identified. The information gained here should be used as a basis for further research to determine whether or not the presence of these plants do in fact influence the presence of phytophagous and predatory mites in the vines. In apple orchards, trees near the *T. urticae* host plant *Solanum nigrum* were the first to be infested with this mite (Heunis 1992). It was also argued that suitable *T. urticae* host plants in the cover crop could influence mite infestation patterns in pear orchards (Flexner *et al*. 1991).

Only after the actual effects of the presence of these plants in the cover crop on the presence of mites in the vine is determined, can a proper cover crop management plan be proposed.

5.5. References

Aucejo, S., Foo, M., Gimeno, E., Gomez-Cadenas, A., Monfort, R., Obiol, F., Prades, E., Ramis, M., Ripolles, J.L., Tirado, V., Zaragoza, L., Jacas, J.A. & Martinez-Ferrer, M.T. 2003. Management of *Tetranychus urticae* in citrus in Spain: acarofauna associated to weeds. *Bulletin OILB/SROP* 26(6): 213-220.

Botha, C. 2001. *Common Weeds of Crops and Gardens in Southern Africa*. ARC – Grain Crops Institute, Potchefstroom.

Bromilow, C. 1995. *Problem Plants of South Africa*. Briza Publications cc, Arcadia.

Du, X.G. & Yan, Y.H. 1994. Effect of cover crops on the pest mite *Panonychus ulmi* and its predator *Orius sauteri*. *Chinese Journal of Biological Control* 10: 114-117.

Flexner, J.L., Westigard, P.H., Gonzalves, P. & Hilton, R. 1991. The effect of groundcover and herbicide treatment on twospotted spider mite density and dispersal in southern Oregon pear orchards. *Entomologia Experimentalis et Applicata* 60: 111-123.

Grabandt, K. 1985. *Weeds of Crops and Gardens in Southern Africa*. Seal Publishing (Pty) Limited, Johannesburg.

Greenacre, M.J. 1984. *Theory and Applications of Correspondence Analysis*. Academic Press, London.

Hendricks, L.C. 1995. Almond growers reduce pesticide use in Merced County field trials. *California Agriculture* 49(1): 5-10.

Heunis, J. M. 1992. *The Influence of Synthetic Pyrethroids on Phytophagous Mites and their Natural Enemies in Apple Orchards*. MSc Thesis, University of Stellenbosch.

Nel, P.J. & Addison, M.F. 1993. The development of an integrated pest management programme in apple orchards in Elgin, South Africa and the implications for integrated fruit production. *Acta Horticulturae* 347: 323-326.

Pedigo, L.P. 1999. *Entomology and Pest Management. Third Edition.* Prentice-Hall, Inc., New Jersey.

Pringle, K.L. 1995. The role of the cover crop in biological control of mites using *Phytoseiulus persimilis* in apple orchards in South Africa. *European Journal of Plant Pathology. XIII International Plant Protection Congress, The Hague, The Netherlands, 2-7 July, 1995, Abstracts*: 859.

Tillman, G., Schomberg, H., Phatak, S., Timper, P. & Olson, D. 2002. Enhancing sustainability in cotton with reduced chemical inputs, cover crops, and conservation tillage. In: Van Santen, E. (Ed.) *Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proceedings of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, 24-26 June, 2002*. 366-368. Alabama Agricultural Experiment Station & Auburn University, Alabama.

CHAPTER 6

THE SPATIAL DISTRIBUTION OF TABLE GRAPE PESTS AND IMPORTANT PREDATORS IN THE HEX RIVER VALLEY (WESTERN CAPE PROVINCE, SOUTH AFRICA)

6.1 Introduction

The pattern or arrangement of insects in space is referred to as their dispersion. This provides information about population dynamics, which may influence the way sampling in a certain area will be conducted (Pedigo 1999). The most common dispersion pattern of insects is either random, where the insect's chance of being present in one place is as good as being present in another place, or clustered, where if one insect of a certain species is found, the chances are good that more will be found in the vicinity (Pedigo 1999). Clustering may be caused by behavioural factors, like mating and feeding, or environmental factors, like a heterogeneous habitat, or both (Pedigo 1999).

Information on spatial association between two insect species or between different types of damage may be of value in pest management, since the presence of one species or damage type maybe correlated with the presence of another. *Epichoristodes acerbella*, for example, physically damages the berries, which attracts drosophilid flies. Therefore, if bunch infestation of these two insects is spatially associated, drosophilid fly bunch infestation could give an indication of the presence of *E. acerbella*, a phytosanitary pest, in the bunches. Such an association would facilitate sampling for *E. acerbella*, which is more difficult to detect than drosophilid flies. In the case of a positive association, sampling could concentrate on areas in which drosophilid flies are present. If *Planococcus ficus* bunch and stem infestation are spatially associated, stem infestation, which precedes bunch infestation (see Chapter 3, section 3.3.3), can give an indication of where the latter could be expected. Similarly, if halo spot damage, caused by *Frankliniella occidentalis*, and thrips presence on the vine leaves are spatially associated, the latter could be used as a

warning system for halo spot bunch damage. The presence of *Phlyctinus callosus* under cardboard bands (see Chapter 2, section 2.2.2) may provide an indication of where damage could be expected by this pest. This will only be the case if there is a positive spatial association between weevil counts under the bands and weevil damage.

In biological control an understanding of spatial association between the pest and its predator is important. There was a positive association between *Tetranychus urticae* and *Neoseiulus californicus* on soybean leaves in Italy (Castagnoli *et al*. 1993). These two species were also positively spatially associated on strawberry leaves in Spain (Garcia Mari *et al*. 1991). Information on the spatial association between *T. urticae* and predatory mites on vine leaves will provide insight on the spatial interaction in this important biological control system. Cover crop plants may influence biological control of *T. urticae* by the predatory mites (see Chapter 5). Information on the spatial association between *T. urticae* (and predatory mites) and the distribution of important cover crop plants would therefore also be valuable, as this will show whether or not the presence of certain cover crop plants may influence the presence of these mites in the vine itself.

This study was performed to determine the spatial distribution patterns of table grape pests, important predators and selected cover crop plants in vineyards in the Hex River Valley in the Western Cape Province of South Africa. The spatial distribution patterns of insects are well documented. However, when searching the databases Inspec (1969 to 2005), CAB-Abstracts (1990 to 2005) and Web of Science (1987 to 2005), no published information on the spatial distribution patterns of the above-mentioned pests in vineyards, either in terms of their presence or the damage they cause, or the spatial association between the above-mentioned damage types, pest species and pest and natural enemies in vineyards was obtained. The findings in this study will therefore not be compared to the findings by other authors. Instead, only the findings of the present study will be discussed in terms of their importance in pest management.

6.2. Material and methods

6.2.1. Experimental design and study sites

See Chapter 2, sections 2.1, 2.2 and 2.3.

6.2.2. Statistical analysis

The computer programme SADIE (Spatial Analysis by Distance IndicEs) (Perry 1995) was used to spatially analyze the data. The overall index of aggregation, I_a, was determined. When I_a is near to unity, the observed counts have a spatially random arrangement (Perry 1996, 1998a; Perry *et al*. 1999; Maestre & Cortina 2002). Values larger than unity indicate an aggregated arrangement and values smaller than unity a regular arrangement (Perry 1995, 1996, 1998a, 1998b; Maestre & Cortina 2002). The test statistic, P_a, can be used to test for deviations from random dispersions (Perry 1998a). A two-tailed test at the 5% level was used, with $P_a > 0.975$ indicating a regular dispersion, $P_a < 0.025$ indicating spatial aggregation and $0.025 < P_a < 0.975$ indicating randomness (Perry 1998a).

Another index given by SADIE is v, a dimensionless index of clustering. This index was used to measure the degree of clustering of the data into areas with above-average density, or patches, or into areas with below-average density, or gaps (Holland *et al*. 1999b; Perry *et al*. 1999; Maestre & Cortina 2002). The index is ascribed to each sample unit, with a subscript i, when it forms part of a patch, and j, when it forms part of a gap (Holland *et al*. 1999b; Perry & Dixon 2002). A patch is indicated by large positive values for v_i (larger than 1.5) and a gap by large negative values for v_j (smaller than –1.5) (Perry *et al*. 1999; Winder *et al*. 2001; Maestre & Cortina 2002). Values of v_i equal to 1 and v_j equal to –1, indicate randomness (Winder *et al*. 2001; Perry & Dixon 2002). To test for non-randomness, the mean value of the clustering indices, $\overline{v_i}$ and $\overline{v_j}$, can be used. The value of $\overline{v_i}$ was compared with its expectation of 1 for randomness and $\overline{v_j}$ with its expectation of –1 for randomness (Holland *et al*. 2001; Perry & Dixon 2002), using a one-tailed test at the 5% level. This index can be

more powerful for detecting non-randomness than the overall index, I_a, especially for data with edge effects (Perry *et al*. 1999).

The index X was used to measure overall spatial association (Winder *et al*. 2001; Perry & Dixon 2002; Perry *et al*. 2002) between two pest species, between pest and predator species, between different types of damage caused by the same species and between the distribution of cover crop plants and mites on the vine leaves (see section 6.2.3 for pests and predators included in the analysis). This index is the mean of individual local associations, χ_k, first calculated by SADIE by comparing cluster indices at every sampling unit (Winder *et al*. 2001; Perry & Dixon 2002; Perry *et al*. 2002). The significance of X is determined through randomizations, with values of the cluster indices reassigned amongst the sample units, after allowance for small-scale spatial autocorrelation in the cluster indices of either population (Winder *et al*. 2001). Large values of local association are indicated by the coincidence of a patch cluster for one set, say a pest species, with a patch cluster for the other set, say a predator species, or by the coincidence of two gaps. Disassociation (negative association) is indicated by a patch coinciding with a gap (Perry & Dixon 2002). A two-tailed test was used with a null-hypothesis of no association against the alternatives of positive association (from here on just called association) and disassociation (Scott *et al*. 2003). This test was conducted at the 5% level, with the test statistic $P < 0.025$ indicating significant association and $P > 0.975$ indicating significant disassociation.

In cases where significant association or disassociation were detected, the gap, patch and local association indices were mapped, using ArcView and its extension Spatial Analyst (Editors of ESRI Press 1999) to interpolate between data points, using the inverse distance weighted method. In most cases only values of v_i larger than 1.5 (significant patches), values of v_j smaller than –1.5 (significant gaps) (Perry *et al*. 1999) and values of $\chi_k > 0.5$ (significant association) or < -0.5 (significant disassociation) (Veldtman & McGeoch 2004) were used in the maps.

Spatial analysis, using SADIE, requires at least 25, but preferably 36 spatial sampling points or units (Holland *et al*. 1999a). The 12 vineyard blocks could therefore not be

analyzed separately, since each block only contained 20 sampling points. In order for the analysis to make biological sense, it is also important that a certain proportion of the units (about 50% when only 36 sampling units are used and about 30% when a large number of sampling units, for example 100, are used) should have positive or non-zero values (M. McGeoch, personal communication[*]). The combinations of vineyards used for the analysis is given in Table 6.1. Vineyard Nr 3 (De Vlei Boerdery) was removed before the onset of the 2003/2004 season. Since this was the only vineyard adjacent to vineyard Nr 2 (the sampling points need to be in adjacent vineyards), data from the latter could only be used in the spatial analyses during the 2002/2003 season. Vineyard Nr 10 (De Vlei Boerdery) was not adjacent to any other vineyards. Therefore, data from this vineyard were not used in these analyses.

Table 6.1. Combinations of vineyards used for the spatial analyses, using the SADIE (Spatial Analysis by Distance IndicEs) programme. S1 = 2002/2003 season; S2 = 2003/2004 season; S3 = 2004/2005 season; All = combination of all three seasons.

Farm	Vineyard (cultivar)	Number of sampling points	Number of positive counts needed**	Seasons
Boplaas	B5 & B6 (Barlinka)	40	15	S1, S2, S3, All
Boplaas	C6* (Dauphine)	40	15	S1, S2, S3, All
De Vlei Boerdery	Nr 2 & Nr 3 (Barlinka)	40	15	S1
De Vlei Boerdery	Nr 8 & Nr 9 (Dauphine)	40	15	S1, S2, S3, All
Klipheuwel	A04* (Barlinka) & B03* (Dauphine)	80	24	S1, S2, S3, All

*Divided into two equal blocks
**M. McGeoch, personal communication

[*] Department of Conservation Ecology and Entomology, Faculty of AgriSciences, University of Stellenbosch, Private Bag X1, 7602 Matieland.

6.2.3. Pests and predators included in the analysis

Spatial distribution patterns were determined for the presence of *T. urticae*, the predatory mite complex (see Chapter 3, section 3.3.2) and thrips on the vine leaves, *P. ficus* bunch and stem infestation, halo spot bunch damage caused by *F. occidentalis*, *E. acerbella* and vinegar fly bunch infestation and *P. callosus* bunch, leaf and shoot damage, as well as weevil counts under the cardboard bands. Spatial association between *T. urticae* and the predatory mites was investigated, as well as between these mites and the cover crop plant *Malva parviflora*, which was an important cover crop host plant of *T. urticae*, and both *M. parviflora* and *Raphanis raphanistrum*, since these were the two most important host plants of the predatory mites (see Chapter 5, section 5.3). The spatial association between *P. ficus* bunch and stem infestation, between halo spot damage and thrips presence on the leaves, between *E. acerbella* and drosophilid fly bunch infestation, as well as between *P. callosus* counts under the bands and fruit, leaf and shoot damage was also determined.

For all the pests, sampling was conducted during all the seasons (Table 6.1). Spatial analysis was however only performed on data where sufficient positive counts were obtained (see section 6.2.2).

6.3. Results

6.3.1. Phytophagous and predatory mites

Tetranychus urticae had an overall spatially aggregated dispersion pattern in more than half of the cases (Table 6.2). The exceptions were in vineyards B5, B6 (Boplaas), A04 and B03 (Klipheuwel) during the 2003/2004 season and at De Vlei Boerdery. In most cases where overall spatial aggregation was observed, *T. urticae* was clustered into both patches and gaps. At Klipheuwel, during the 2003/2004 season, *T. urticae* was clustered into patches even though overall spatial aggregation was not detected (Table 6.2).

The predatory mite complex on vine leaves consisted of *Euseius addoensis*, *Neoseiulus californicus*, *Tydeus grabouwi* and an undescribed phytoseiid in the genus *Typhlodromus* (see Chapter 3, section 3.3.2). However, *T. grabouwi* was not included in the analysis (see Chapter 3, section 3.3.2). In most cases (64.71%), the predatory mites had an overall spatially aggregated dispersion pattern (Table 6.2). The exceptions were in vineyards B5 and B6 during the 2004/2005 season, vineyard C6 during the 2002/2003 and 2003/2004 seasons, vineyards Nr 2 and Nr 3 (De Vlei Boerdery) during the 2002/2003 season and vineyards Nr 8 and Nr 9 (De Vlei Boerdery) during the 2002/2003 and 2003/2004 seasons. In most cases where overall spatial aggregation was observed, the predatory mites were clustered into both patches and gaps. In vineyards B5 and B6 during the 2004/2005 season, the predatory mites were clustered into gaps even though overall spatial aggregation was not detected. The index of aggregation did however border on significance (Table 6.2).

Tetranychus urticae and the predatory mite complex was spatially disassociated in vineyards B5 and B6 during the 2002/2003 and 2004/2005 seasons as well as when counts for all seasons were combined and in vineyards A04 and B03 in all cases (Table 6.2, Figures 6.1 and 6.2). In vineyards B5 and B6, where there was disassociation, *T. urticae* formed a patch in vineyard B5 and a gap in vineyard B6 (Figure 6.1). For the predatory mites the opposite was true (Figure 6.1). *Tetranychus urticae* formed a patch in vineyard A04 (Barlinka) and a gap in vineyard B03 (Dauphine) (Figure 6.2). The opposite pattern was detected for the predatory mites (Figure 6.2). *Tetranychus urticae* and the predatory mites were spatially associated in vineyards Nr 2 and Nr 3 during the 2002/2003 season (Table 6.2, Figure 6.3). In this case the patch and gap indices were not significant. Positive association was detected in areas where patches (mostly not significant) overlapped, as well as in areas where gaps (also mostly not significant) overlapped (Figure 6.3). In all other cases, no significant association or disassociation was detected.

Table 6.2. Spatial pattern of *Tetranychus urticae* and the predatory mite complex on vine leaves, as well as their spatial association. I_a = index of aggregation (P_a = probability level); $\overline{v_i}$ = cluster index (patch) (P_i = probability level); $\overline{v_j}$ = cluster index (gap) (P_j = probability level); X = index of overall spatial association (P = probability level). Vineyards B5, B6, Nr 2, Nr 3 and A04 = Barlinka; Vineyards C6, Nr 8, Nr 9 and B03 = Dauphine. Farm names are in brackets (BP = Boplaas; DV = De Vlei Boerdery; KH = Klipheuwel). S1 = 2002/2003 season; S2 = 2003/2004 season; S3 = 2004/2005 season.

Vineyard	Season	*Tetranychus urticae*						Predatory mites						Association	
		I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j	I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j	X	P
B5 & B6 (BP)	S1	2.615	<0.001	2.500	<0.001	-2.110	0.004	1.736	0.015	1.365	0.077	-1.769	0.014	-0.5840	>0.999
	S2	0.839	0.719	0.840	0.744	-0.831	0.729	2.413	<0.001	2.021	0.004	-2.585	<0.001	-0.1193	0.771
	S3	1.918	0.004	2.425	<0.001	-1.691	0.017	1.603	0.027	1.416	0.063	-2.037	0.004	-0.6056	0.997
	All	2.985	<0.001	3.211	<0.001	-2.522	0.001	2.843	<0.001	2.733	<0.001	-2.460	<0.001	-0.5539	>0.999
C6 (BP)	S1	-	-	-	-	-	-	0.971	0.430	0.969	0.432	-0.960	0.437	-	-
	S2	-	-	-	-	-	-	1.577	0.036	1.411	0.074	-1.467	0.066	-	-
	S3	1.769	0.011	1.393	0.071	-1.569	0.038	2.749	<0.001	2.481	<0.001	-2.652	<0.001	-0.2878	0.946
	All	1.738	0.015	1.442	0.055	-1.564	0.039	1.841	0.013	1.842	0.009	-1.499	0.052	-0.0107	0.519
Nr 2 & 3 (DV)	S1	1.252	0.086	1.279	0.071	-1.285	0.073	1.179	0.157	1.066	0.282	-1.084	0.259	0.3699	0.016
Nr 8 & 9 (DV)	S1	-	-	-	-	-	-	1.251	0.125	1.259	0.117	-1.119	0.229	-	-
	S2	1.245	0.139	1.007	0.372	-1.237	0.140	1.174	0.180	1.152	0.185	-1.134	0.211	0.2379	0.086
	S3	-	-	-	-	-	-	2.229	<0.001	2.036	0.001	-2.085	0.001	-	-
	All	1.265	0.133	0.927	0.520	-1.285	0.119	2.036	0.001	2.103	0.001	-1.711	0.009	0.0429	0.402
A04 & B03 (KH)	S1	2.392	0.002	2.307	0.003	-2.441	0.001	3.716	<0.001	4.214	<0.001	-3.932	<0.001	-0.5949	>0.999
	S2	1.376	0.126	1.627	0.042	-1.446	0.091	3.170	<0.001	2.649	0.001	-3.167	<0.001	-0.3835	>0.999
	S3	-	-	-	-	-	-	4.560	<0.001	4.929	<0.001	-4.744	<0.001	-	-
	All	1.924	0.013	1.825	0.020	-1.888	0.019	5.133	<0.001	5.694	<0.001	-5.409	<0.001	-0.4338	>0.999
% aggregation, using I_a		58.33						64.71							
% clustering, using $\overline{v}$				66.67						70.59					

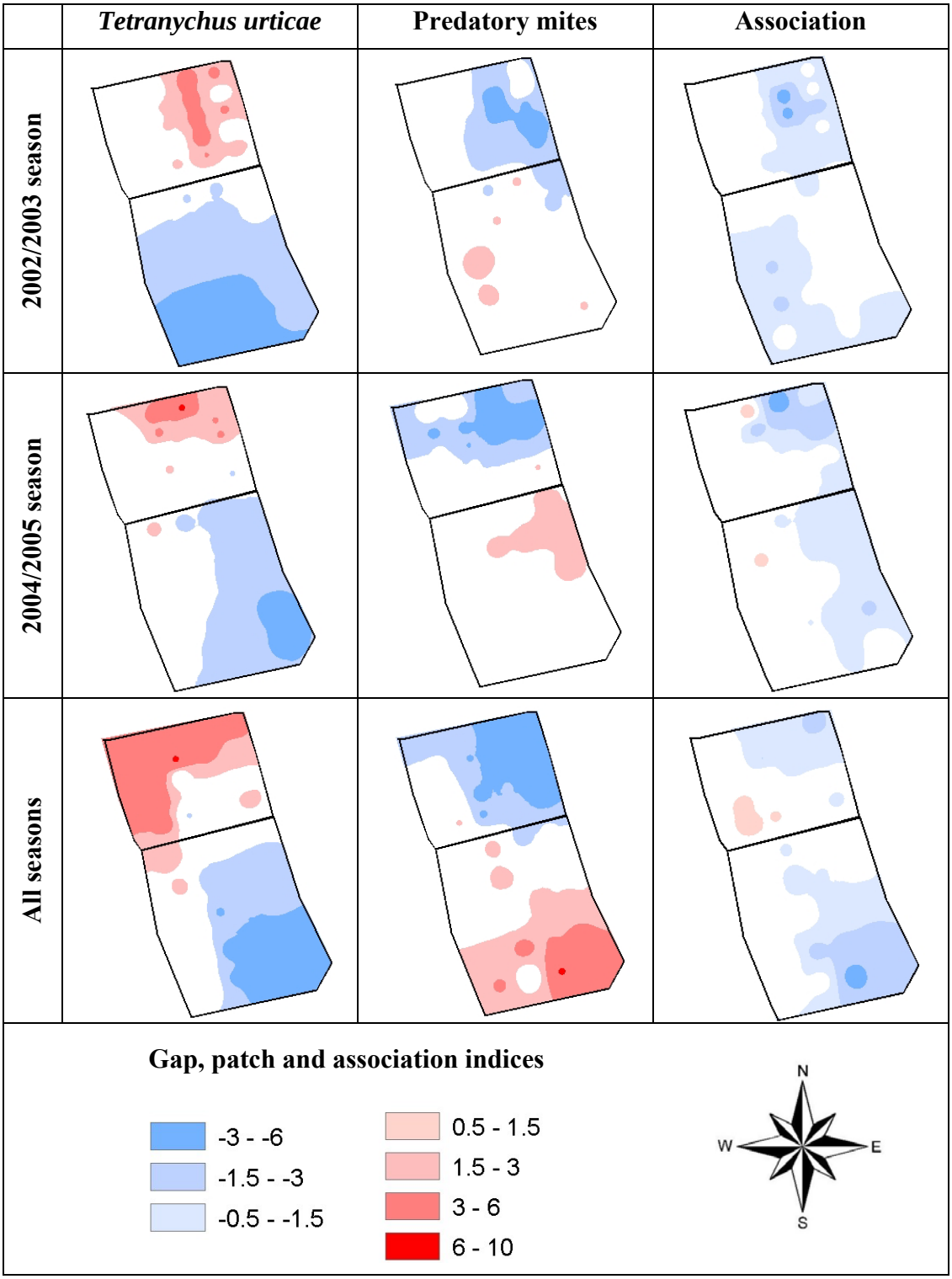


Figure 6.1. Interpolated spatial clustering and association of *Tetranychus urticae* and the predatory mite complex on vine leaves at Boplaas, vineyards B5 (northern block) and B6 (southern block) (Barlinka). Only significant indices were mapped: $v_i > 1.5$ (patches) and $v_j < -1.5$ (gaps) for aggregation; $\chi_k > 0.5$ for positive association or $\chi_k < -0.5$ for disassociation. Red indicates patches and association. Blue indicates gaps and disassociation.

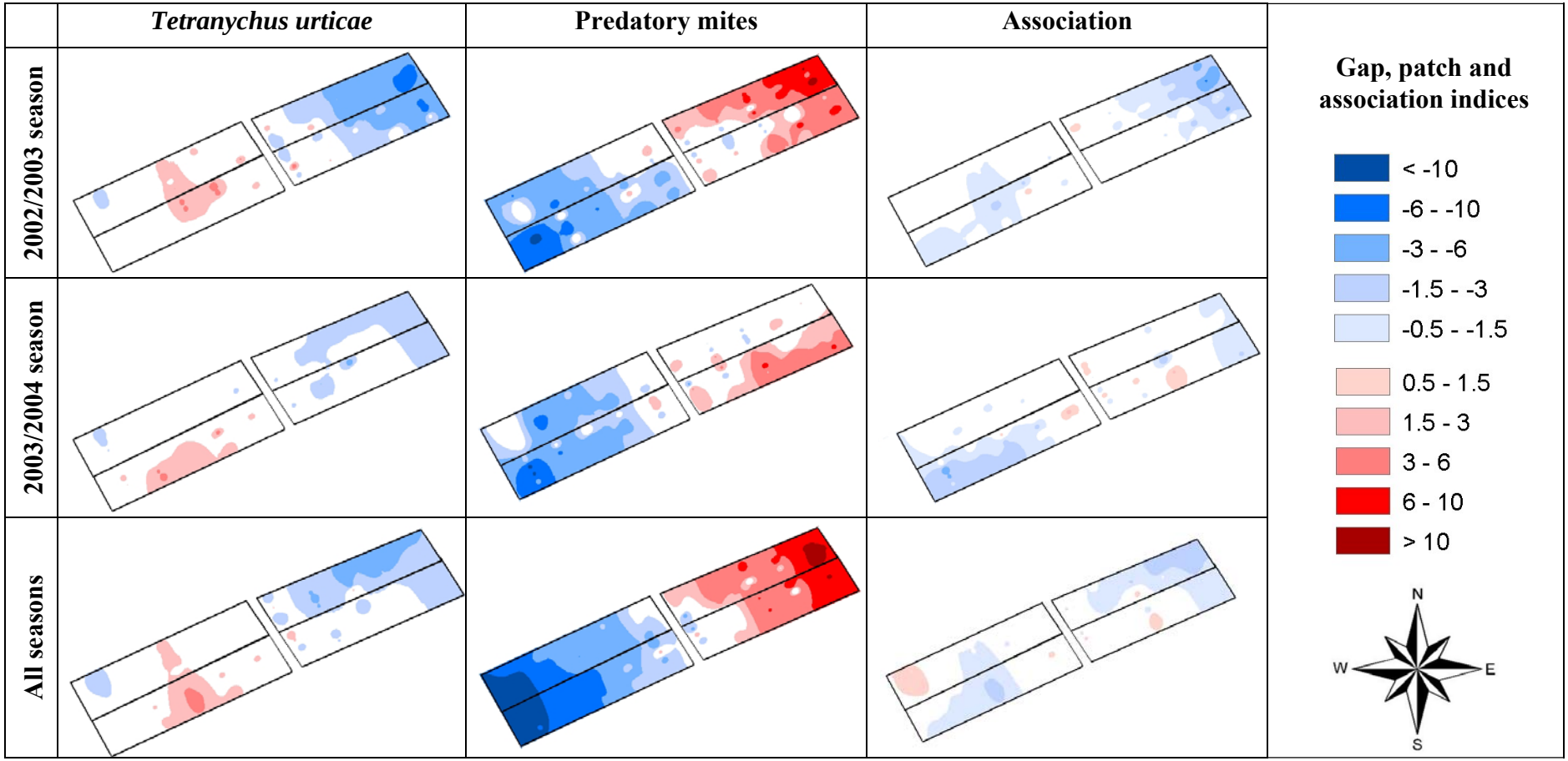


Figure 6.2. Interpolated spatial clustering and association of *Tetranychus urticae* and the predatory mite complex on vine leaves at Klipheuwel, vineyards A04 (western Barlinka blocks) and B03 (eastern Dauphine blocks). Only significant indices were mapped: v_i > 1.5 (patches) and v_j < -1.5 (gaps) for aggregation; χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. Red indicates patches and association. Blue indicates gaps and disassociation.

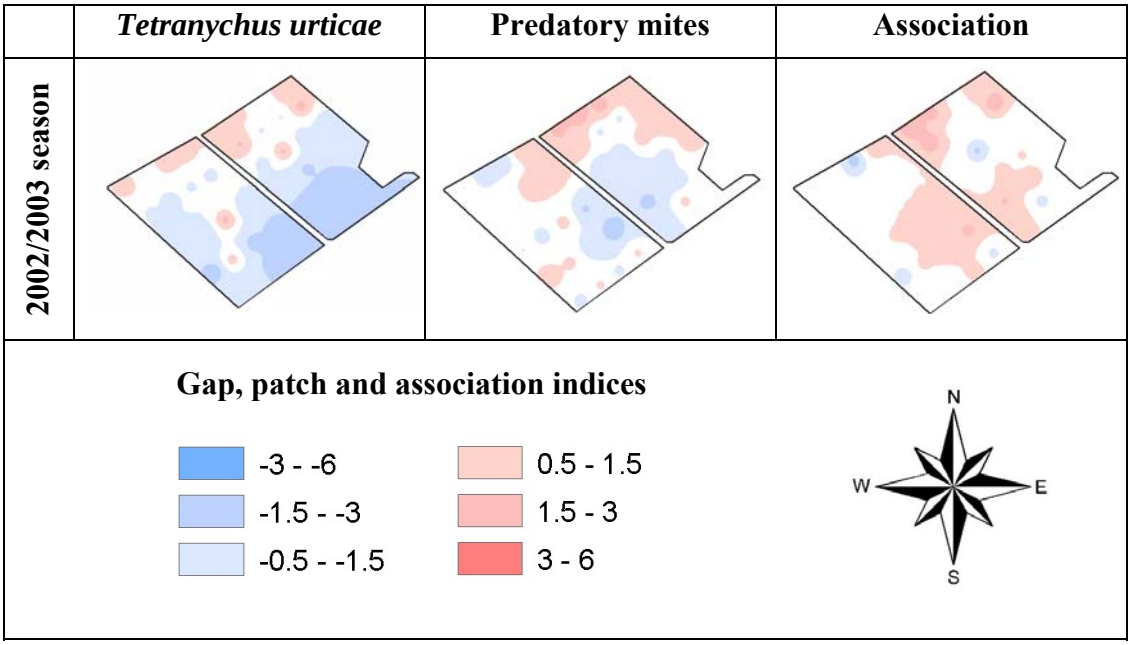


Figure 6.3. Interpolated spatial clustering and association of *Tetranychus urticae* and the predatory mite complex on vine leaves at De Vlei Boerdery, vineyards Nr 2 (eastern block) and Nr 3 (western block) (Barlinka). For association, only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. For aggregation, both significant (v_i > 1.5 for patches and v_j < -1.5 for gaps) and non-significant indices (0.5 < v_i < 1.5 and –1.5 < v_j < -0.5) were mapped. Red indicates patches and association. Blue indicates gaps and disassociation.

This lack of association between *T. urticae* and the predatory mite complex put some doubt on the possibility of biological control of *T. urticae* by the predatory mites. Therefore, the distribution of these mites during the season was investigated for these four cases of disassociation. Similar patterns were obtained for all these cases, but only the pattern for the 2003/2004 season at Klipheuwel is shown (Figure 6.4). Initially both *T. urticae* and predatory mite population levels were low (Figure 6.4). *Tetranychus urticae* then started to spread through the vineyards and increased in numbers. Only after high numbers of *T. urticae* were recorded did the predatory mites start to increase in numbers. Almost immediately thereafter, *T. urticae* decreased in numbers and the predatory mites kept on increasing in numbers and spread through the vineyards. The economic threshold of six *T. urticae* per leaf (see Chapter 4, section 4.2.2.5) was never reached.

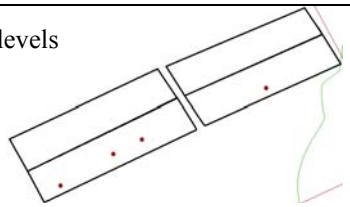
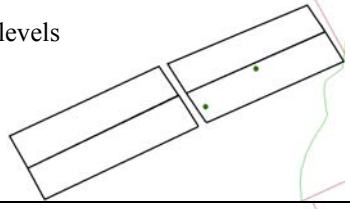
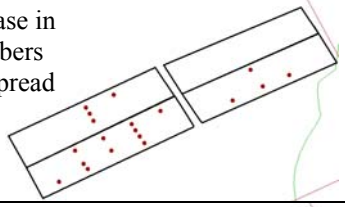
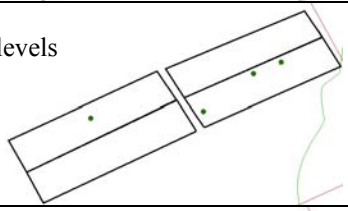
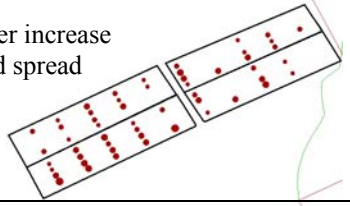
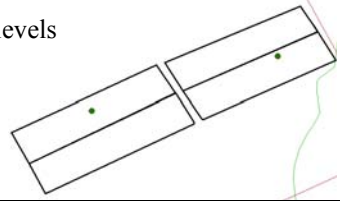
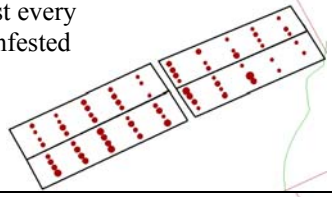
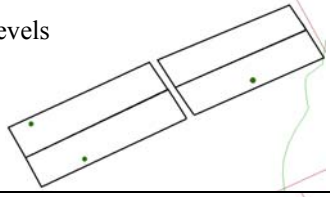
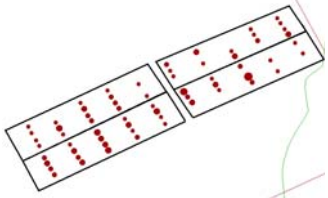
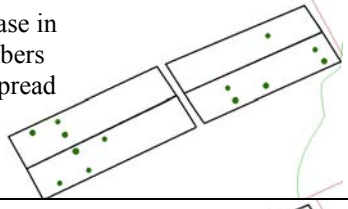
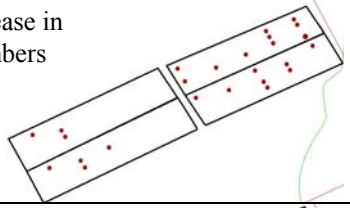
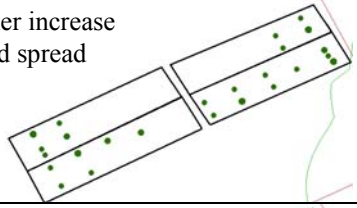
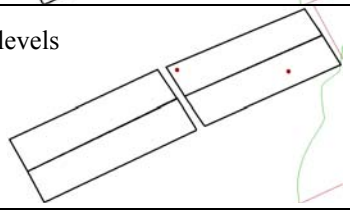
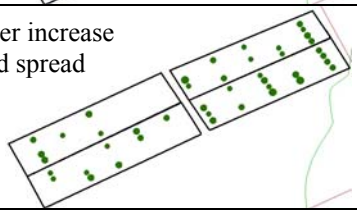
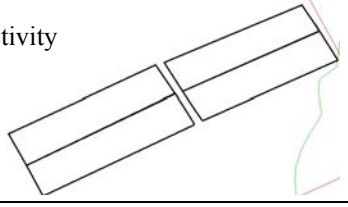
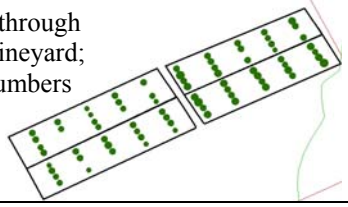
	Tetranychus urticae (red dots)	Predatory mites (green dots)
31 Oct-20 Nov	Low levels 	Low levels 
20 Nov - 1 Dec	Increase in numbers and spread 	Low levels 
1 - 22 Dec	Further increase and spread 	Low levels 
22 Dec - 8 Jan	Almost every plot infested 	Low levels 
8 - 22 Jan		Increase in numbers and spread 
22 Jan - 5 Feb	Decrease in numbers 	Further increase and spread 
5 - 19 Feb	Low levels 	Further increase and spread 
19 Feb - 15 Apr	Very low levels	Further increase and spread
15 Apr - 3 May	No activity 	Spread through whole vineyard; high numbers 

Figure 6.4. Temporal and spatial distribution of *Tetranychus urticae* and predatory mites on vine leaves for the 2003/2004 season at Klipheuwel. Larger dots indicate higher mite counts.

Separate spatial analyses for the individual predatory mite species were also performed. *Euseius addoensis* followed the same clustering trends as the predatory mite complex (Tables 6.2 and 6.3).

No overall spatial aggregation was detected for the undescribed *Typhlodromus* species (Table 6.3). The index of aggregation did however border on significance for vineyards B5 and B6 when counts for all seasons were combined. In this case, the *Typhlodromus* species was clustered into gaps (Table 6.3). In vineyards Nr 8 and Nr 9, the *Typhlodromus* species was clustered into both patches and gaps during the 2004/2005 season and when counts for all seasons were combined (Table 6.3).

In the case of *N. californicus*, the only deviation from randomness was in vineyard C6, where this mite was clustered into patches (Table 6.3). The gap index also bordered on significance (Table 6.3).

Spatial association between *T. urticae* and *E. addoensis* was similar to the association between *T. urticae* and the predatory mite complex (Tables 6.2 and 6.3). In vineyards Nr 8 and Nr 9, during the 2003/2004 season and when counts for all the seasons were combined, *T. urticae* was spatially associated with the undescribed *Typhlodromus* species (Table 6.3). Similar clustering and association patterns were detected in both these cases (Figure 6.5). In all other cases there was no significant association or disassociation between *T. urticae* and the undescribed *Typhlodromus* species (Table 6.3). *Tetranychus urticae* and *N. californicus* were not significantly associated or disassociated in any of the cases (Table 6.3).

The presence of *M. parviflora* on the vineyard floor was spatially associated with the presence of *T. urticae* on the vine leaves and spatially disassociated with the predatory mites on the vine leaves in the vineyards at Klipheuwel (Table 6.4, Figure 6.6). At De Vlei Boerdery, no significant association or disassociation was detected (Table 6.4).

Table 6.3. Spatial pattern of *Euseius addoensis*, *Neoseiulus californicus* and an undescribed *Typhlodromus* species on vine leaves, as well as their spatial association with *Tetranychus urticae*. I_a = index of aggregation (P_a = probability level); $\overline{v_i}$ = cluster index (patch) (P_i = probability level); $\overline{v_j}$ = cluster index (gap) (P_j = probability level); X = index of overall spatial association (P = probability level). Vineyards B5, B6, Nr 2, Nr 3 and A04 = Barlinka; Vineyards C6, Nr 8, Nr 9 and B03 = Dauphine. Farm names are in brackets (BP = Boplaas; DV = De Vlei Boerdery; KH = Klipheuwel). S1 = 2002/2003 season; S2 = 2003/2004 season; S3 = 2004/2005 season.

Vineyard	Season	I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j	X	P
E. addoensis									
B5 & B6 (BP)	S1	1.858	0.006	1.422	0.051	-2.093	0.002	-0.6418	>0.999
	S2	1.662	0.019	1.572	0.028	-1.633	0.024	-0.3005	0.963
	S3	1.610	0.028	1.282	0.100	-1.987	0.005	-0.7171	>0.999
	All	2.460	<0.001	2.028	0.003	-2.540	<0.001	-0.4424	0.995
C6 (BP)	All	2.065	0.002	1.647	0.020	-1.988	0.003	-0.0757	0.645
Nr 2 & Nr 3 (DV)	S1	1.212	0.129	1.070	0.295	-1.116	0.229	0.3779	0.013
Nr 8 & Nr 9 (DV)	S1	1.218	0.147	1.276	0.101	-1.085	0.266	-	-
	S2	1.199	0.163	1.196	0.139	-1.135	0.196	0.0959	0.291
	S3	2.120	<0.001	1.926	0.002	-2.038	0.001	-	-
	All	1.912	0.002	1.931	0.003	-1.746	0.008	-0.0215	0.557
A04 & B03 (KH)	S1	3.728	<0.001	4.153	<0.001	-3.979	<0.001	-0.6009	>0.999
	S2	3.056	<0.001	2.561	0.001	-3.017	<0.001	-0.3481	0.999
	S3	4.497	<0.001	4.822	<0.001	-4.629	<0.001	-	-
	All	5.140	<0.001	5.598	<0.001	-5.311	<0.001	-0.4382	>0.999
% aggregation, using I_a		71.43							
% clustering, using $\overline{v}$				78.57					
***Typhlodromus* sp.**									
B5 & B6 (BP)	S3	1.013	0.377	0.985	0.414	-0.946	0.489	0.0899	0.317
	All	1.624	0.025	1.405	0.067	-1.628	0.025	-0.2074	0.869
C6 (BP)	S2	1.180	0.190	1.132	0.217	-1.140	0.239	-0.1257	0.780
	S3	1.568	0.041	1.205	0.156	-1.447	0.069	0.2580	0.897
	All	1.121	0.249	0.959	0.443	-1.144	0.221	-0.0459	0.587
Nr 8 & Nr 9 (DV)	S2	1.065	0.287	1.093	0.260	-1.078	0.294	0.3287	0.021
	S3	1.479	0.038	1.478	0.033	-1.434	0.048	-	-
	All	1.471	0.034	1.439	0.049	-1.485	0.037	0.4198	0.007
% aggregation, using I_a		0							
% clustering, using $\overline{v}$				37.50					
N. californicus									
B5 & B6 (BP)	All	1.078	0.278	1.222	0.140	-1.020	0.349	0.0377	0.399
C6 (BP)	All	1.475	0.053	1.483	0.048	-1.502	0.050	0.0842	0.339
Nr 8 & Nr 9 (DV)	All	1.340	0.077	1.216	0.135	-1.326	0.084	0.1786	0.167
% aggregation, using I_a		0							
% clustering, using $\overline{v}$				33.33					

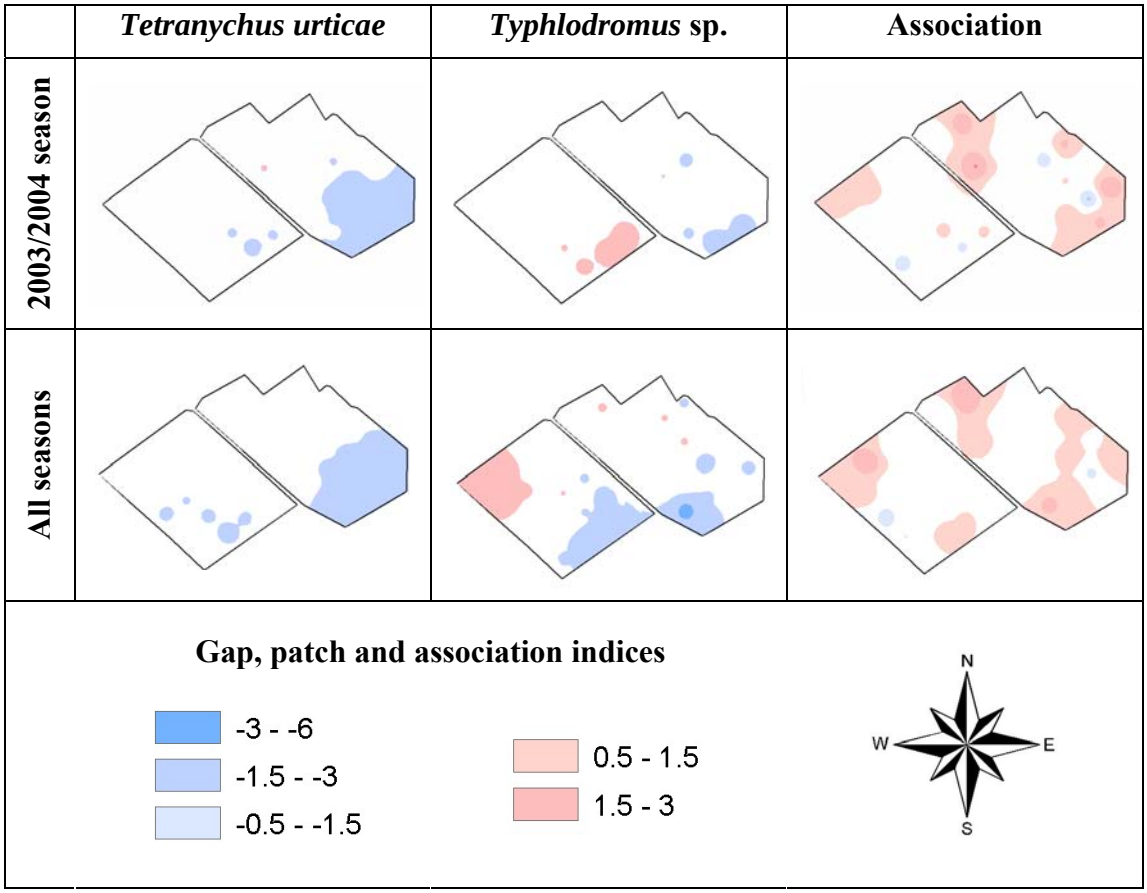


Figure 6.5. Interpolated spatial clustering and association of *Tetranychus urticae* and an undescribed *Typhlodromus* species on vine leaves at De Vlei Boerdery, vineyards Nr 8 (eastern block) and Nr 9 (western block) (Dauphine). Only significant indices were mapped: v_i > 1.5 (patches) and v_j < -1.5 (gaps) for aggregation; χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. Red indicates patches and association. Blue indicates gaps and disassociation.

In vineyards Nr 2 and Nr 3 during the 2002/2003 seasons and vineyards A04 and B03 when counts for all seasons were combined, the presence of *M. parviflora* and *R. raphanistrum* on the vineyard floor was spatially disassociated with the presence of predatory mites on the vine leaves (Table 6.4) (Figure 6.7). However, there was spatial association between these two plants and *T. urticae* on leaves in vineyards Nr 8 and Nr 9 during the 2003/2004 season and when all counts were combined for data from vineyards A04 and B03 (Table 6.4, Figure 6.7). In all other cases, no significant association or disassociation was detected.

At Klipheuwel, when significant association between the cover crop plants and *T. urticae* was detected, as well as significant disassociation between the cover crop plants and the predatory mites, significant disassociation between *T. urticae* and the predatory mites was also detected (Figures 6.2, 6.6, 6.7). In vineyards Nr 2 and Nr 3, significant disassociation between the cover crop plants and the predatory mites was detected when *T. urticae* and the predatory mites were spatially associated (Figures 6.3 and 6.7), while in vineyards Nr 8 and Nr 9, spatial association between the cover crop plants and *T. urticae* was detected where *T. urticae* and the undescribed *Typhlodromus* species was spatially associated (Figures 6.5 and 6.7). Therefore, the spatial association between *T. urticae* and the predatory mites on the vine leaves was not linked with the association between *T. urticae* or predatory mites and cover crop plants.

Table 6.4. Spatial association between the presence of the cover crop plants *Malva parviflora* and *Raphanus raphanistrum* on the vineyard floor and the presence of *Tetranychus urticae* and the predatory mite complex on vine leaves. *X* = index of overall spatial association (*P* = probability level). Vineyards Nr 2, Nr 3 and A04 = Barlinka; Vineyards C6, Nr 8, Nr 9 and B03= Dauphine. Farm names are in brackets (BP = Boplaas; DV = De Vlei Boerdery; KH = Klipheuwel).

Vineyard	Season	Association of cover crop plants with:			
		T. urticae		Predatory mites	
		X	***P***	***X***	***P***
M. parviflora					
Nr 8 & Nr 9 (DV)	All*	0.0760	0.345	0.1446	0.208
A04 & B03 (KH)	All*	0.3901	<0.001	-0.7620	>0.999
M. parviflora* and *R. raphanistrum					
C6 (BP)	All*	-0.0574	0.620	0.1860	0.118
Nr 2 & Nr 3 (DV)	2002/2003	-0.2505	0.903	-0.4492	0.977
Nr 8 & Nr 9 (DV)	2002/2003	-	-	-0.2364	0.921
	2003/2004	0.5186	0.004	0.2888	0.070
	All*	0.1237	0.266	-0.0966	0.720
A04 & B03 (KH)	All*	0.3736	0.001	-0.6377	>0.999

* Months in between fruit seasons (May to September) included for cover crop plant data

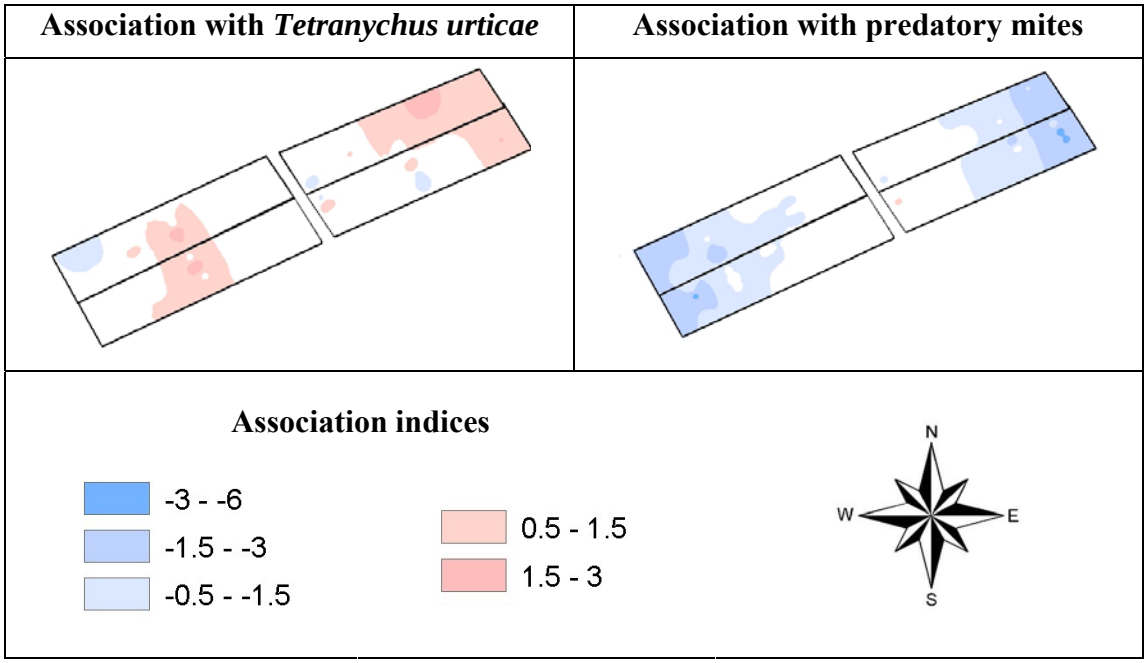


Figure 6.6. Interpolated spatial association of *Malva parviflora* on the vineyard floor with *Tetranychus urticae* and the predatory mite complex on vine leaves at Klipheuwel, vineyards A04 (western Barlinka blocks) and B03 (eastern Dauphine blocks) when counts for all seasons were combined (months in between fruit seasons were included for cover crop plant data). Only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. Red indicates association. Blue indicates disassociation.

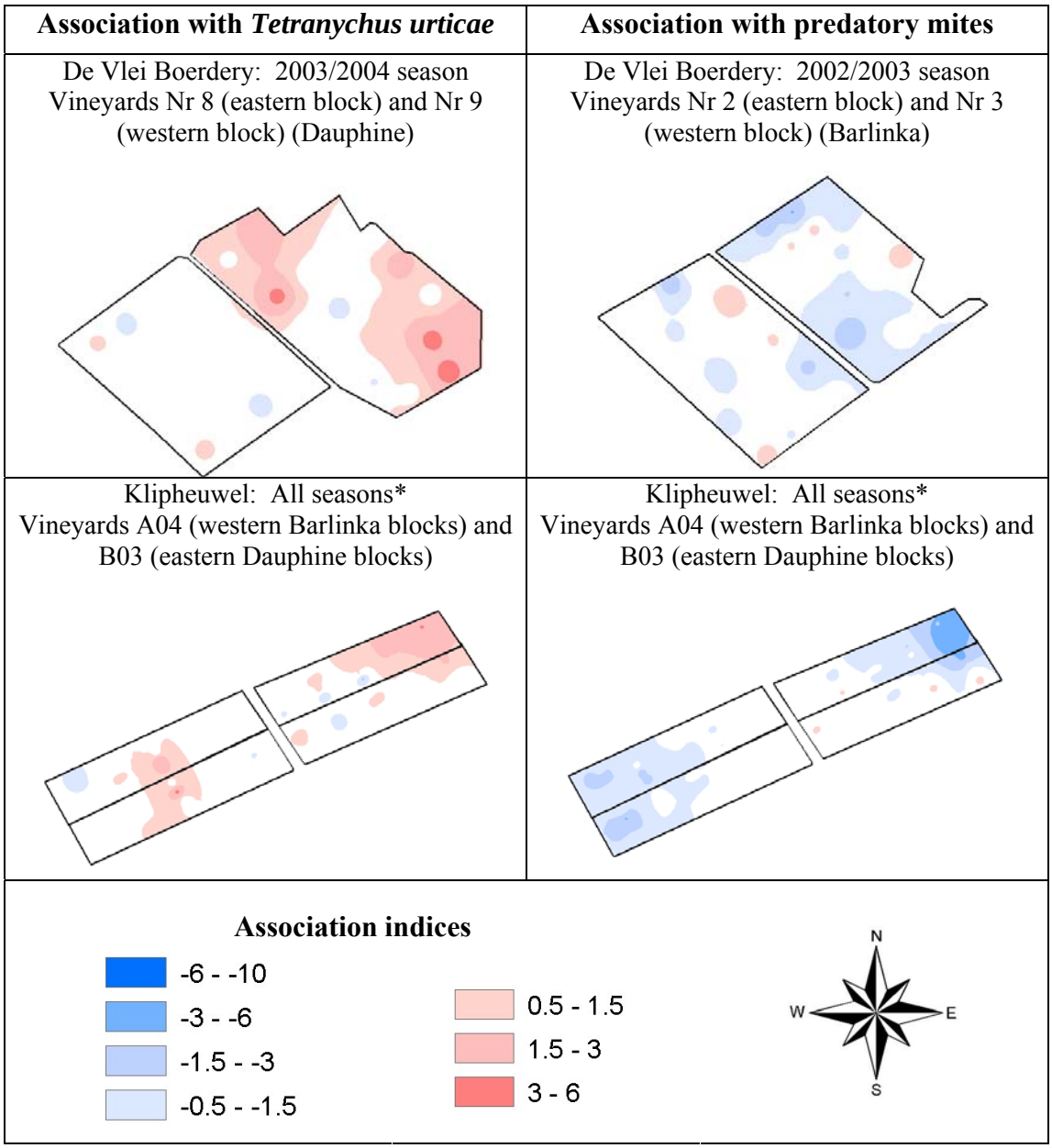


Figure 6.7. Interpolated spatial association of *Malva parviflora* and *Raphanus raphanistrum* on the vineyard floor with *Tetranychus urticae* and the predatory mite complex on vine leaves at De Vlei Boerdery and Klipheuwel. Only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. Red indicates association. Blue indicates disassociation. *Months in between fruit seasons were included for cover crop plant data.

6.3.2. *Planococcus ficus*

Planococcus ficus bunch and stem infestation had an overall spatially aggregated pattern in all cases (Table 6.5). All infestations were clustered into both patches and gaps (Table 6.5). Bunch infestation was strongly associated with stem infestation (Table 6.5, Figure 6.8). Bunch and stem infestation formed a gap in vineyard A04 and a patch in vineyard B03 (Figure 6.8).

Table 6.5. Spatial pattern of *Planococcus ficus* bunch and stem infestation, as well as the spatial association between bunch and stem infestation. I_a = index of aggregation (P_a = probability level); $\overline{v_i}$ = cluster index (patch) (P_i = probability level); $\overline{v_j}$ = cluster index (gap) (P_j = probability level); X = index of overall spatial association (P = probability level). Vineyard A04 = Barlinka (Klipheuwel); Vineyard B03= Dauphine (Klipheuwel). S1 = 2002/2003 season.

Vineyard	Season	I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j	X	P
Bunch infestation									
A04 &B03	S1	3.856	<0.001	3.851	<0.001	-3.893	<0.001		
	All	3.731	<0.001	3.594	<0.001	-3.821	<0.001		
% aggregation, using I_a		100							
% clustering, using $\overline{v}$						100			
Stem infestation								**Bunch vs stem**	
A04 &B03	S1	2.970	<0.001	3.853	<0.001	-3.020	<0.001	0.8602	<0.001
	All	3.264	<0.001	3.805	<0.001	-3.232	<0.001	0.8467	<0.001
% aggregation, using I_a		100							
% clustering, using $\overline{v}$						100			

6.3.3. *Frankliniella occidentalis*

There was an overall spatially aggregated pattern of halo spot damage in all cases at Klipheuwel and in some cases at Boplaas and De Vlei Boerdery (Table 6.6). Similar results were obtained for the occurrence of thrips on vine leaves, except that there was not an overall spatial aggregated pattern during the 2003/2004 season at Klipheuwel (Table 6.6). In most cases where there was overall spatial aggregation of both halo

spots and thrips on leaves, there was also clustering into both patches and gaps (Table 6.6).

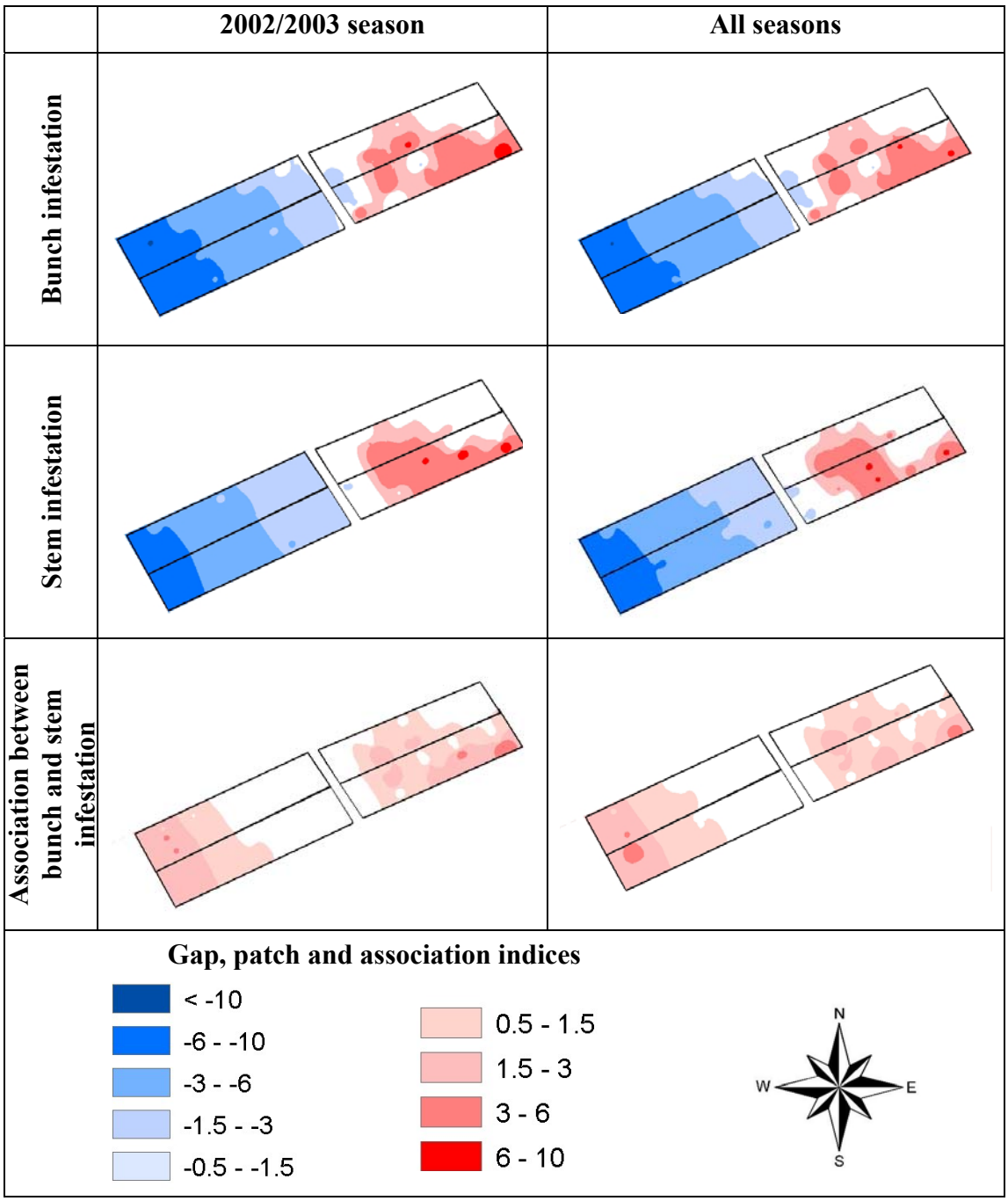


Figure 6.8. Interpolated spatial clustering and association of *Planococcus ficus* bunch and stem infestation at Klipheuwel, vineyards A04 (western Barlinka blocks) and B03 (eastern Dauphine blocks). Only significant indices were mapped: v_i > 1.5 (patches) and v_j < -1.5 (gaps) for aggregation; χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. Red indicates patches and association. Blue indicates gaps and disassociation.

Halo spot bunch damage and the presence of thrips on the vine leaves were spatially disassociated in vineyards Nr 8 and Nr 9 (De Vlei Boerdery) during the 2003/2004 season, as well as at Klipheuwel during the 2002/2003 and 2004/2005 seasons and when counts for all seasons were combined (Table 6.6, Figures 6.9 and 6.10). At Klipheuwel, halo spot damage formed a gap in vineyard A04 and a patch in vineyard B03 in all these cases (Figure 6.9). The opposite pattern was evident in the case of thrips on the leaves (Figure 6.9). Halo spot damage and thrips on leaves were spatially associated in vineyards Nr 8 and Nr 9 during the 2004/2005 season and when counts for all seasons were combined (Table 6.6). This was due to an overlapping gap in vineyard Nr 9 and overlapping patches in vineyard Nr 8 (Figure 6.10). In all the other cases, no significant association or disassociation was detected (Table 6.6).

6.3.4. *Epichoristodes acerbella* and vinegar flies

The drosophilid or vinegar flies that were found in the berries belonged to the genera *Drosophila* and *Zaprionus*. Vinegar fly bunch infestation did not usually have an overall spatially aggregated pattern. The exceptions were in vineyards B5 and B6 (Boplaas) during the 2003/2004 and 2004/2005 seasons and when counts for all seasons were combined, as well as in vineyard C6 (Boplaas) during the 2003/2004 season (Table 6.7). In these cases bunch infestation was clustered into both patches and gaps (Table 6.7). Bunch infestation was also clustered into patches and gaps in vineyard C6 when counts for all seasons were combined and clustered into patches in vineyards Nr 2 and Nr 3 (De Vlei Boerdery) during the 2002/2003 season (Table 6.7).

Epichoristodes acerbella bunch damage did not have an overall spatially aggregated pattern, but the patch index was significant and the gap index bordered on significance (Table 6.7).

Epichoristodes acerbella and vinegar fly bunch infestation was spatially disassociated (X = -0.5267; P = 0.998) (Figure 6.11). *Epichoristodes acerbella* bunch damage formed patches in the northern block of vineyard C6 and gaps in the southern block (Figure 6.11). The opposite pattern was evident for vinegar fly bunch infestation (Figure 6.11).

Table 6.6. Spatial pattern of halo spot damage, caused by *Frankliniella occidentalis*, and the presence of thrips on vine leaves, as well as their spatial association. I_a = index of aggregation (P_a = probability level); $\overline{v_i}$ = cluster index (patch) (P_i = probability level); $\overline{v_j}$ = cluster index (gap) (P_j = probability level); X = index of overall spatial association (P = probability level). Vineyards B5, B6, Nr 2, Nr 3 and A04 = Barlinka; Vineyards C6, Nr 8, Nr 9 and B03 = Dauphine. Farm names are in brackets (BP = Boplaas; DV = De Vlei Boerdery; KH = Klipheuwel). S1 = 2002/2003 season; S2 = 2003/2004 season; S3 = 2004/2005 season.

Vineyard	Season	Halo spot damage						Thrips on leaves						Association	
		I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j	I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j	X	P
B5 & B6 (BP)	S1	-	-	-	-	-	-	0.762	0.893	0.810	0.848	-0.767	0.885	-	-
	S2	0.891	0.596	0.889	0.620	-0.914	0.561	0.897	0.588	0.974	0.429	-0.898	0.584	0.1666	0.153
	S3	1.258	0.134	1.081	0.259	-1.334	0.086	1.987	0.004	1.394	0.069	-2.165	0.002	0.0598	0.356
	All	1.254	0.141	1.116	0.244	-1.219	0.162	1.922	0.007	1.451	0.047	-2.074	0.002	-0.0338	0.582
C6 (BP)	S1	1.751	0.018	1.698	0.017	-1.627	0.031	0.873	0.623	0.967	0.427	-0.859	0.657	-0.0606	0.643
	S2	2.260	0.001	2.020	0.003	-2.157	0.001	0.955	0.468	1.098	0.268	-0.932	0.524	-0.0952	0.719
	S3	1.803	0.010	2.000	0.002	-1.855	0.007	2.166	0.001	2.354	0.001	-2.003	0.004	0.2984	0.080
	All	1.219	0.173	1.241	0.132	-1.214	0.164	1.889	0.008	1.893	0.008	-1.589	0.036	0.2104	0.127
Nr 2 & 3 (DV)	S1	1.094	0.255	1.067	0.302	-1.058	0.318	1.292	0.075	1.187	0.133	-1.223	0.111	0.0843	0.299
Nr 8 & 9 (DV)	S1	1.651	0.014	1.513	0.029	-1.749	0.010	1.445	0.047	1.186	0.152	-1.406	0.055	0.2084	0.092
	S2	1.197	0.167	1.074	0.279	-1.147	0.222	0.837	0.752	0.748	0.963	-0.912	0.588	-0.3740	0.988
	S3	2.697	<0.001	2.177	<0.001	-2.422	<0.001	1.498	0.041	1.254	0.108	-1.727	0.011	0.5547	<0.001
	All	2.856	<0.001	2.423	<0.001	-2.964	<0.001	1.500	0.029	1.279	0.104	-1.438	0.049	0.5101	0.001
A04 & B03 (KH)	S1	5.396	<0.001	6.175	<0.001	-5.533	<0.001	2.762	<0.001	2.749	0.001	-3.120	<0.001	-0.5999	>0.999
	S2	4.148	<0.001	4.971	<0.001	-4.333	<0.001	0.812	0.686	0.791	0.732	-0.780	0.757	-0.1578	0.922
	S3	3.338	<0.001	3.649	<0.001	-3.269	<0.001	3.136	<0.001	2.907	<0.001	-3.213	<0.001	-0.6470	>0.999
	All	5.307	<0.001	5.955	<0.001	-5.717	<0.001	3.203	<0.001	2.797	<0.001	-3.336	<0.001	-0.6270	>0.999
% aggregation, using I_a		62.50						41.18							
% clustering, using $\overline{v}$				62.50						52.94					

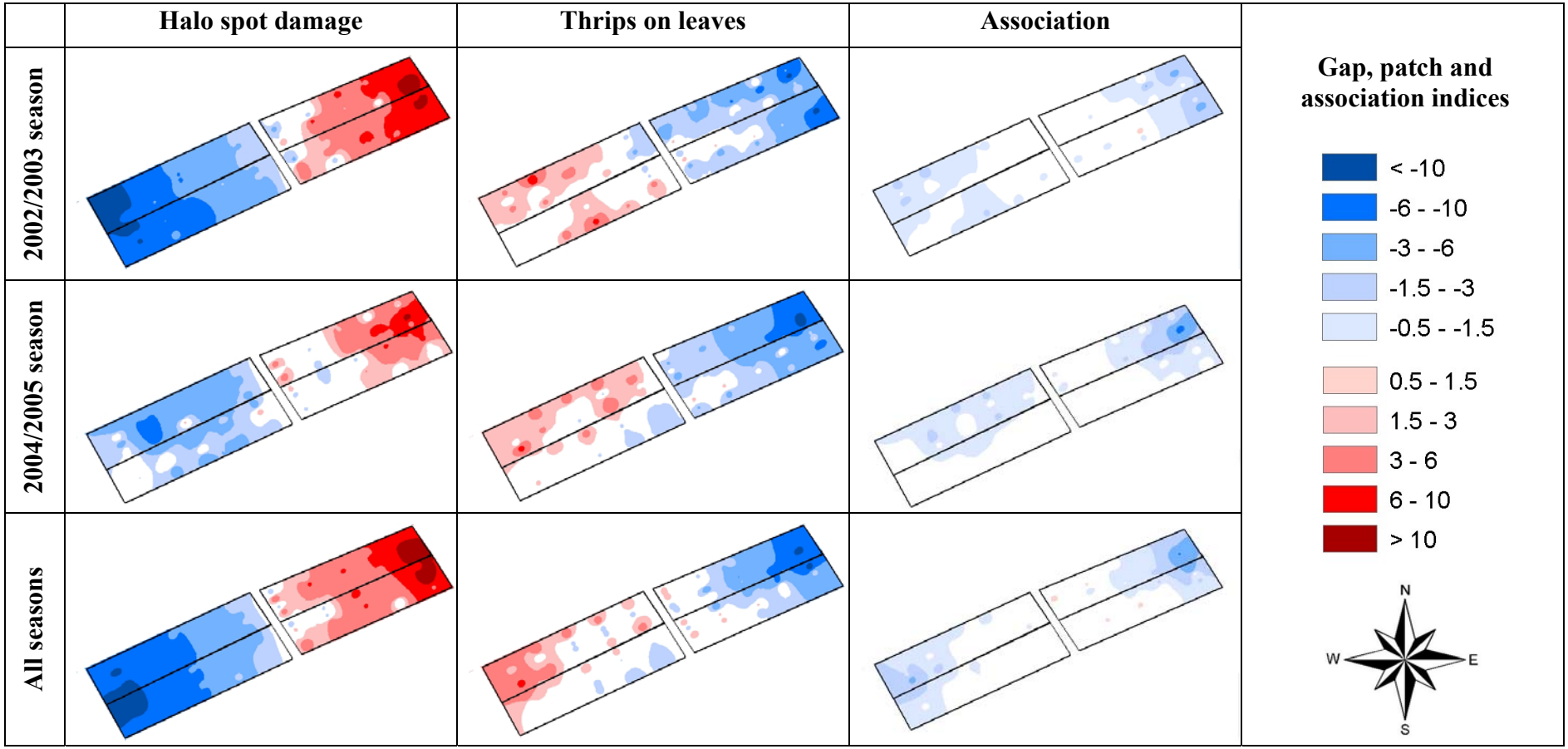


Figure 6.9. Interpolated spatial clustering of halo spot bunch damage, caused by *Frankliniella occidentalis*, and thrips found on vine leaves at Klipheuwel, vineyards A04 (western Barlinka blocks) and B03 (eastern Dauphine blocks). Only significant indices were mapped: $v_i > 1.5$ (patches) and $v_j < -1.5$ (gaps) for aggregation; $\chi_k > 0.5$ for positive association or $\chi_k < -0.5$ for disassociation. Red indicates patches and association. Blue indicates gaps and disassociation.

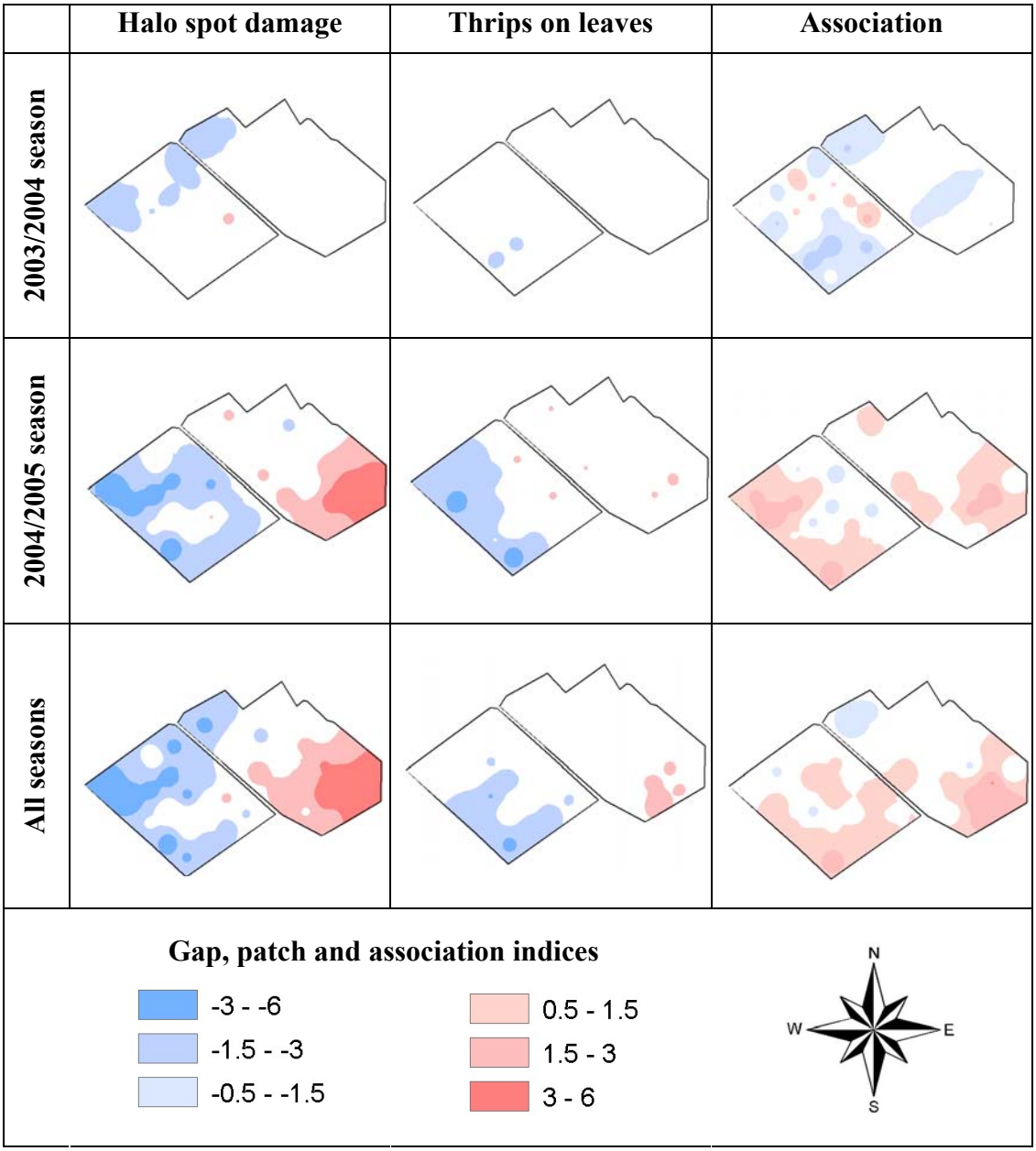


Figure 6.10. Interpolated spatial clustering and association of halo spot bunch damage, caused by *Frankliniella occidentalis*, and thrips found on vine leaves at De Vlei Boerdery, vineyards Nr 8 (eastern block) and Nr 9 (western block) (Dauphine). Only significant indices were mapped: v_i > 1.5 (patches) and v_j < -1.5 (gaps) for aggregation; χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. Red indicates patches and association. Blue indicates gaps and disassociation.

Table 6.7. Spatial pattern of bunch infestation caused by vinegar flies (*Drosophila* and *Zaprionus* spp.) and *Epichoristodes acerbella*. I_a = index of aggregation (P_a = probability level); $\overline{v_i}$ = cluster index (patch) (P_i = probability level); $\overline{v_j}$ = cluster index (gap) (P_j = probability level). Vineyards B5, B6, Nr 2, Nr 3 and A04 = Barlinka; Vineyards C6, Nr 8, Nr 9 and B03 = Dauphine. Farm names are in brackets (BP = Boplaas; DV = De Vlei Boerdery; KH = Klipheuwel).

Vineyard	Season	I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j
Vinegar flies							
B5 & B6 (BP)	2002/2003	1.225	0.155	1.255	0.116	-1.145	0.207
	2003/2004	2.073	0.002	1.899	0.007	-1.926	0.007
	2004/2005	2.288	<0.001	3.020	<0.001	-1.800	0.012
	All	2.321	<0.001	1.606	0.025	-2.693	<0.001
C6 (BP)	2002/2003	0.839	0.708	0.886	0.623	-0.853	0.688
	2003/2004	1.818	0.010	1.706	0.015	-1.787	0.014
	2004/2005	0.939	0.498	0.909	0.564	-0.899	0.578
	All	1.598	0.034	1.523	0.039	-1.584	0.034
Nr 2 & Nr 3 (DV)	2002/2003	1.341	0.054	1.435	0.027	-1.345	0.054
Nr 8 & Nr 9 (DV)	All	1.484	0.042	1.287	0.097	-1.303	0.091
A04 & B03 (KH)	2002/2003	1.550	0.067	1.302	0.132	-1.590	0.055
	2003/2004	1.623	0.047	1.505	0.076	-1.594	0.059
	All	0.731	0.833	0.674	0.916	-0.775	0.758
% aggregation, using I_a		30.77					
% clustering, using $\overline{v}$					46.15		
E. acerbella							
C6 (BP)	All	1.406	0.081	1.525	0.038	-1.464	0.058
% aggregation, using I_a		0					
% clustering, using $\overline{v}$					100		

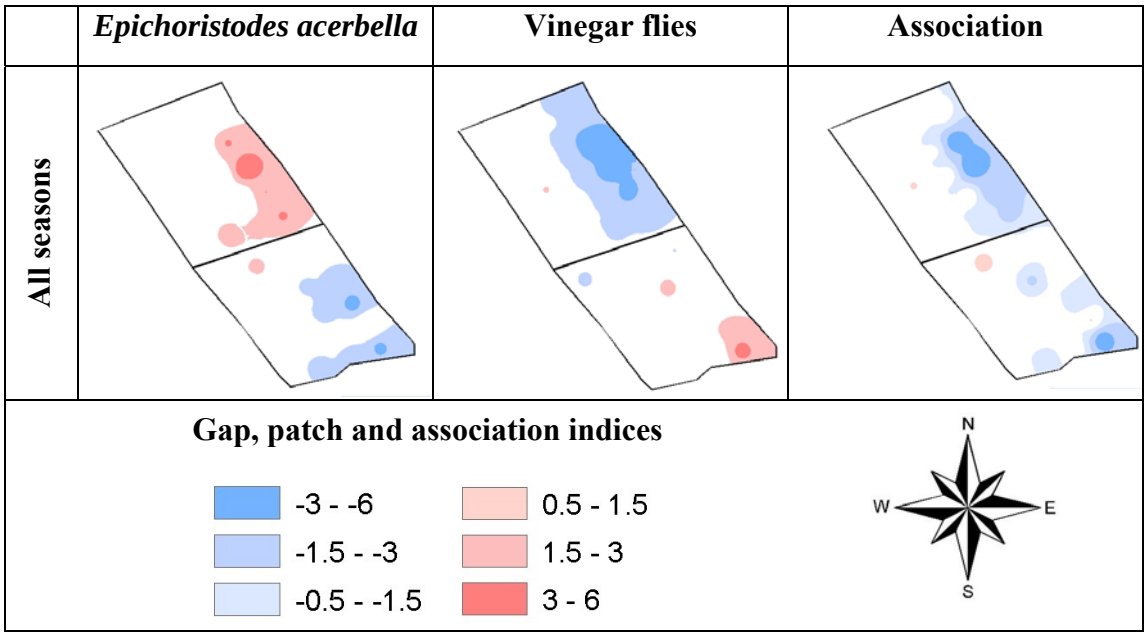


Figure 6.11. Interpolated spatial clustering and association of bunch damage caused by *Epichoristodes acerbella* and vinegar flies (*Drosophila* and *Zaprionus* spp.) at Boplaas, vineyard C6 (Dauphine). Only significant indices were mapped: v_i > 1.5 (patches) and v_j < -1.5 (gaps) for aggregation; χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. Red indicates patches and association. Blue indicates gaps and disassociation.

6.3.5. *Phlyctinus callosus*

Phlyctinus callosus bunch damage was random (Table 6.8). In vineyards B5 and B6 (Boplaas), *P. callosus* leaf damage had an overall spatially aggregated pattern and was also clustered into both patches and gaps (Table 6.8). In vineyards C6 (Boplaas) and the vineyards at De Vlei Boerdery, leaf damage was random (Table 6.8).

Phlyctinus callosus shoot damage had an overall spatially aggregated pattern in vineyards B5 and B6 when counts for all the seasons were combined (Table 6.8). In this case shoot damage was clustered into both patches and gaps. In vineyard C6, during the 2004/2005 season, shoot damage was clustered into patches, even though no overall spatial aggregation was detected (Table 6.8). In all other cases, shoot damage was random (Table 6.8).

Table 6.8. Spatial pattern of *Phlyctinus callosus* bunch, leaf and shoot damage and counts under the bands, as well as the spatial association between counts under the bands and bunch, leaf and shoot damage. I_a = index of aggregation (P_a = probability level); $\overline{v_i}$ = cluster index (patch) (P_i = probability level); $\overline{v_j}$ = cluster index (gap) (P_j = probability level); X = index of overall spatial association (P = probability level). Vineyards B5 and B6 = Barlinka; Vineyards C6, Nr 8 and Nr 9 = Dauphine. Farm names are in brackets (BP = Boplaas; DV = De Vlei Boerdery). S2 = 2003/2004 season; S3 = 2004/2005 season.

Vineyard	Season	I_a	P_a	$\overline{v_i}$	P_i	$\overline{v_j}$	P_j	X	P
Bunch damage								**Bunch vs band**	
Nr 8 & Nr 9 (DV)	All	1.037	0.348	1.155	0.170	-1.030	0.341	0.5080	0.002
% aggregation, using I_a		0							
% clustering, using $\overline{v}$						0			
Leaf damage								**Leaf vs band**	
B5 & B6 (BP)	S3	2.150	<0.001	1.753	0.011	-2.387	0.001	0.8090	0.003
	All	2.219	<0.001	2.129	0.002	-2.362	0.001	0.7607	0.002
C6 (BP)	S2	0.903	0.570	1.002	0.389	-0.881	0.606	0.6494	0.007
	S3	1.373	0.094	1.440	0.059	-1.379	0.096	0.6909	<0.001
	All	1.141	0.237	1.186	0.179	-1.131	0.253	0.7111	0.002
Nr 8 & Nr 9 (DV)	S3	0.938	0.522	1.975	0.423	-0.912	0.571	0.4123	0.056
	All	0.948	0.502	1.042	0.320	-0.908	0.594	0.4163	0.022
% aggregation, using I_a		28.57							
% clustering, using $\overline{v}$						28.57			
Shoot damage								**Shoot vs band**	
B5 & B6 (BP)	All	2.045	0.001	1.781	0.009	-2.053	0.003	0.8278	0.001
C6 (BP)	S2	0.844	0.704	1.005	0.377	-0.891	0.601	0.7346	<0.001
	S3	1.428	0.075	1.504	0.045	-1.416	0.079	0.6667	<0.001
	All	1.107	0.266	1.170	0.191	-1.136	0.238	0.6549	0.004
Nr 8 & Nr 9 (DV)	All	0.819	0.805	0.898	0.606	-0.801	0.845	0.4380	0.013
% aggregation, using I_a		20.00							
% clustering, using $\overline{v}$						40.00			
Counts under the bands									
B5 & B6 (BP)	S3	1.801	0.009	1.547	0.031	-1.931	0.007		
	All	1.797	0.009	1.446	0.053	-1.934	0.010		
C6 (BP)	S2	1.314	0.118	1.261	0.124	-1.225	0.161		
	S3	1.402	0.085	1.280	0.119	-1.483	0.068		
	All	1.047	0.330	1.115	0.228	-1.002	0.381		
Nr 8 & Nr 9 (DV)	S2	1.528	0.022	1.683	0.015	-1.471	0.033		
	S3	2.098	<0.001	1.528	0.035	-1.876	0.002		
	All	2.160	<0.001	1.963	0.003	-1.959	0.001		
% aggregation, using I_a		62.50							
% clustering, using $\overline{v}$						62.50			

In vineyard C6, *P. callosus* counts under the bands were random (Table 6.8). In vineyards B5, B6, Nr 8 and Nr 9, there was overall spatial aggregation in all cases (Table 6.8). Clustering into both patches and gaps was significant, except in vineyards B5 and B6, when counts for all seasons were combined. In this case the patch index bordered on significance (Table 6.8).

Phlyctinus callosus counts under the bands were spatially associated with bunch, leaf and shoot damage in all cases, except in vineyards Nr 8 and Nr 9 during the 2004/2005 season (Table 6.8, Figures 6.12 to 6.16). However, in these vineyards the spatial association between leaf damage and weevils under the bands bordered on significance (Table 6.8).

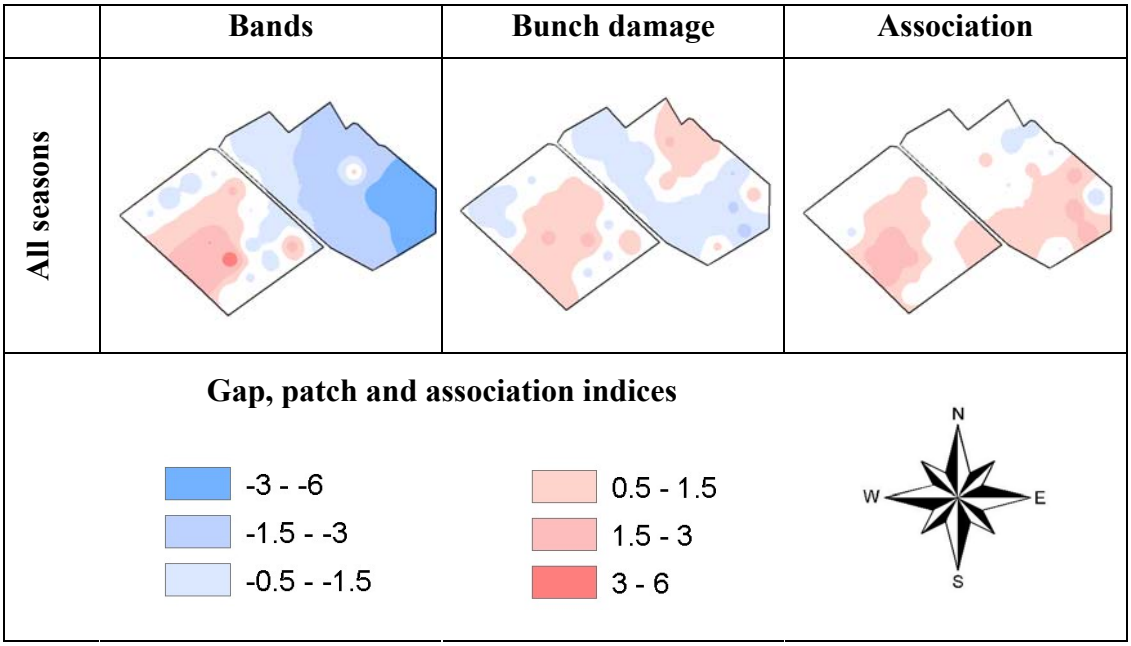


Figure 6.12. Interpolated spatial clustering and association of *Phlyctinus callosus* under the bands and bunch damage at De Vlei Boerdery, vineyards Nr 8 (eastern block) and Nr 9 (western block) (Dauphine). For association, only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. For aggregation, both significant (v_i > 1.5 for patches and v_j < -1.5 for gaps) and non-significant indices (0.5 < v_i < 1.5 and –1.5 < v_j < -0.5) were mapped.

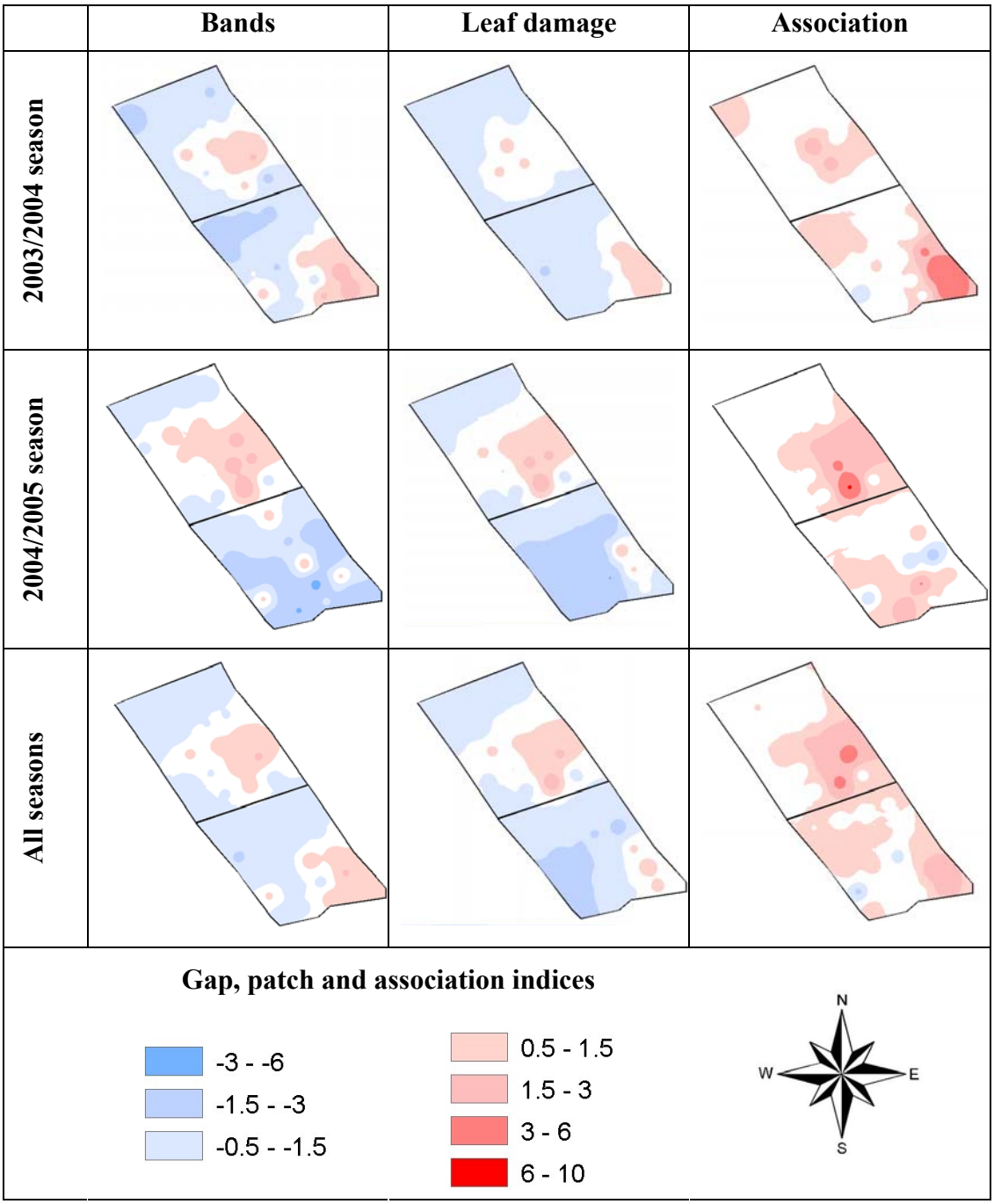


Figure 6.13. Interpolated spatial clustering and association of *Phlyctinus callosus* under the bands and leaf damage at Boplaas, vineyard C6 (Dauphine). For association, only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. For aggregation, both significant (v_i > 1.5 for patches and v_j < -1.5 for gaps) and non-significant indices (0.5 < v_i < 1.5 and –1.5 < v_j < -0.5) were mapped. Red indicates patches and association. Blue indicates gaps and disassociation.

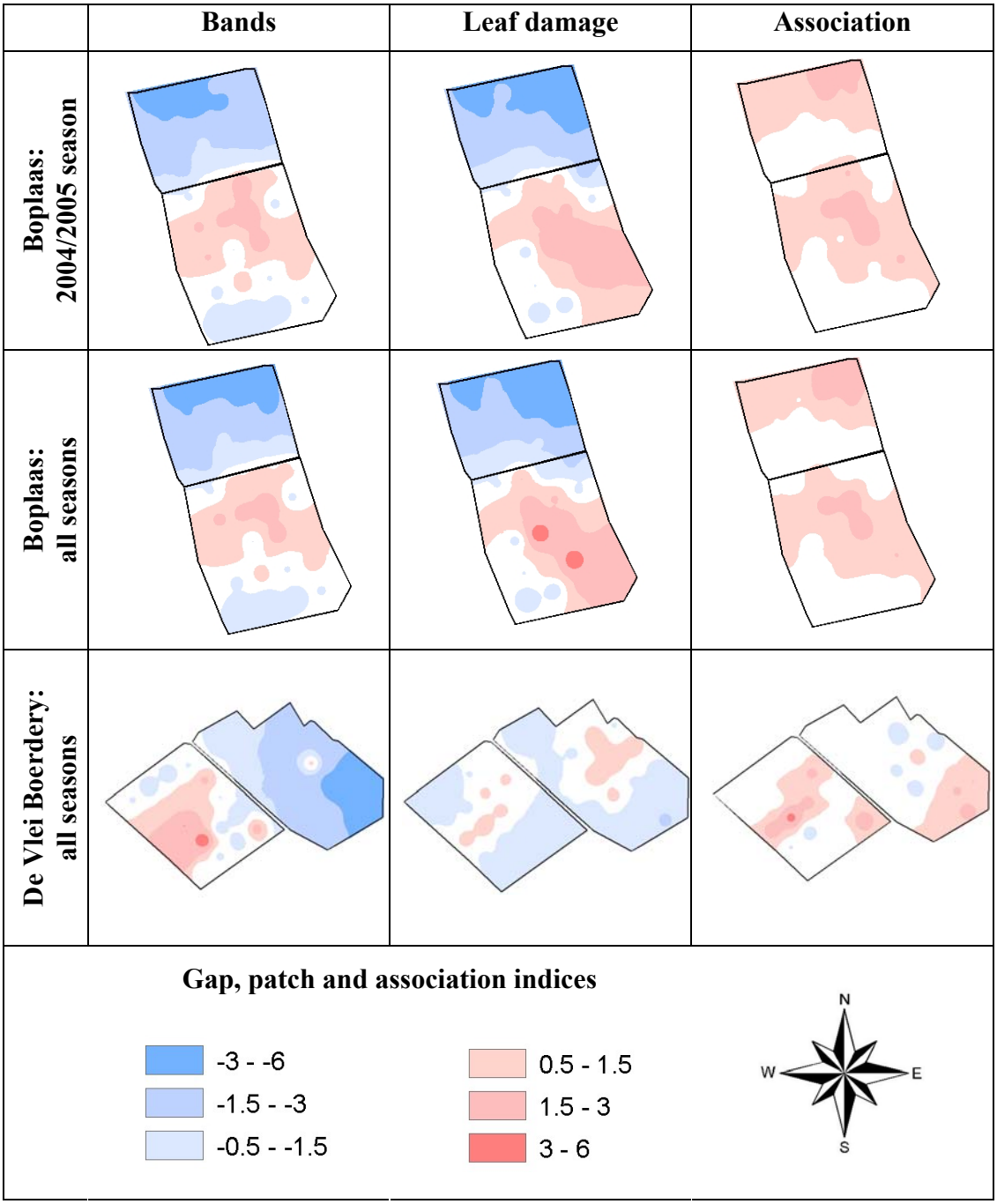


Figure 6.14. Interpolated spatial clustering and association of *Phlyctinus callosus* under the bands and leaf damage at Boplaas, vineyards B5 (northern block) and B6 (southern block) (Barlinka) and De Vlei Boerdery, vineyards Nr 8 (eastern block) and Nr 9 (western block) (Dauphine). For association, only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. For aggregation, both significant (v_i > 1.5 for patches and v_j < -1.5 for gaps) and non-significant indices (0.5 < v_i < 1.5 and –1.5 < v_j < -0.5) were mapped. Red indicates patches and association. Blue indicates gaps and disassociation.

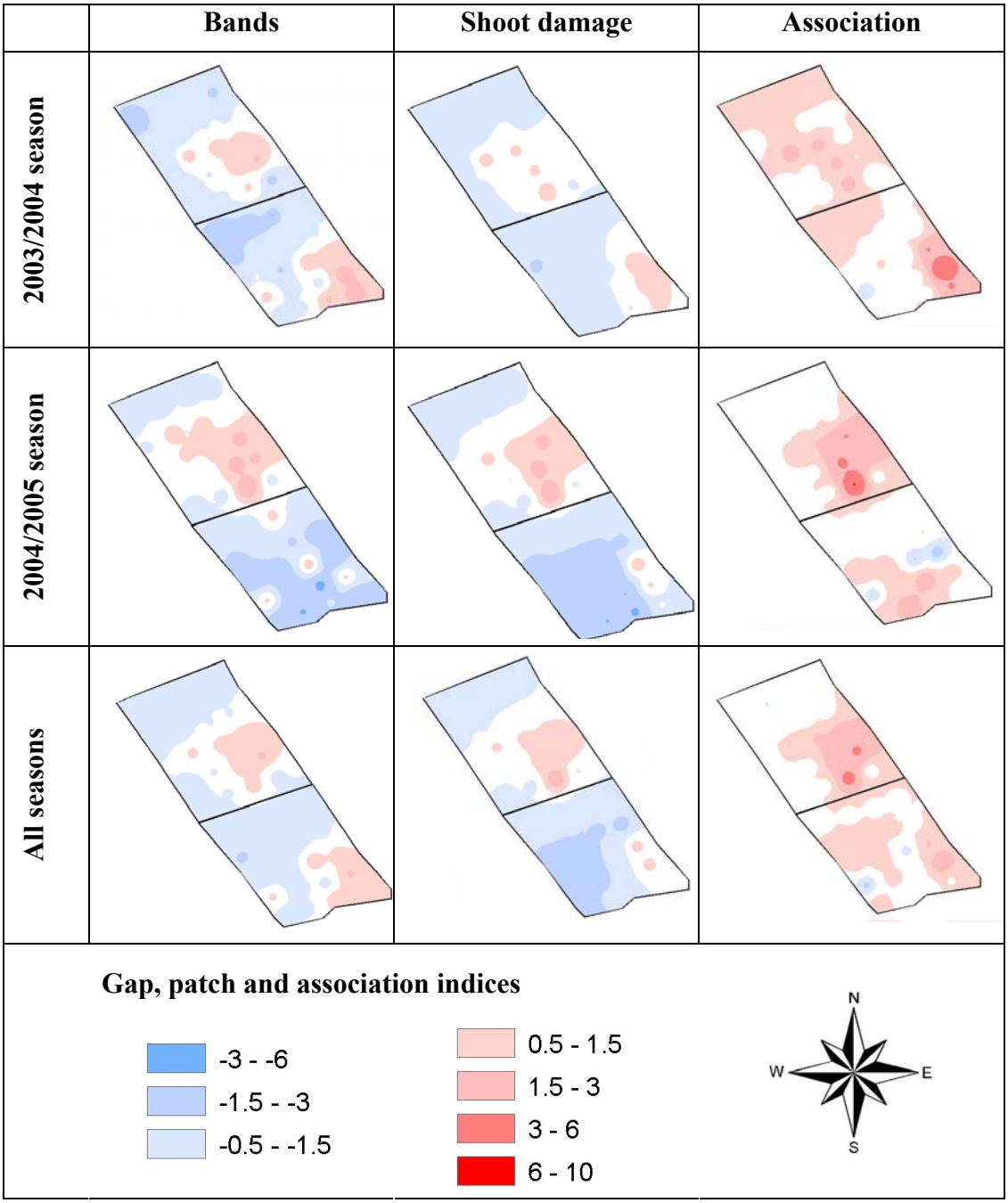


Figure 6.15. Interpolated spatial clustering and association of *Phlyctinus callosus* under the bands and shoot damage at Boplaas, vineyard C6 (Dauphine). For association, only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. For aggregation, both significant (v_i > 1.5 for patches and v_j < -1.5 for gaps) and non-significant indices (0.5 < v_i < 1.5 and –1.5 < v_j < -0.5) were mapped. Red indicates patches and association. Blue indicates gaps and disassociation.

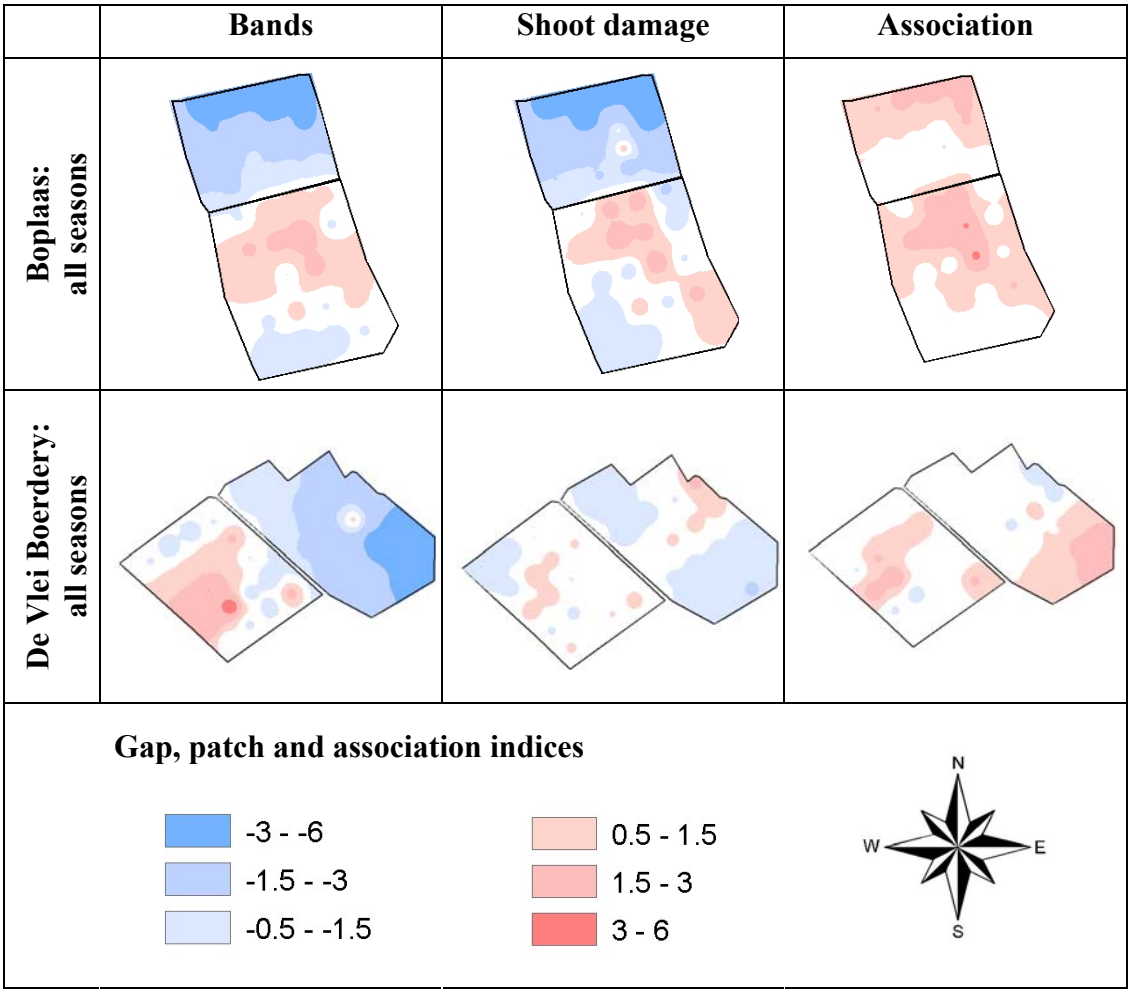


Figure 6.16. Interpolated spatial clustering and association of *Phlyctinus callosus* under the bands and shoot damage at Boplaas, vineyards B5 (northern block) and B6 (southern block) (Barlinka) and De Vlei Boerdery, vineyards Nr 8 (eastern block) and Nr 9 (western block) (Dauphine). For association, only significant indices were mapped: χ_k > 0.5 for positive association or χ_k < -0.5 for disassociation. For aggregation, both significant (v_i > 1.5 for patches and v_j < -1.5 for gaps) and non-significant indices (0.5 < v_i < 1.5 and –1.5 < v_j < -0.5) were mapped. Red indicates patches and association. Blue indicates gaps and disassociation.

6.4. Discussion

Not all of the predator species, pest species, or damage caused by these pests, were spatially aggregated or clustered in all cases. This contradicted Taylor *et al*. (1978) who stated that randomness is very rare, occurring only when the density is so low that the one individual that can be found has no others with which to respond. However, Taylor *et al*. (1978) used the more traditional models (Taylor, Iwao, negative binomial and Poisson), based on the relationship between the sample mean and sample variance, as apposed to the SADIE system used in the present study. These traditional measures for aggregation do not use the available spatial information in the sample, but operate only on the list of counts and relate only to the numeric properties of the underlying frequency distribution (Perry *et al*. 1999). Their ability to describe spatial pattern is therefore limited (Perry *et al*. 1999).

The predatory mite population consisted mostly of *E. addoensis*, a generalist feeder, which is not dependent on the presence of *T. urticae* for its survival. This is also the case with *N. californicus* (see Chapter 3, section 3.4). This probably explains the lack of association and even disassociation between *T. urticae* and the predatory mites. Spatial association was detected between *T. urticae* and the undescribed *Typhlodromus* species, for which the feeding habits and preferences are not known. Another reason for the lack of association maybe the fact that, in the spatial analysis, data was combined for one whole season. However, an investigation on distribution patterns during a season showed that *Tetranychus urticae* and the predatory mites were found in the same area only for a very short period of time. In the spatial analysis, this short time frame during which they were in the same area and during which the predatory mites could have provided biological control, was masked by the other data. The predatory mites did seem to provide biological control of *T. urticae*, since the proposed economic threshold of six mites per leaf were never reached and no acaricide sprays were applied (see Appendix A). An attempt should therefore be made to preserve these natural enemies. This could be achieved by avoiding certain chemicals (Schwartz 1990; Grout & Richards 1992; Heunis 1992; Grout *et al*. 1996, 1997) or through vineyard floor management (see Chapter 5).

Due to the lack of a pattern in association between mites on the vine leaves and preferred cover crop plants, it may seem that the presence of cover crop plants did not influence the presence of phytophagous and predatory mites on the vine leaves and may therefore not contribute to biological control of the phytophagous mites. However, the vineyard floor is inhabited by various cover crop plants which serve as mite hosts, not only *M. parviflora* and *R. raphanistrum* (see Chapter 5). The combination of all these plants created suitable conditions for the survival of both phytophagous and predatory mites and may have influenced their presence on the vine leaves and therefore also biological control of the former.

Planococcus ficus bunch infestation was spatially associated with stem infestation in all cases. Bunch infestation could therefore be expected in areas where stem infestation was found and was not expected in areas where stem infestation was absent. Therefore, stem infestation could be used as an indicator of where bunch infestation could be expected. Since stem infestation preceded bunch infestation (see Chapter 3, section 3.3.3), detection of stem infestation could be used as a warning of where bunch infestation was to be expected later in the season. This can facilitate the planning of spot treatments in those areas where stem infestation were detected to prevent bunch infestation.

The general lack of association between thrips on vine leaves and halo spot damage could be ascribed to the fact that a variety of thrips species are found on the leaves and not just *F. occidentalis*, which was responsible for the halo spot damage. Due to this lack of association, the presence of thrips on the vine leaves could not be used to predict halo spot bunch damage.

Epichoristodes acerbella and vinegar fly bunch infestation was spatially disassociated, meaning that vinegar fly bunch infestation could not be used as an indication of *E. acerbella* bunch damage. However, more data are needed to confirm this, as there was only one instance in this investigation where sufficient data were obtained for the analysis.

The positive spatial association between *P. callosus* found under the cardboard bands and *P. callosus* bunch, leaf and shoot damage means that damage can be expected in

areas where *P. callosus* is found under the cardboard bands. Therefore, the cardboard bands can be used to identify areas where damage can be expected.

6.5. References

Castagnoli, M., Liguori, M. & Simoni, S. 1993. Distribution, sampling and association of soyabean mites in Italy. *Redia* 76: 111-120.

Editors of ESRI Press. 1999. *Getting to Know ArcView GIS*. ESRI, California.

Garcia Mari, F., Gonzalez Zamora, J.E., Orenga Royo, S., Saques Fernandez, J., Laborda Cenjor, R., Soto Sanchez, A. & Ribes Koninckx, A. 1991. Spatial distribution and association between phytophagous mite species (Tetranychidae) and predators (Phytoseiidae) on strawberry leaves. *Boletin de Sanidad Vegetal, Plagas* 17: 401-415.

Grout, T.G. & Richards, G.I. 1992. Susceptibility of *Euseius addoensis addoensis* (Acari: Phytoseiidae) to field-weathered residues of insecticides used on citrus. *Experimental & Applied Acarology* 15: 199-204.

Grout, T.G., Richards, G.I. & Stephen, P.R. 1996. Residual toxicity of pesticides used on citrus to predacious mites (*Euseius* spp.). *Citrus Journal* 6(2): 17-20.

Grout, T.G., Richards, G.I. & Stephen, P.R. 1997. Further non-target effects of citrus pesticides on *Euseius addoensis* and *Euseius citri* (Acari: Phytoseiidae). *Experimental & Applied Acarology* 21: 171-177.

Heunis, J. M. 1992. *The Influence of Synthetic Pyrethroids on Phytophagous Mites and their Natural Enemies in Apple Orchards*. MSc Thesis, University of Stellenbosch.

Holland, J.M., Begbie, M., Birkett, T., Reynolds, C.J.M. & Thomas, C.F.G. 2001. The influence of hedgerows on coleopteran distributions: results from a multi-field sampling study. In: Barr, C.J. & Petit, S. (Eds) *Hedgerows of the World: their Ecological Functions in Different Landscapes.* 177-186. International Association of Landscape Ecology, UK.

Holland, J.M., Perry, J.N. & Winder, L. 1999a. The within-field spatial and temporal distribution of arthropods in winter wheat. *Bulletin of Entomological Research* 89: 499-513.

Holland, J.M., Winder, L. & Perry, J.N. 1999b. Arthropod prey of farmland birds: their spatial distribution within a sprayed field with and without buffer zones. *Aspects of Applied Biology* 54: 53-60.

Maestre, F.T. & Cortina, J. 2002. Spatial patterns of surface soil properties and vegetation in a Mediterranean semi-arid steppe. *Plant and Soil* 241: 279-291.

Pedigo, L.P. 1999. *Entomology and Pest Manatement. Third Edition.* Prentice-Hall, Inc., New Jersey.

Perry, J.N. 1995. Spatial analysis by distance indices. *Journal of Animal Ecology* 64: 303-314.

Perry, J.N. 1996. Simulating spatial patterns of counts in agriculture and ecology. *Computers and Electronics in Agriculture* 15: 93-109.

Perry, J.N. 1998a. Measures of spatial pattern for counts. *Ecology* 79: 1008-1017.

Perry, J.N. 1998b. Measures of spatial pattern and spatial association for insect counts. In: Baumgärtner, J., Brandmayr, P. & Manly, B.J.F. (Eds) *Population and Community Ecology for Insect Management and Conservation*. 21-33. Balkema, Rotterdam.

Perry, J.N. & Dixon, P.M. 2002. A new method to measure spatial association for ecological count data. *Ecoscience* 9: 133-141.

Perry, J.N., Liebhold, A.M., Rosenberg, M.S., Dungan, J., Miriti, M., Jakomulska, A. & Citron-Pousty, S. 2002. Illustrations and guidelines for selecting statistical methods for quantifying spatial pattern in ecological data. *Ecography* 25: 578-600.

Perry, J.N., Winder, L., Holland, J.M. and Alston, R.D. 1999. Red-blue plots for detecting clusters in count data. *Ecology Letters* 2: 106-113.

Schwartz, A. 1990. Pesticide effect on populations of *Tetranychus urticae* Koch (Acari: Tetranychidae) and a predaceous mite on table grapes in the Hex River Valley. *South African Journal of Enology and Viticulture* 11: 33-37.

Scott, J.B., Hay, F.S., Wilson, C.R., Cotterill, P.J. & Fist, A.J. 2003. Spatiotemporal analysis of epiphytotics of downy mildew of oilseed poppy in Tasmania, Australia. *Phytopathology* 93: 752-757.

Taylor, L.R., Woiwod, I.P. & Perry, J.N. 1978. The density-dependence of spatial behaviour and the rarity of randomness. *Journal of Animal Ecology* 47: 383-406.

Veldtman, R. & McGeoch, M.A. 2004. Spatially explicit analyses unveil density dependence. *Proceedings of the Royal Society of London Bulletin* 271: 2439-2444.

Winder, L., Alexander, C.J., Holland, J.M., Woolley, C. and Perry, J.N. 2001. Modelling the dynamic spatio-temporal response of predators to transient prey patches in the field. *Ecology Letters* 4: 568-576.

CHAPTER 7

THE EFFECT OF TEMPERATURE ON THE DEVELOPMENT, SURVIVAL AND FECUNDITY OF THE PEAR LEAFROLLER, *EPICHORISTODES ACERBELLA* (WALKER) (LEPIDOPTERA: TORTRICIDAE)

7.1. Introduction

It is important to know under what conditions economic pest population levels may become destructive (Watson 1964). For poikilothermic animals, like insects, temperature is an important factor influencing longevity and fecundity and therefore their capacity to increase in numbers (Andrewartha & Birch 1954; Romoser 1981). The chemical reactions that take place within insects are directly dependent on temperature (Romoser & Stoffolano 1998). In warm weather, poikilothermic animals complete their development more rapidly than in cool weather (Andrewartha & Birch 1954). Developmental rate, which is regulated by temperature, is the most important factor influencing the intrinsic rate of increase of colonizing species (Romoser & Stoffolano 1998). Even though insects may have a wide geographic distribution, they generally become pests in those areas where optimal temperatures occur (Romoser & Stoffolano 1998).

Epichoristodes acerbella (Walker) is an important phytosanitary pest, causing rejections of table grapes presented for export to the USA and Israel (Pryke 2005). Bolton (1979) and Gabarra *et al*. (1986) studied the effects of constant temperature on *E. acerbella* from Krugersdorp in South Africa and Spain respectively. They found temperatures above 25°C to be to unfavorable for the development of this insect. The present study was performed to determine whether or not the strain attacking table grapes in the Hex River Valley in the Western Cape Province of South Africa differed in its response to constant temperature from the strains studied by Bolton (1979) and Gabarra *et al*. (1986). Life table parameters were also determined, the results of which could form the basis of a degree day model that could be used to manage the pest. In addition, if a sterile insect technique (SIT) programme is developed in the

future to eradicate this important phytosanitary pest from the Hex River Valley (see Chapter 1, section 1.3.1), the information gained in this study can be used for breeding purposes.

7.2. Material and methods

7.2.1. Experimental design

Epichoristodes acerbella moths were collected at Boplaas, a farm in the Hex River Valley (see Chapter 2, section 2.1), using a light trap. These moths were kept together, allowing mating and oviposition. As soon as the larvae hatched, they were transferred to an artificial diet (Guennelon *et al*. 1981) (Table 7.1) in an environment chamber at a constant temperature of 25 ± 1°C.

Table 7.1. Composition of the artificial medium used for rearing *Epichoristodes acerbella*.

Ingredients	Quantity
Agar	40 *g*
Water	1.5 *l*
4-Hydroxybenzoic acid (Nipagin M)	3.6 *g*
Benzoic acid	4.6 *g*
Formalin (40%)	2.6 *ml*
Maize	282 *g*
Wheat germ	71 *g*
Brewers yeast	75.6 *g*
Ascorbic acid (Vitamin C)	10 *g*

The water was boiled to dissolve the agar. After boiling the agar-water mixture, it was allowed to cool to 65°C and was then mixed with the rest of the ingredients.

Life table studies were conducted at six constant temperatures, namely 15, 20, 22, 25, 28 and 30°C. There was a fluctuation of 1°C above and below each temperature. A photoperiod of 12L:12D was maintained. Eggs were placed in glass vials (7.3 cm depth, 2.2 cm diameter) and closed with a plastic lid (Figure 7.1A). These were then placed in environment chambers set at one of the temperatures above. After hatching

the larvae were placed on a small piece of diet (about 2 x 1.5 x 1 cm) in plastic containers (3.5 cm depth, 5 cm diameter at the bottom and 6.3 cm diameter at the top) (Figure 7.1B), closed with a plastic lid and then returned to the environment chamber. There were five larvae per container with one piece of diet. Pupae were removed daily, placed in groups of no more than five in the same glass vials used for the eggs. They were also closed with a lid. A piece of filter or blotting paper was placed in each vial to absorb moisture (Figure 7.1C). Upon emergence, moths were paired and placed in plastic containers (8.5 cm depth, 7.5 cm diameter at the bottom and 9.5 cm diameter at the top), one male and one female per container (Figure 7.1D). The containers were lined with blotting paper to prevent oviposition on the sides and closed with pierced transparent plastic (Figure 7.1D and E). A piece of plastic on which eggs could be deposited, as well as a straw that served as a mating site, were placed in each container (Figure 7.1D).

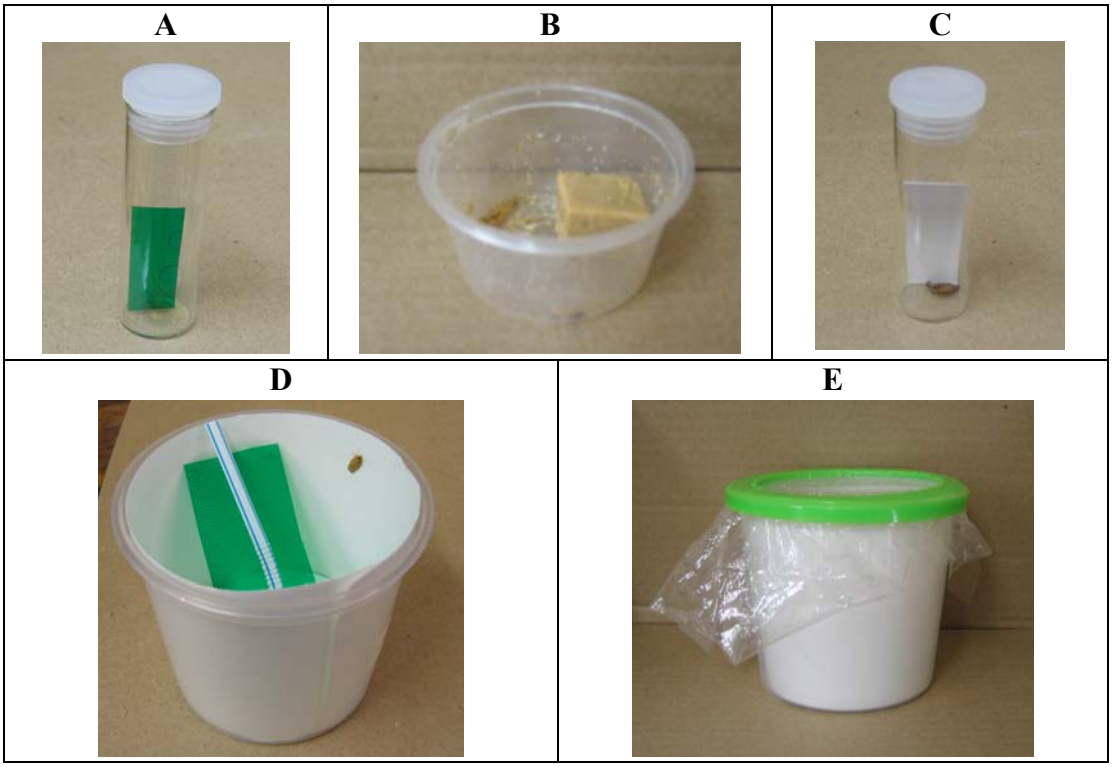


Figure 7.1. The containers used to rear *Epichoristodes acerbella*. (A) Glass tube with a piece of plastic on which eggs were deposited; (B) plastic container with a piece of diet for rearing larvae; (C) glass tube with pupae and blotting paper; (D) plastic container, lined with blotting paper and containing a piece of plastic for oviposition and a straw to serve as mating site; (E) the same container as in D, closed with pierced transparent plastic.

7.2.2. Statistical analysis

A F-test was used to determine if the variances of male and female developmental times and lifespans were equal at the 5% level. This was followed by an appropriate t-test to determine if there were differences in the developmental times and lifespan of males and females at the 5% level.

Developmental time, mortality data and fecundity were used to construct life tables for *E. acerbella*. The net replacement rate, $R_{o,}$ defined as the number of daughters that replace an average female in the course of a generation, was estimated using (Price 1984):

$$R_0 = \sum l_x m_x \qquad (1),$$

where l_x was the daily proportion of the population surviving in age interval x and m_x was the daily birth rate, converted to number of females per female, in age interval x. Since the exact day on which egg, larval and pupal mortality occurred could not be determined, it was assumed that all deaths in these stages occurred at the beginning of the stage.

The value for m_x was estimated using:

$$m_x = Pm_x^{'} \qquad (2),$$

where P was the proportion of females and $m_x^{'}$ was the total progeny produced per surviving female in age interval x.

The mean generation time, T, was estimated using (Andrewartha & Birch 1954; Price 1984):

$$T = \frac{\sum x l_x m_x}{\sum l_x m_x} \qquad (3),$$

where *x* was the age interval of each female. The intrinsic rate of natural increase was obtained by solving (Watson 1964):

$$\sum e^{-r_m x} l_x m_x = 1 \qquad (4).$$

This could only be done by iteration. Trial values for r_m were entered into expression (4) until the value on the left-hand side differed from one by not more than 0.0001. The first value entered into expression (4) was the instantaneous rate of increase determined using the following equation (Andrewartha & Birch 1954; Price 1984):

$$r_m = \frac{\ln(R_0)}{T} \qquad (5).$$

The reciprocal of the time to complete development from egg to adult (in days) was regressed (linearly) on temperature. The minimum temperature for development from egg to adult was determined by solving the regression for 1/*Time* = 0 (Campbell *et al*. 1974). The experiment at 15°C was not completed due to mechanical failure of the environment chamber. A few moths did however reach maturity before the experiment was terminated. The developmental times of these moths were used in this regression. Dummy variable regression (Gujarati 1970a, b) was used to determine whether or not there were differences in the regressions between the males and females. The following full model was used:

Y = A0 + B1D1 + (B0)X + (B2D1)X,

where

A0 = Basic intercept (males, all temperatures),
B0 = Basic slope (males, all temperatures),
B1 = Change in intercept,
B2 = Change in slope,

and

D1 = females, all temperatures

and

Y = 1/*Time*
X = Temperature.

This full model was compared, using a F-test, with a reduced model where a common slope and intercept for both sexes were assumed:

Y = (A0.1) + (B0.1)X.

The following hypotheses were tested:

H0: $B_i = 0$ for all i = 1 and 2 in the full model.
Ha: $B_i \neq 0$ for at least one i = 1 and 2 in the full model.

The reciprocals of the developmental times of the egg, larval and pupal stages were also regressed on temperature. The minimum temperature for development for the individual stages was determined by solving the regression for 1/*Time* = 0 (Campbell *et al*. 1974). At 15°C all the eggs hatched before the experiment was terminated and could therefore be used in the regression. The larvae and pupae that completed development before the experiment was terminated were used in these regressions.

The number of degree days (°*D*) needed for development was calculated using (Campbell *et al*. 1974):

$$°D = 1/b \qquad (6),$$

where *b* was the slope of the regression of 1/*Time* on temperature. The population doubling time, *D*, was determined using (Asante 1994):

$$D = \frac{\ln 2}{r_m} \qquad (7).$$

7.3. Results

7.3.1. Development

Only 0.45% of the eggs hatched at 30°C. Therefore, this temperature was not included in Table 7.2 that gives the duration of the development of males and females at each stage. Male and female eggs had similar developmental times (Table 7.2). Female larvae took longer to complete their development than male larvae, although this was only significant at 25 and 28°C (Table 7.2). Male pupae took significantly longer to complete their development than female pupae at all temperatures (Table 7.2). The development from egg to adult was similar for males and females (Table 7.2). The adult lifespan of female *E. acerbella* was significantly longer than that of males at all temperatures and the total lifespan of females was significantly longer than that of males at 20, 25 and 28°C (Table 7.2).

The developmental time of the eggs and pupae, as well as the adult and total lifespan, decreased with increasing temperature (Table 7.2). The developmental time of the larvae and development from egg to adult decreased when temperatures increased from 20 to 25°C, but was similar at 25 and 28°C (Table 7.2).

The proportion of females was 0.50%, 0.56% 0.41% and 0.54% at 20, 22, 25 and 28°C respectively (Table 7.2).

Table 7.2. The effect of temperature on the developmental time of *Epichoristodes acerbella*. The standard deviation and number of individuals are in brackets.

Temperature (°C)		20	22	25	28
Developmental time (in days)					
Egg	Female	10.38 (0.49; 80)	8.86 (0.54; 37)	7.03 (0.17; 34)	7.00 (0; 37)
	Male	10.31 (0.46; 81)	8.76 (0.44; 29)	7.02 (0.14; 48)	7.03 (0.18; 31)
	Difference between sexes	$t_{159} = 1.975$; P = 0.378	$t_{64} = 1.998$; P = 0.389	$t_{80} = 1.990$; P = 0.807	$t_{66} = 1.997$; P = 0.278
Larva	Female	35.74 (5.21; 80)	34.30 (6.80; 37)	25.44 (3.69; 34)	28.54 (8.71; 37)
	Male	34.15 (5.08; 81)	32.48 (5.78; 29)	23.42 (2.70; 48)	24.77 (4.68; 31)
	Difference between sexes	$t_{159} = 1.975$; P = 0.052	$t_{64} = 1.998$; P = 0.255	$t_{57} = 2.002$; P = 0.009	$t_{57} = 2.002$; P = 0.027
Pupa	Female	11.89 (0.60; 80)	10.08 (0.68; 37)	8.62 (0.60; 34)	8.03 (0.55; 37)
	Male	13.59 (0.80; 81)	11.24 (0.64; 29)	9.56 (0.58; 48)	8.84 (0.52; 31)
	Difference between sexes	$t_{148} = 1.976$; P < 0.001	$t_{64} = 1.998$; P < 0.001	$t_{80} = 1.990$; P < 0.001	$t_{66} = 1.997$; P < 0.001
Egg to adult	Female	58.00 (5.36; 80)	53.24 (7.22; 37)	41.09 (3.54; 34)	43.57 (8.77; 37)
	Male	58.05 (5.11; 81)	52.48 (5.87; 29)	40.00 (2.71; 48)	40.65 (4.69; 31)
	Difference between sexes	$t_{159} = 1.975$; P = 0.952	$t_{64} = 1.998$; P = 0.647	$t_{59} = 2.001$; P = 0.137	$t_{57} = 2.002$; P = 0.085
Adult lifespan	Female	12.76 (3.31; 80)	8.84 (1.86; 37)	8.50 (1.97; 34)	5.08 (1.26; 37)
	Male	8.89 (2.62; 81)	7.52 (2.35; 29)	7.56 (2.06; 48)	4.45 (1.12; 31)
	Difference between sexes	$t_{150} = 1.976$; P < 0.001	$t_{64} = 1.998$; P = 0.013	$t_{80} = 1.990$; P = 0.042	$t_{66} = 1.997$; P = 0.034
Total lifespan	Female	70.76 (6.45; 80)	62.08 (6.92; 37)	49.59 (3.83; 34)	48.65 (8.62; 37)
	Male	66.94 (5.93; 81)	60.00 (6.51; 29)	47.56 (2.70; 48)	45.10 (5.22; 31)
	Difference between sexes	$t_{159} = 1.975$; P < 0.001	$t_{64} = 1.998$; P = 0.218	$t_{56} = 2.003$; P = 0.010	$t_{60} = 2.000$; P = 0.041
Proportion females		0.50	0.56	0.41	0.54

7.3.2. Survival

Egg survival was highest at 22 and 25°C, lower at 20°C and very low at 28°C (Table 7.3). Almost no eggs hatched at 30°C (Table 7.3). Therefore, survival of the larvae and pupae and survival from egg to adult at this temperature are not shown in Table 7.3. Survival of the larvae and survival from egg to adult was highest at 20°C, lower at 22 and 25°C and lowest at 28°C (Table 7.3). Pupal survival decreased with increasing temperature (Table 7.3). Generally, the highest survival was in the pupal stage, except at 25°C (Table 7.3). Pupal survival was above 80% at all temperatures.

Table 7.3. The effect of temperature on the survival of *Epichoristodes acerbella*.

Temperature (°C)	Percentage survival			
	Egg	**Larva**	**Pupa**	**Egg to Adult**
20	74.43	76.65	92.53	52.79
22	86.01	60.98	88.00	46.15
25	87.65	65.77	83.67	48.24
28	43.03	47.16	81.93	16.63
30	0.45	-	-	-

7.3.3. Fecundity

The number of females ovipositing, the number of eggs produced per female, as well as the maximum number of eggs produced by a female, was highest at 20°C, lower at 22 and 25°C and very low at 28°C (Table 7.4). Oviposition almost ceased at 28°C, with only 5% of the females ovipositing. There was large variation in the number of eggs produced per female (Table 7.4). At 20 and 28°C, oviposition started within three days and at 22 and 25°C within about two days (Table 7.4). The duration of oviposition decreased with increasing temperature (Table 7.4). The post reproductive period of females was longer than the reproductive period, except at 22°C (Table 7.4).

Table 7.4. The effect of temperature on the fecundity of *Epichoristodes acerbella*. *n* = number of females; *SD* = standard deviation.

Temp (°C)	*n*	Proportion females ovipositing	Number of eggs per female		Reproductive life (days) ± *SD*		
			Average ± *SD*	Range	Pre-	During	Post-
20	80	0.66	135.70±156.86	0-497	3.00±2.98	4.25±2.16	4.85±2.38
22	37	0.43	76.05±117.88	0-401	1.94±1.39	3.44±1.46	3.25±1.53
25	34	0.50	83.50±129.21	0-410	2.18±1.42	2.53±0.87	3.76±2.08
28	37	0.05	6.54±30.33	0-173	3.00±1.41	1.00±0	2.50±0.71

7.3.4. Life table parameters

At 20, 22 and 25°C, the proportion surviving, l_x, was very similar for the first 30 to 40 days, after which it declined. This decline was more rapid at 25°C than at 20 and 22°C (Figure 7.2). The proportion surviving was much lower at 28°C than at 20, 22 and 25°C. Fecundity, m_x, was similar at 20 and 22°C, lower at 25°C and very low at 28°C (Figure 7.2). The production of females started later at 20°C than at the other temperatures (Figure 7.2).

The net replacement rate, mean generation time and the time (in days) to develop from the egg to the onset of reproduction decreased with an increase in temperature (Table 7.5). The intrinsic rate of increase was very similar at 20 and 22°C and decreased as temperature increased there after (Table 7.5). The net replacement rate and intrinsic rate of increase was especially low at 28°C due to the low fecundity at this temperature (Tables 7.4 and 7.5). The doubling time was similar at 20, 22 and 25°C, but much higher at 28°C due to the low fecundity (Tables 7.4 and 7.5).

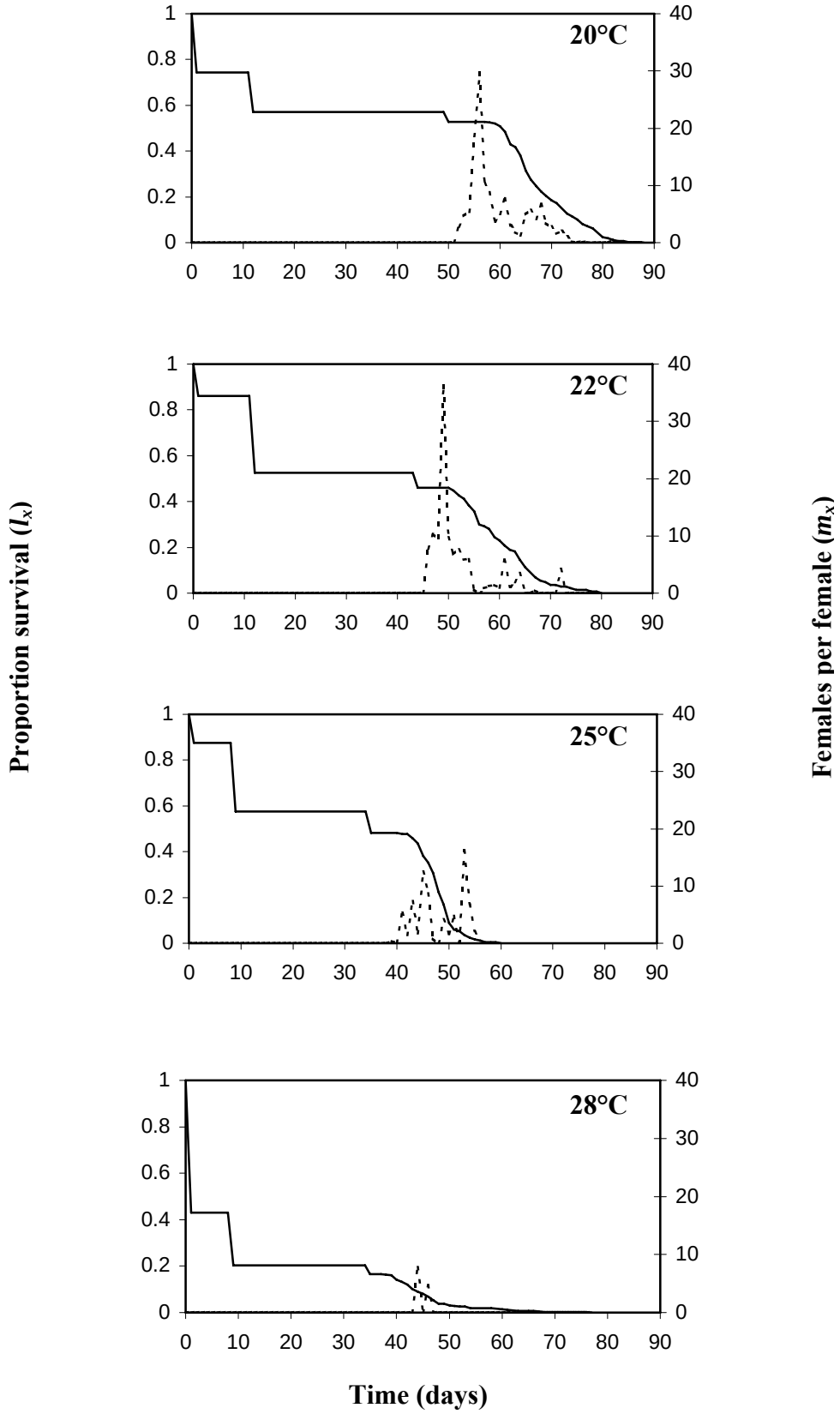


Fig. 7.2. Survivorship (l_x) (—) and fecundity (m_x) (----) curves of *Epichoristodes acerbella* at constant temperatures of 20, 22, 25 and 28°C.

Table 7.5. Life table statistics for *Epichoristodes acerbella,* reared at four constant temperatures. R_o = Net replacement rate; r_m = Intrinsic rate of increase; *T* = Mean generation time; *SD* = Standard deviation.

Temp (°C)	R_o	r_m	Doubling time (days)	*T* (days)	Egg to beginning of reproduction (days) ± *SD*
20	60.75	0.0714	9.70	58.07	62.04±6.12
22	48.99	0.0780	8.88	50.29	54.06±7.18
25	17.73	0.0648	10.70	44.66	45.06±3.21
28	1.03	0.0007	1016.34	44.62	42.50±2.12

Both the slope and intercept of the regression of 1/*Time* on temperature of females differed significantly from those of the males (Table 7.6). Therefore, the full model could not be reduced to a model with a common slope and intercept for males and females (F = 6.063; d.f. = 2, 388; P = 0.003). The regressions for the males and females, as well as the regression equations, are shown in Figure 7.3. The minimum temperature for development from egg to adult was lower for the females (1.64°C) than for the males (5.07°C) (Figure 7.3). The number of degree days needed for *E. acerbella* females to complete development was 1051.01 °D and 856.46 °D for males. The regressions of 1/*Time* on temperature, as well as the regression equations, for egg, larval and pupal development are shown in Figure 7.4. The minimum temperatures for development of the egg, larval and pupal stages were 5.63, 3.71 and 5.85°C respectively (Figure 7.4).

Table 7.6. Regression coefficients with their standard errors and probability levels for the full model for the regression of the reciprocal of developmental time of *Epichoristodes acerbella* from egg to adult over temperature. A0 = Basic intercept (males); B0 = Basic slope (males); B1 = Change in intercept (females); B2 = Change in slope (females).

	Regression coefficient	Standard error	Probability level
A0	-0.0059	0.001	<0.001
B0	0.0012	<0.001	<0.001
B1	0.0043	0.002	0.009
B2	-0.0002	<0.001	0.003

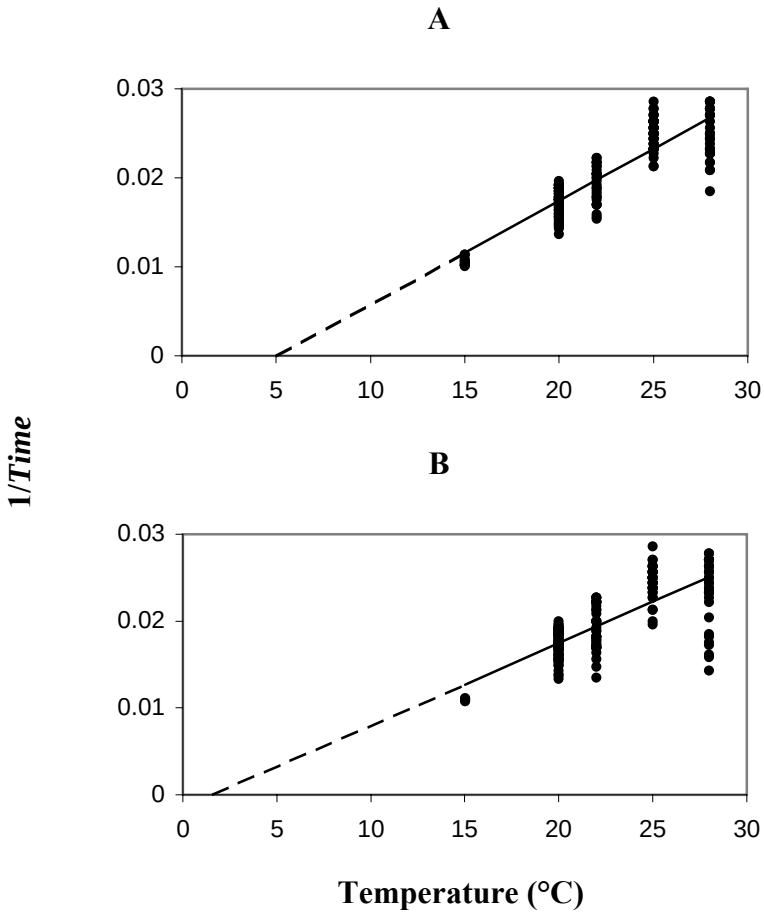


Figure 7.3. Linear relationship between the reciprocal of the generation time and temperature for (A) male (y = 0.0012x – 0.0059) and (B) female (y = 0.0010x – 0.0016) *Epichoristodes acerbella*. P < 0.001; R = 0.83.

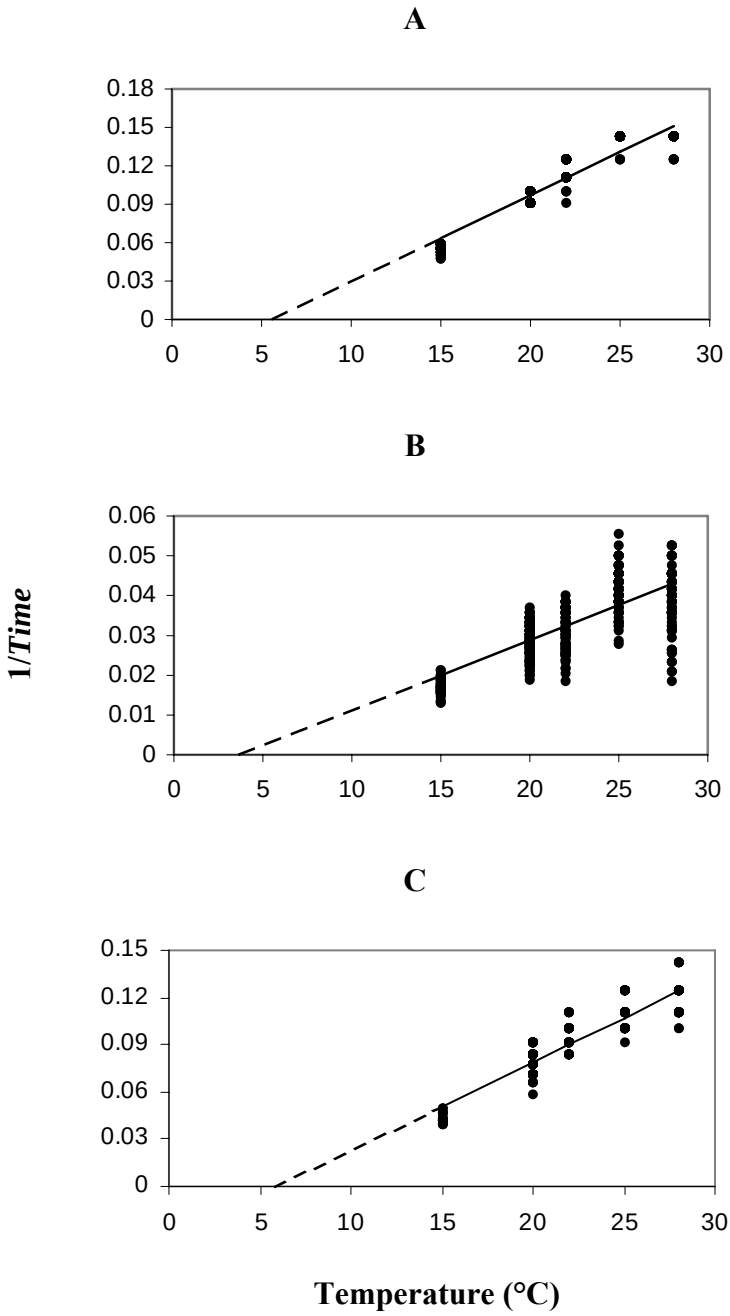


Figure 7.4. Linear relationship between the reciprocal of developmental time and temperature for (A) eggs (y = 0.0068x – 0.0381; r = 0.96), (B) larvae (y = 0.0018x – 0.0066; r = 0.75) and (C) pupae (y = 0.0056x – 0.0328; r = 0.91) of *Epichoristodes acerbella*. P < 0.001 for all regressions.

7.4. Discussion

Developmental time, adult lifespan and total lifespan generally decreased with increasing temperature. At 20, 22 and 25°C, the developmental times for the eggs, larvae and pupae were similar to the results obtained by Bolton (1979). Bolton (1979) did not investigate the influence of a constant temperature of 28°C on the development of *E. acerbella*. Egg development was generally one day shorter and larval development one to two days longer than that observed by Bolton (1979). The exception was at 22°C where larval development was about one week longer than that recorded by Bolton (1979). The adult lifespan was however shorter. Both female and male moths lived about five days less at 20°C and about three days less at 25°C than reported by Bolton (1979). At 22°C, male moths lived about four days less and female moths about seven days less. However, Bolton (1979) kept the moths in constant darkness as apposed to the present study where moths were kept at a photoperiod of 12 hours light and 12 hours dark. Bolton (1979) also supplied the moths with water-saturated cotton wool. In the present study, moths were not supplied with water, since this resulted in fungal growth in the closed containers. In addition, Bolton (1979) used the diet by Bot (1967), which differed slightly from the one used in the present study, containing wheat germ (26 *g*), vitamin free casein (4 *g*), brewers yeast (25 *g*), agar (6 *g*), ascorbic acid (2.5 *g*), inositol (0.1 *g*), cholesterol (0.1 *g*), choline chloride (0.2 *g*), nipagin M (1.3 *g*) and water (250 *g*). Bolton (1979) also found that the female moths lived longer than the males, as was the case in the present study. Gabarra *et al*. (1986), however found no difference between the adult lifespan of the males and females collected from carnation crops in El Maresme in Spain.

Survival generally decreased with increasing temperature. At 20, 22 and 25°C, survival of all stages was lower than that observed by Bolton (1979). Egg survival was between 8 and 20% lower than observed by Bolton (1979), larval survival between 12 and 29% lower and pupal survival between 2 and 14% lower, depending on the temperature. Egg survival recorded by Gabarra *et al*. (1986) was not as high as the survival recorded by Bolton (1979). In the present study egg survival at 20°C was about 4% lower than observed by Gabarra *et al*. (1986) and about 7% higher at 22 and 25°C. Gabarra *et al*. (1986) kept the eggs at a photoperiod of 16L:18D and the eggs were oviposited by moths collected in carnation crops and not by moths reared in the

laboratory as was the case in the present study and in Bolton's (1979) study. In the present study, only 0.45% of the eggs hatched at 30°C. Low egg survival at 30°C was also observed by Bolton (1979), whom recorded 0.8% egg hatch. Gabarra *et al*. (1986) observed no egg hatch at 30°C. Generally the pupal stage had the highest survival. This was also reported by Bolton (1979).

Fecundity also generally decreased with increasing temperature. It was very low at 28°C. At 20, 22 and 25°C, the number of eggs per female was much lower than observed by Bolton (1979) and Gabarra *et al*. (1986). Gabarra *et al*. (1986) recorded the number of eggs per female for moths collected in carnation crops, for second generation moths reared on a diet containing water (700 *c.c.*), agar (15 *g*), maize semolina (25 *g*), wheat germ (21 *g*), alfalfa powder (27 *g*), ascorbic acid (4 *g*), sorbic acid (4.5 *g*) and mineral vitamin complex Micebrina ® (7 pills) and, at 22°C, for moths reared on this alfalfa diet, carnation cuttings and carnation flowers. In all cases the number of eggs per female was higher than in the present study. Gabarra *et al*. (1986) did not investigate the influence of a constant temperature of 28°C on oviposition. The lower oviposition rate in the present study can possibly be attributed to a lack of water. Gabarra *et al*. (1986) and Bolton (1979) supplied water. Gabarra *et al*. (1986) did not keep the moths in constant darkness as was the case in Bolton's (1979) study and recorded higher oviposition than Bolton (1979). Therefore, it is unlikely that the 12L:12D photoperiod in the present study was responsible for the low oviposition recorded here. It is also doubtful that the diet used in the present study could have lead to lower oviposition. Gabarra *et al*. (1986) found no significant difference in fecundity of moths when the larvae were reared on carnation flowers, carnation cuttings and the alfalfa diet. Bolton (1979) also found no significant difference in fecundity of moths when the larvae were reared on carnation cuttings and an artificial diet at 20°C. At 25°C, more eggs per female were oviposited when reared on the artificial diet than on the carnation cuttings (Bolton 1979).

The net replacement rate and intrinsic rate of increase decreased with increasing temperature, again being extremely low at 28°C, resulting in an extremely high population doubling time. It was clear that *E. acerbella* favoured more moderate constant temperatures (between 20 and 25°C), with the higher temperature of 28°C being unfavorable for sustainable development. Bolton (1979) found constant

temperatures between 15 and 25°C to be optimal for development. Gabarra *et al*. (1986) found the highest fecundity at a constant temperature of 25°C and lower fecundity at extreme temperatures of 10, 27 and 30°C. The minimum temperature for development for males in the present study was 5.07°C and for females 1.64°C. This difference between male and female development was also reflected in the number of degree days needed to complete development from egg to adult. The females needed more degree days than the males to complete development. Bolton (1979) and Gabarra *et al*. (1986) did not determine the number of degree days needed for development. Bolton (1979) also reared *E. acerbella* at a constant temperature of 9.5°C. At this temperature, developmental time was long and mortality high. In the present study, the minimum temperature for development of the egg, larval and pupal stages were lower than observed by Bolton (1979) (1.57, 3.29 and 2.05°C lower for egg, larval and pupal development respectively), indicating that *E. acerbella* in the Hex River Valley maybe able to tolerate lower temperatures better than *E. acerbella* in the Krugersdorp district from where larvae and pupae were collected for the study by Bolton (1979).

It is concluded that the *E. acerbella* strain in the Hex River Valley is also sensitive to high temperatures and that this may be the reason why moth activity decreases during the middle of the fruit season (from the end of October onwards) (see Chapter 3, section 3.3.5). However, infestation by the larvae did not decline during this period. The first larval bunch infestation were recorded during November and they were active throughout the fruit season (see Chapter 3, section 3.3.5). However, there was a decline in bunch infestation during the warm months of January and February (see Chapter 3, section 3.3.5). This maybe due to their sensitivity to high temperatures.

7.5. References

Andrewartha, H.G. & Birch, L.C. 1954. *The Distribution and Abundance of Animals*. University of Chicago Press, Chicago.

Asante, S.K. 1994. *Biological and Ecological Studies on the Woolly Apple Aphid,* Eriosoma lanigerum *(Hausmann) (Hemiptera: Pemphigidae), with Reference to Control*. PhD Dissertation. University of New England.

Bolton, M.C. 1979. Some effects of temperature, humidity and larval diet on the life cycle of the South African carnation worm, *Epichoristodes acerbella* (Walker) (Lepidoptera: Tortricidae). *Journal of the Entomological Society of Southern Africa* 42: 129-135.

Bot, J. 1967. An artificial rearing medium for three Noctuids of economic importance belonging to the genus *Spodoptera* (Lepidoptera). *Journal of the Entomological Society of Southern Africa* 29: 157-160.

Campbell, A., Frazer, B.D., Gilbert, N., Gutierrez, A.P. & Mackauer, M. 1974. Temperature requirements of some aphids and their parasites. *Journal of Applied Ecology* 11: 431-438.

Gabarra, R., Buisán, A., Avilla, J. & Albajes, R. 1986. Longevity, fecundity and egg hatching of *Epichoristodes acerbella* under constant temperatures (Lepidoptera: Tortricidae). *Entomologia Generalis* 12: 45-50.

Guennelon, G., Audemard, H., Fremond, J.C. & Idrissi Ammari, A.M. 1981. Progrès réalisés dans l'élevage du carpocapse (*Laspeyresia pomonella* L.) sur milieu artificiel. *Agronomie* 1: 59–64.

Gujarati, D. 1970a. Use of dummy variables in testing for equality between sets of coefficients in two linear regressions: a note. *American Statistician* 24(1): 50-53.

Gujarati, D. 1970b. Use of dummy variables in testing between sets of coefficients in linear regression: a generalization. *American Statistician* 24(5): 18-22.

Price, P.W. 1984. *Insect Ecology. Second Edition.* John Wiley & Sons, New York.

Pryke, J.S. 2005. *Insect Contaminants in Table Grapes*. MSc Thesis, University of Stellenbosch.

Romoser, W.S. 1981. *The Science of Entomology. Second Edition.* Macmillan Publishing Co., Inc., New York.

Romoser, W.S. & Stoffolano, J.G. 1998. *The Science of Entomology. Fourth Edition.* McGraw-Hill Companies, Inc., Boston.

Watson, T.F. 1964. Influence of host plant condition on population increase of *Tetranychus telarius* (Linnaeus) (Acarina: Tetranychidae). *Hilgardia* 35: 273-322.

CHAPTER 8

SUMMARY AND PROPOSED MONITORING SYSTEM

8.1. Summary

A sampling system, based on inspecting 20 plots of five vines per plot per hectare, has been developed for monitoring population levels of *Planococcus ficus*, the key pest of table grapes (Walton 2003). Due to the feasibility of this sampling system to farmers, monitoring in the present study was based on this sampling plan in order to try and extend this protocol to the rest of the table grape pest complex. This would result in a generic monitoring system that can be used for the major table grape pests instead of using different sampling systems for different pests.

For phytophagous mites, one leaf from each of the five vines in each of the 20 plots was inspected. The only phytophagous mite species found on the vine leaves was *Tetranychus urticae*. Mites can be sampled either by counting all the mites on the leaves, using an economic threshold of six mites per leaf, or by simply classifying the leaves as infested or uninfested (presence-absence sampling). The presence-absence sampling was far less reliable, but since *T. urticae* is not a direct pest, a high degree of precision is not needed, as is the case with the direct pests, since under reacting will not lead to direct crop losses. An economic threshold of 11 to 29% infested leaves is recommended for presence-absence sampling, depending on other factors such as leaf quality.

Important predatory mites found on both vine leaves and cover crop plants in the Hex River Valley were *Euseius addoensis*, *Neoseiulus californicus* and an undescribed phytoseiid in the genus *Typhlodromus*. On vine leaves, the predatory mite complex was not spatially associated with *T. urticae*. This was ascribed to the fact that the predatory mite complex consisted mostly of *E. addoensis*. The latter is a generalist feeder and therefore not dependent on the presence of *T. urticae* for its survival. The

predatory mites did however keep *T. urticae* under control since the economic threshold was never reached and no acaricides were applied.

A wide variety of cover crop plants served as hosts for *T. urticae* and the predatory mites throughout the year. The most important cover crop plants for the predatory mites were *Malva parviflora* and *Raphanis raphanistrum*, which harbored predatory mites throughout the year. The presence of all these plants created suitable conditions for the survival of both phytophagous and predatory mites and may have influenced their presence on the vine leaves. The exact impact of these plants on the presence of spider and predatory mites in the vine itself still need to be determined in future studies.

Planococcus ficus was monitored by inspecting one stem, shoot, leaf and bunch from each of the five vines in each of the 20 plots, as well as inspecting pheromone traps at a density of one trap per block of one to two hectares. *Planococcus ficus* stem infestation preceded bunch infestation. This was also observed by Walton (2003) who suggested that stem infestation should be used as an early warning for bunch infestation. Due to the positive spatial association between *P. ficus* bunch infestation and stem infestation, the latter gave an indication of where bunch infestation could be expected, facilitating the planning of spot treatments to prevent bunch infestation. Control measures for *P. ficus* should be applied at 2% stem infestation (Walton 2003). Where pheromone traps were used, stem inspections should start when more than 65 *P. ficus* males were caught per pheromone trap per two weeks (Walton *et al*. 2003). Counting *P. ficus* males on the sticky pads, placed in the pheromone traps, was time consuming. To reduce the counting time, the number of blocks in the grid of the traps in which *P. ficus* males were present was counted in the field and correlated with the actual *P. ficus* counts. When *P. ficus* males were found in 27 grid blocks on the sticky pad, stem inspections could be initiated.

The presence of thrips in the vine was monitored by sampling one leaf from each of the five vines in each of the 20 plots, as well as using four to five blue sticky traps per block of one to two hectares. Halo spot damage caused by *Frankliniella occidentalis* was assessed by inspecting five bunches per plot of five vines. There was a correlation between thrips found on the blue sticky traps and halo spot damage

observed four weeks later in some of the vineyards. The use of the sticky traps for predicting damage is however not recommended, due to difficulty with identification of thrips on the sticky traps. A variety of thrips species was found on the vine leaves. Their presence on the leaves could not be used to predict halo spot damage, due to the general lack of spatial association between thrips on the leaves and halo spot damage, caused only by *F. occidentalis*. A suitable sampling method for *F. occidentalis* still needs to be developed. The monitoring system described here could only provide information on the infestation status of the vineyard.

Epichoristodes acerbella was monitored by inspecting one bunch from each of the five vines in each of the 20 plots, as well as inspecting pheromone traps at a density of one trap per block of one to two hectares. The number of moths found in the pheromone traps could not be used as an indication of the amount of bunch damage that could be expected. The traps could therefore only be used to identify vineyards where this pest was present and where phytosanitary problems may arise. If a threshold of 5% bunch damage was used for *E. acerbella*, there would have been a good chance of not under spraying if control measures were applied at 1% bunch damage. Bunch infestation by *Epichoristodes acerbella* and vinegar flies (*Drosophila* and *Zaprionus* species) was spatially disassociated. Vinegar fly bunch infestation, which was easy to detect, could therefore not be used as an indication of *E. acerbella* bunch damage, which was more difficult to detect. This finding was however based on the investigation of only one instance and more data are needed to confirm this.

Epichoristodes acerbella favoured more moderate constant temperatures (between 20 and 25°C), with temperatures of 28°C and above being unfavourable for development. This confirmed the findings of Bolton (1979) and Gabarra *et al*. (1986) that *E. acerbella* is sensitive to high temperatures. There was a difference between male and female development, with females having a longer adult lifespan than males. The females were able to develop at lower temperatures than males. The minimum temperature for development for males was 5.07°C and 1.64°C for females. The minimum temperatures for development of the egg, larval and pupal stages were lower than observed by Bolton (1979), indicating that *E. acerbella* in the Hex River Valley may be able to tolerate lower temperatures better than *E. acerbella* in the

Krugersdorp district from where larvae and pupae were collected for the study by Bolton (1979).

Helicoverpa armigera was monitored by inspecting one bunch from each of the five vines in each of the 20 plots, as well as one pheromone trap per block of one to two hectares. *Helicoverpa armigera* were caught in the pheromone traps, but no damage was observed, indicating that the number of moths found in pheromone traps did not give a good indication of the amount of damage that could be expected. The traps could only be used to identify vineyards where this pest was present and where phytosanitary problems may arise. *Helicoverpa armigera* has been found infesting bunches in other grape producing areas in South Africa.

Phlyctinus callosus was monitored by inspecting one shoot and bunch from each of the five vines in each of the 20 plots, the leaves around the stems of each of the five vines in each plot and one cardboard band, tied around the stem of one vine in each of the 20 plots. *Phlyctinus callosus* shoot and bunch damage occurred at about the same time. Shoot damage could therefore not be used as an early warning for bunch damage. In general, the number of *P. callosus* under the cardboard bands gave an indication of the amount of *P. callosus* bunch damage that could be expected two weeks later. This was however not the case in individual vineyard blocks. The cardboard bands could be used to identify areas where damage could be expected, due to the positive spatial association between weevils under the bands and bunch, leaf and shoot damage. The bands could also be used to identify vineyards where *P. callosus* was present and therefore where phytosanitary problems may arise for the USA and Israeli markets. If a threshold of 5% bunch damage was used for *P. callosus*, there would have been a good chance of not under spraying if control measures were applied at 1% bunch damage.

For *T. urticae* (only on the Dauphine leaves), *P. ficus* bunch and stem infestation and *F. occidentalis*, *E. acerbella* and *P. callosus* bunch damage, the sampling error when 20 plots of five vines per plot were inspected, exceeded 20%, an acceptable value for pest management purposes (Reusink & Kogan 1994). This did not imply that the monitoring system could not be used. Operational characteristic curves were used as an indication of the degree of precision of decision making based on the monitoring

system. It should not be necessary to sample more than 20 plots, of five vines per plot, per one to two hectares for *T. urticae* on the vine leaves, *P. ficus* bunch and stem infestation and *F. occidentalis*, *E. acerbella* and *P. callosus* bunch damage, since the sampling error did not decline dramatically when more than 20 sampling units were used.

In the case of phytosanitary pests, the number of sampling units required to conclude with a 99% degree of certainty that infestation levels in the pack shed would be 10% or less, exceeded 20 plots by a large amount (Table 8.1). This was particularly the case for bunches of 100 grams. Pringle (unpublished report) suggested a pre-inspection sampling plan for pack sheds. The number of bunches that needed to be inspected to detect a 10% infestation of boxes of grapes at a binomial probability of 99% was calculated. The results were similar to the results in the present study, suggesting that either of the two methods (field or pack-shed inspections) could be used (Table 8.1).

Table 8.1. The number of plots (consisting of five vines) and bunches that need to be inspected, either in the field or in the pack shed, to conclude with a 99% degree of certainty that a 10% infestation level (of boxes of grapes) in the pack shed will be detected.

Bunch size (gram)	**Field inspection:** Number of plots (number of bunches in brackets) *Epichoristodes acerbella*	**Pack shed inspection:** Number of bunches* All phytosanitary pests
100	463 (2315)	2070
200	222 (1110)	1034
300	142 (710)	688
400	106 (530)	516
500	84 (420)	412
600	69 (345)	343
700	58 (290)	294
800	51 (255)	257
900	45 (225)	228

* Pringle (unpublished report)

8.2. Proposed monitoring system for table grape pests in the Hex River Valley

Twenty plots of five vines per plot should be selected per one to two hectares. The way in which the protocol used for monitoring *P. ficus* (Walton 2003) can be extended to include the rest of the table grape pest complex is summarised in Table 8.2. This protocol needs to be evaluated on farm level to make sure the farmers find it feasible and reliable. Information gained in this study may also aid in the future development of a pest management system, incorporating the proposed monitoring system, as well as exploring vineyard floor management for biological control of *T. urticae*.

8.3. References

Bolton, M.C. 1979. Some effects of temperature, humidity and larval diet on the life cycle of the South African carnation worm, *Epichoristodes acerbella* (Walker) (Lepidoptera: Tortricidae). *Journal of the Entomological Society of Southern Africa* 42: 129-135.

Gabarra, R., Buisán, A., Avilla, J. & Albajes, R. 1986. Longevity, fecundity and egg hatching of *Epichoristodes acerbella* under constant temperatures (Lepidoptera: Tortricidae). *Entomologia Generalis* 12: 45-50.

Reusink, W.G. & Kogan, M. 1994. The quantitative basis of pest management: Sampling and measuring. In: Metcalf, R.L. & Luckman, W.H. (Eds) *Introduction to Insect Pest Management, Third Edition*. 355-391. John Wiley and Sons, Inc., New York.

Walton, V.M. 2003. *Development of an Integrated Pest Management System for Vine mealybug,* Planococcus ficus *(Signoret), in Vineyards in the Western Cape Province, South Africa*. PhD Dissertation, University of Stellenbosch.

Walton, V.M., Pringle, K.L. & Daane, K.M. 2003. Geïntegreerde beheer van wingerdwitluis (*Planococcus ficus*) met behulp van feromoonvalletjies in wingerde in Suid-Afrika. *Wynboer: 'n Tegniese Gids vir Wynprodusente* 168: 15-16.

Table 8.2. Proposed monitoring system for table grape pests in the Hex River Valley. For plant inspections, only the presence or absence of the pests should be recorded. For *Planococcus ficus* traps, the number of grid blocks on the sticky pad with males present should be counted. For *Phlyctinus callosus* bands and *Epichoristodes acerbella* and *Helicoverpa armigera* traps, the number of insects should be counted. *Helicoverpa armigera* is a sporadic pest and monitoring is optional.

	Plant part or trap/band	Pest	When to sample	Information gained	Frequency	When to control
PLANT INSPECTIONS	Top fork of each of the five vines per plot, to a distance of within 30cm of the stem	*Planococcus ficus*	After *P. ficus* males were found in 27 grid blocks on the sticky pad in the pheromone trap. Sample until harvest.*	Infestation status; When to control	Biweekly	2% stem infestation
	One leaf per vine	*Tetranychus urticae*	October until harvest	Infestation status; When to control	Biweekly	11-29% leaf infestation
	One bunch per vine	*Frankliniella occidentalis*	November until end of harvest (late cultivars); October until end of harvest (early cultivars)	Infestation status	Biweekly	-
		Epichoristodes acerbella	November until end of harvest (late cultivars); October until end of harvest (early cultivars)	Infestation status and when to control; Identify vineyards where *E. acerbella* is present and where phytosanitary problems may arise	Biweekly	1% bunch damage (for markets where pest is allowed)
		Phlyctinus callosus	October until end of harvest (late cultivars); September until end of harvest (early cultivars)	Infestation status and when to control; Identify vineyards where *P. callosus* is present and where phytosanitary problems may arise	Biweekly	1% bunch damage (for markets where pest is allowed)
		Planococcus ficus	January until end of harvest (late cultivars); December until end of harvest (early cultivars)	Infestation status	Biweekly	-
TRAPS AND BANDS	Corrugated cardboard bands, tied around the stems of one vine per plot	*Phlyctinus callosus*	Mid-September until end of harvest. After sampling, move band onto next vine in plot.	Identify vineyards where *P. callosus* is present and where phytosanitary problems may arise; Identify areas where *P. callosus* bunch damage can be expected	Biweekly	-
	Pheromone traps, at a density of one trap per one to two hectares	*Planococcus ficus*	October until end of harvest	When to start stem inspections	Biweekly	-
		Epichoristodes acerbella	May until end of harvest	Identify vineyards where *E. acerbella* is present and where phytosanitary problems may arise	Weekly	-
		Helicoverpa armigera	September until end of harvest	Identify vineyards where *H. armigera* is present and where phytosanitary problems may arise	Weekly	-

*Sampling may also be done during the rest of the year, on a monthly basis, in commercial blocks with a history of high infestation (Walton *et al*. 2003).

Appendix A

Table A1. Information on the vineyard blocks that were used in the study. Vineyards A04, B03 and C6 were divided into two equal blocks.

Farm	Vineyard	Cultivar	Year of planting	Block size in hectares	Soil type
Klipheuwel	A04, block A	Barlinka	1994	1.17	Sand-clay
	A04, block B	Barlinka	1994	1.17	Sand-clay
	B03, block A	Dauphine	2000	1.17	Sand-clay
	B03, block B	Dauphine	2000	1.17	Sand-clay
Boplaas	B5	Barlinka	1988	0.78	Sand & stone
	B6	Barlinka	1981	1.33	Sand & stone
	C6, block A	Dauphine	1994	1.68	Sand & stone
	C6, block B	Dauphine	1994	1.68	Sand & stone
De Vlei Boerdery	Nr 2	Barlinka	1990	1.36	Sand-loam
	Nr 3	Barlinka	1993	1.79	Sand-loam
	Nr 8	Dauphine	1992	1.65	Clay
	Nr 9	Dauphine	1996	1.20	Clay
	Nr 10*	Barlinka	1988	0.80	Clay

*Vineyard Nr 10 was used from the 2003/2004 season onwards due to the removal of vineyard Nr 3 prior to this season.

Table A2. Chemicals sprayed against pests in the vineyard blocks at Klipheuwel (2002/2003 season's data not available). BR = Barlinka; DP = Dauphine.

Season	Vineyard	Cultivar	Date	Chemical	Pest
2003/2004	A04 (blocks A & B)	BR	10 Nov 03	Prothiofos	*P. ficus*
	B03 (blocks A & B)	DP	12 Nov 03	Prothiofos	*P. ficus*
2004/2005	A04 (blocks A & B)	BR	10, 24 Aug 04	Chlorpyrifos	*P. ficus*
	B03 (blocks A & B)	DP	10, 24 Aug 04	Chlorpyrifos	*P. ficus*

Table A3. Chemicals sprayed against pests in the vineyard blocks at Boplaas. BR = Barlinka; DP = Dauphine.

Season	Vineyard	Cultivar	Date	Chemical	Pest
2002/2003	B5 & B6	BR	5, 20 Aug 02	Chlorpyrifos	*P. ficus*
			2, 14 Oct 02	Bromopropylate	*Colomerus vitis*
			2 Oct 02; 13, 27 Nov 02; 6, 23 Jan 03	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
			5 Nov 02	Formetanate & sugar	*F. occidentalis*
			10, 27 Dec 02	*Bacillus thuringiensis* var. *kurstaki*	*H. armigera*
	C6 (blocks A & B)	DP	12 Sep 02	Chlorpyrifos	*P. ficus*
			2, 15 Oct 02	Bromopropylate	*Colomerus vitis*
			24 Oct 02	Formetanate & sugar	*F. occidentalis*
			2 Oct 02; 12, 26 Nov 02; 6, 23 Jan 03	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
			11, 28 Dec 02	*Bacillus thuringiensis* var. *kurstaki*	*H. armigera*

Table A3. Continued

Season	Vineyard	Cultivar	Date	Chemical	Pest
2003/2004	B5 & B6	BR	13, 30 Aug 03	Chlorpyrifos	*P. ficus*
			22 Oct 03; 6 Nov 03	Endosulfan	*Colomerus vitis*
			20 Nov 03; 3, 15, 30 Dec 03	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
			8 Jan 04	Mevinphos	*P. ficus*
	C6 (blocks A & B)	DP	22 Aug 03; 2 Sep 03	Chlorpyrifos	*P. ficus*
			22 Oct 03	Endosulfan	*Colomerus vitis*
			28 Oct 03	Prothiofos	*P. ficus*
			7, 19 Nov 03; 4, 15 Dec 03; 6, 13 Jan 04	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
			11 Nov 03	Formetanate & sugar	*F. occidentalis*
2004/2005	B5 & B6	BR	25 Oct 04	Endosulfan	*Colomerus vitis*
			9, 22 Nov 04; 7 Dec 04; 4, 18 Jan 05	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
	C6 (blocks A & B)	DP	26 Oct 04	Endosulfan	*Colomerus vitis*
			2 Nov 04	Spinosad	*F. occidentalis*
			9, 25 Nov 04; 8 Dec 04; 5, 17 Jan 05	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*

Table A4. Chemicals sprayed against pests in the vineyard blocks at De Vlei Boerdery. BR = Barlinka; DP = Dauphine; Vineyard Nr 3 was replaced with vineyard Nr 10 with the onset of the 2003/2004 season.

Season	Vineyard	Cultivar	Date	Chemical	Pest
2002/2003	Nr 2 & Nr 3	BR	20 Aug 02	Chlorpyrifos	*P. ficus*
			3, 17 Oct 02	Endosulfan	*E. acerbella*
			31 Oct 02; 11, 27 Nov 02; 11, 27 Dec 02; 20 Jan 03; 10 Feb 03	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
	Nr 8 & Nr 9	DP	3 Sep 02	Chlorpyrifos	*P. ficus*
			10, 16 Oct 02	Endosulfan	*E. acerbella*
			30 Oct 02; 13, 27 Nov 02; 11, 23 Dec 02	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
			27 Nov 02	Mercaptothion & protein	*Ceratitis* spp.
2003/2004	Nr 2, Nr 10 & Nr 8, Nr 9	BR & DP	7 Aug 03	Chlorpyrifos	*P. ficus*
			13, 27 Oct 03; 10 Nov 03	Endosulfan	*E. acerbella*
			24 Nov 03; 8, 22 Dec 03; 12, 26 Jan 04; 16 Feb 04	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*
			15 Dec 03	Mercaptothion & protein	*Ceratitis* spp.
			19 Jan 04	Mevinphos	*P. ficus*
2004/2005	Nr 2, Nr 10 & Nr 8, Nr 9	BR & DP	4 Aug 04	Chlorpyrifos	*P. ficus*
			29 Sep 04*; 13 Oct 04	Endosulfan	*E. acerbella*
			9, 24 Nov 04; 6, 21 Dec 04; 19**, 26 Jan 05**	*Bacillus thuringiensis* var. *kurstaki*	*E. acerbella*

* Not in Nr 9; ** Only in Nr 2 & Nr 10