Integrated Control of Soft Scale Insect on *Boronia megastigma* Nees in Southern Tasmania

by

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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and to the best of my knowledge contains no copy of material published by any other person except where due reference has been made.

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Summary

Two scale insects, black scale (*Saissetia oleae* Oliver) and soft brown scale (*Coccus hesperidum* L.). (Coccidae) have been found infesting Tasmanian commercial boronia plantations. These species have become serious pests to some boronia growers. Black scale is the most serious pest.

These scale species have been intensively studied on olive and citrus trees and in this investigation scale taxonomy, morphology, population performance and damage on boronia were examined.

Damage to the boronia bush caused by these scale species can be directly caused by feeding the sap of the boronia plant and indirectly by the secretion of honey-dew that leads to the development of sooty-mould which, in turn reduces photosynthesis. In heavily infested bushes vegetative growth may be suppressed and flower yield reduced by up to 37 %. In extreme cases parts of the bush may die or be killed due to scale infestation. Bushes that have been mechanically damaged at the base of the plant during cultural practices and particularly following mechanical flower harvesting are highly susceptible to infestation due to the growth of new callus at points of injury .

The black scale (*Saissetia oleae*) has one generation per year. The female deposits an average of 1208 eggs. Active crawlers of the black scale appear in January and they wander around before settling at suitable sites. Under glasshouse conditions they settled within 48 hours. The distribution of this scale is over the entire bush. Immature stages settle on the lower and upper surfaces of leaves or on stems; however, in the adult stage most scale prefer to settle on the shoots. Migration of immature stages from leaves to shoots occured before the adult stage formed to secure further scale development from winter through spring. High temperatures were a key factor influencing mortality of first stage nymphs and very high mortality of black scale was recorded when temperatures reached 41^{o} C in summer.

The soft brown scale has three generations each year. The distribution of this scale, both immature and mature stages, tends to be on the top half of the bush on

leaves and stems but during spring through summer it prefers to settle on leaves rather than stems. New generations appear in summer, autumn and spring.

Some weeds act as an alternative host for immature black scale. These weeds are *Rumex acetosella.* Fourr (sorrel), *Leontondon taraxacoides.* (Vill) Merat (hawkbit), *Hypochaeris sp..* (flat weed or cat's ear), *Trifolium repens.* L(White clover), *Stylidium graminifolium.* Swartz (trigger plant) and *Solanum nigrum* L (black nightshade).

Five parasitoids of both scale species were recognised and identified to belong to the families Aphenilidae (two species), Encyrtidae (two species) and Pteromalidae (one *Moranila* sp.). Four coccinellids (*H. conformis, C. mellyi, Rhyzobius. sp.* and *Stethorus* spp.), a predatory mite (*Anystis.* sp.), the green lacewing (*Chrysopus* sp.) and brown lacewing (*Mycromus* sp.) were found to prey on scale populations.

As natural enemies cannot keep the scale species below economic threshold levels chemicals have been applied to control the scale populations. Some chemicals were therefore evaluated for their effectiveness in controlling the scale insects. Petroleum spray oil (D-C-Tron NR) at a concentration of 1.0 - 1.2% (10 - 12 ml/L water) was found to be the most effective agent and resulted in mortalities of ca. 92 % if applied from the sides and to the top of the bushes, or the entire plant sprayed until run-off. However, petroleum spray oil must be applied to the vulnerable stages (first and second stage nymphs) of the scale insects' life cycle to achieve this level of control. Petroleum spray oil (1.0 - 1.2%) applied in February and repeated after 4 weeks gave good control of both scales on two farms. When the soft brown scale occurred alone, the oil was best applied in January or early February and then repeated after 4 weeks. At concentrations of 1.0 - 1.2% the oil did not affect the vegetative growth or flower yield of the bush.

Three insect growth regulators (IGRs), buprofezin (Applaud 40 SC), kinoprene (Enstar 5E) and methoprene (Diacon 40) significantly suppressed the development of subsequent generations of both scales by inhibiting their development. A better result was achieved with the IGRs when they were mixed with the oil than when they were used alone. The phenology of the scale insect affects the effectiveness of these materials i.e. they must, as with oils, be applied to first and second stage nymphs.

Pruning reduced scale insect populations and remnant prunings must be removed to avoid reinfestation. Complete weeding is necessary to support a successful control program.

Levels of immature black scale infesting 15cm long shoots of boronia bush (cultivar HC. 17) in February were considered to be at the economic threshold at 7 nymphs. The soft brown scale was of lesser economic significance and in no instance was the decision to undertake control based on infestation by this species.

Introduction

The commercial planting of boronia (*Boronia megastigma* Nees), which is native to Western Australia, was established as an essential oil crop in Tasmania in 1985. In general, intensive cultural or monocultural practices are vulnerable to pest problems due to lack of species diversity. While psyllid pests have now been controlled, scale insects have become a serious pest in some boronia growers fields.

Two soft scale insects (Hemiptera: Coccidae) attack boronia and have been identified as the black scale, *Saissetia oleae* Oliver, and soft brown scale *Coccus hesperidum* L.. At this time, black scale is considered the most serious pest in commercial plantations despite the occurrence of many natural enemies. Similarly, black scale on citrus in California USA, has remained a problem despite a complex of parasitoids and the repeated importation of new natural enemies (Daane and Caltagirone, 1990; Lampson and Morse, 1992).

Saissetia oleae is an occasional pest insect and its distribution is mainly in temperate and sub-tropical regions. Daane and Caltagirone (1990) noted that it is common for orchards to have repeated outbreaks while neighbouring orchards do not. Black scale occurs throughout Australia with South Australia, New South Wales, and Victoria more affected due to their large citrus growing areas (Wilson, 1960).

Soft brown scale is of European origin (McLeod and Coppel, 1966). It is now common in all tropical and subtropical regions of the world and in greenhouses in cooler regions (Ebeling, 1959; McLeod et al, 1966). Again, South Australia, Western Australia and New South Wales are more affected because of their large citrus growing areas (Wilson, 1960).

Both scale species, *S. oleae* and *C. hesperidum*, are known to have a wide range of host plants. When heavily infested parts of the plant, such as foliage, shoots and fruit, are covered with sooty mould that develops on honeydew excreted by scale insects. Damage to the plant can be either direct, i.e. by sucking sap from the plant or indirect, i.e. by covering parts of the plant with sooty mould that interferes with the efficiency of photosynthesis. Heavy infestation can result in defoliation, fruit drop, twig dieback and in extreme cases, death of the plants (Ebeling, 1959).

The application of insecticides to control scale insects without accurate knowledge of pest population control mechanisms could disrupt any potential regulation by natural enemies (DeBach and Rosen, 1991; Paraskakis et al, 1980). Hely et al. (1982) and Beattie (1991) suggested that application of insecticides against scale insects must be applied at an appropriate time and place in order to get effective results. Boronia growers in Tasmania have relied on materials such as petroleum spray oils and a mixture of these petroleum spray oils with maldison to control black scale and soft brown scale without any sound knowledge of their biology and ecology. This has led to unsuccessful results even though multiple applications have been employed annually.

The aim of this study was to gain an understanding of the population dynamics and the life-cycle of both scale species, to understand their biology and to assess a range of insecticides for possible incorporation into an integrated program to control these species.

Note: added post examination .

Dr. Andrew Beattie has indicated that recent findings (96/97) have revealed that *S. oleae* is native to southern Africa where up to 70 parasitoid species attack it to the extent that in many circumstances it can only live underground in association with ants! (J.Madden, 18/07/97)

Chapter
1
Literature review

1. 1. General

Boronia megastigma Nees (F. Rutaceae) is native to Western Australia and has a high oil content. The oil is in high demand by the food and flavour industry. Therefore, *B. megastigma* has been planted on a large scale in an intensive cultural practice and has become an important crop for the essential oil industry in Tasmania (Mensah, 1990). Since psyllids have been controlled, scale insect infestation (Homoptera: Coccoidea: Coccidae) has increased on boronia and caused severe damage to commercial plantations (Madden, 1991: personal communication).

Scale insects are terrestrial, plant-feeding animals (Ben-dov, 1993), and notorious pests, especially to perennial and indoor plants (Miller and Kosztarab, 1979). They have piercing-sucking mouthparts which are highly efficient in withdrawing the liquid contents of their host plants. Plant sap is a nutritionally dilute food which has a high content of sugar but is low in nitrogen and other minerals (Weis and Berenbaun, 1989).

According to Williams (1991), scale insects can be differentiated by the presence of paired triangular or rounded anal plates around the anal opening of the female. He also noted that spiracular setal and tubular ducts with the inner end cupped are other important characteristics. Atkinson et al (1956) pointed out that having the tarsi of the legs one-jointed and a claw at the tip of the leg may be used to distinguish them from their nearest relatives. As a member of the four-winged Homoptera, male scale insects are unique in having only one pair of wings, the mesothoracic wings, while the metathoracic wings consistently reduce to stubs (hamulohalteres). The adult winged male has no mouth parts and is fragile and short lived. The adult female on the other hand is wingless and its legs are generally reduced or absent (Atkinson et al, 1956; Miller and Kosztarab, 1979, Williams, 1991). Williams (1991) stated that reproduction of some scale insects may be oviparous, ovoviviparous or viviparous and some by parthenogenesis. Nur (1971) classified parthenogenetic coccids into seven groups: haploid and diploid arrhenotoky, facultative and obligate deuterotoky, facultative thelytoky, obligate automictic and apomictic thelytoky. Scale insects (Coccoidea) excrete liquid known as honey-dew which can be harmful to both the insects (Bartlett, 1961; Williams and Williams, 1980) and their host plants. Some species generate wax in various forms and others are naked (Comstock, 1916). The development of waxy secretions which serve as protective domiciles as well as body coverings is a successful adaptation of biological function and morphology (Miller and Kosztarab, 1979) to protect the female and its progeny from predation or contamination of excreted honey-dew (Williams, 1991).

Coccoidea appear in nearly all botanical habitats from the tundra to the tropics and generally occur on leaves, branches, trunks, fruit and roots (Miller and Kosztarab, 1979). They are able to attack a wide variety of plants belonging to different plant orders (Pedigo, 1989). Some are polyphagous, but most oligophagous or monophagous. Loss of sap due to phloem-feeding results in stunting, distortion or wilting of plants (Carver et al, 1991). Coccidae usually have an association with ants (Kosztarab and Kozár, 1988). Hadlington (1978) reported that attending ants on infested trees increase the population of scale insects by disturbing natural enemies.

The super family, Coccoidea consists of 16 - 20 families (Ben-Dov, 1993). Unarmoured scales (Coccidae) and the armoured scales (Diaspididae) are two of these families. The armoured scales (Diaspididae) do not have the actual scale as part of the living insect. The scale is a shield formed from the skins of previous moults. Conversely, in the unarmoured scale the actual scale is part of the living insect (Atkinson et al. 1956) and makes up part of the integument.

The two species of unarmoured scales that currently occur in commercial plantations of boronia in Tasmania were identified by Dr T. K. Qin, CSIRO Entomologist, as *Saissetia oleae* Oliver and *Coccus hesperidum* L.. *Saissetia oleae* is considered the more serious insect pest. Both scale insects are exotic species to Australia. Flanders (1953) claimed that most pest coccids were not native.

1. 2. Life cycle features and biology of black scale, *Saissetia oleae* Oliver

1. 2. 1. Life cycle features of *Saissetia oleae* Oliver

Saissetia oleae has one to three generations each year depending on local conditions and the cultural practices employed. Podoler et al (1979) observed that in Israel *S. oleae* has three generations during a year in the glasshouse, two generations in irrigated citrus gardens and one generation in unirrigated citrus areas. This scale was recorded as having one generation annually in the interior regions and two generations in the coastal regions of California (Comstock, 1916; Quayle and Rust, 1911; Ebeling, 1959; Smith, 1938). One generation per year was reported in Greece (Argyriou, 1963) and Turkey (Tunçyürek and Öncüer, 1976). Three generations of this scale species were observed on grapefruit gardens in Florida (McCoy and Selmime, 1971). *S. oleae* Oliver was recorded as having annually either one in the south (Simmonds, 1951a) or two generations in the north (Hely et al, 1982) of Australia.

According to Daane and Catagirone (1990), black scale on olive tree prefers to settle in the lower and inner part of the canopy. Its distribution may be either random or clumped depending on the type of canopy. With heavy infestations sooty mould develops on trees and fruit and ants attracted to the honey-dew excreted by the scale (Beattie and Gellatley, 1983). *S. oleae* must migrate from leaves to twigs or branches to ensure its survival to reach the adult stage. .

1. 2. 2. Development of black scale, *Saissetia oleae* Oliver

Eggs of black scale are retained beneath the female until hatching occurs (Quayle and Rust, 1911). Then follow six other stages to reach the reproductive stage (Podoler et al, 1979; Argyriou, 1963). Due to its functional legs, *S. oleae* has the ability to move until late in its life-cycle. Ebeling (1959) observed that the local environment could interfere with the biology of black scale through affecting host plant development.

1. 3. Life form features of *Saissetia oleae* Oliver

1. 3. 1. Eggs

The egg of *S. oleae* is pale white, becoming reddish in late development. It measures 0.26 - 0.32 mm in width and 0.13 - 0.22 mm in length. The egg is elongate - oval with the anterior portion being more broadly rounded than the posterior one. It is covered with a thin layer of white waxy substance which prevents the eggs sticking together when deposited under the adult body. Brown specks in the anterior of the egg that develop into eyes can be seen just prior to hatching (Argyriou, 1963).

In the winter season hatching may be prolonged and crawlers have been found throughout this period (Mendel et al, 1984; Quayle and Rust, 1911). Quayle and Rust (1911) found that it was very rare to find unhatched eggs under the adult female. Crawlers come out from beneath the parent through an arch at the posterior tip, which consists of a slightly raised portion of the scale.

1. 3. 2. Immature stages.

The crawler stage is considered the main dispersal stage in all members of Coccoidea (Miller and Kosztarab, 1979). They can easily be transferred by wind, birds, insects, man and his equipment over large areas (Ebeling, 1959). Crawlers of *S. oleae* prefer to settle on the lower surface of leaves along the midrib mostly towards the petiole and on terminal shoots as well (Argyriou, 1963). Quayle and Rust (1911) observed that newly hatched larvae remained under the scale for a certain time, up to 48 hours, before wandering around prior to settling. The authors also reported that crawlers of *S. oleae* exhibited a positive phototropic behaviour. Consequently, this behaviour has been used to collect crawlers from stock cultures (Flanders, 1942b).

Emergence of crawlers mainly occurs during the first hours after sunrise and their longevity is highly dependent on relative humidity and temperature (Mendel et al, 1984). Argyriou (1963) reported that the mortality of crawlers and first stage nymphs was very high, reaching to 99 and 98 % respectively and 10 to 45 % for second and third stage nymphs. High temperatures associated with low humidity are the major factors affecting this mortality rate (Hely et al, 1982; Mendel et al, 1984; Simmonds, 1951a; Quayle and Rust, 1911). Jarraya (1976) also found that abiotic factors were the main regulating factors of black scale in Tunisia. Its immature mortality in summer was estimated at about 97 % and up to 90 % in winter.

The immature black scale, *S. oleae* Oliver, moults three times before reaching a mature stage (Argyriou, 1963; Podoler et al, 1979). Migration from leaves to twigs and branches to secure a permanent food supply, which takes place after the second moult. has been recorded in Australia (Simmonds, 1951a), California (Ebeling, 1959), and Greece (Argyriou, 1963).

1. 3. 3. Mature females

S. oleae may be either a uniparental or bivoltine species depending on climatic conditions and males rarely occur in populations (Ebeling, 1959). The female scale reproduces mostly parthenogenetically (Ben-Dov, 1993). The number of eggs produced by a mature female varies according to the size of the scale. A female scale may produce 400 - 3000 eggs (Simmonds, 1951a) and up to 3000 eggs at a rate of 75 per day for 75 days (Quayle and Rust, 1911). Jarraya (1976) recorded that the black scale produced an average 1060 eggs.

Argyriou (1963) reported that during the reproductive period, offspring at different developmental stages, i.e. eggs and crawlers could be found beneath the adult female's body. At the same time the adult female had its ovaries full of eggs ready to be deposited. A mass of empty egg shells still remained under female scales after completing reproduction. The author reported that the mortality rate of the pre-reproductive stages ranged from 50 to 80 percent during the winter and spring respectively to 0 to 20 percent in the following year. These values reflected the variable severity of climatic factors experienced in the study area in Greece.

As black scale can move in order to seek food throughout its development it is able to migrate from leaves to stems upon which maturation to adult stage occurs

(Simmonds, 1951a). Thus it was rare to find the adult stage settling on the leaves of citrus (Quayle and Rust, 1911).

1. 3. 4. Male scale

Male scales are rarely seen and can be distinguished from females after the first nymphal moult as being more elongate and light brown in colour (Hely et al, 1982).

1. 4. Life cycle features and biology of soft brown scale, *Coccus hesperidum* L.

1. 4. 1. Life cycle feature of *Coccus hesperidum* L.

Several generations of soft brown scale, *Coccus hesperidum* L. may be recorded each year so that different stages of this scale may occur in the populations at any one time (Hely and Duncan, 1959; Hely et al, 1982). Ebeling (1959) observed in California that this scale had up to five generations throughout the year. Three to four generations annually have been recorded in Australia (Lower, 1968). Infestations of soft brown scale generally tend to occur in isolated spots on a tree but this scale species can disperse over the whole tree if not controlled. Soft brown scale prefers to settle along the main and/or subsidiary veins. On heavily infested plants ants are commonly associated with *C. hesperidum* due to its ability to produce a lot of honey-dew (Hely et al, 1982; Beattie and Gellatley, 1983). Ants, *Iridomyrex* spp . commonly to occur on soft brown scale populations (Hely Duncan, 1959). The association of the ant, *Oecophylla longinoda* Latr., with other scale insects such as *Saissetia zanzibarensis* Williams was also recorded (Way, 1954)

Soft brown scale affects plants in the same way as does black scale i.e: either by sucking the sap from plant tissues or by encouraging the growth of sooty mould fungus which develops on honey-dew excreted by this scale (Hely and Duncan, 1959). Hely et al (1982) noted that the important damage was due to heavy sooty mould covering parts of host plants because it could prevent sun light, which is an important aspect of photosynthesis, from reaching into the tissue of the host plant.

1. 4. 2. Development of *Coccus hesperidum* L.

Soft brown scale passes through an egg, three nymphal stages and and pre-reproductive adult stage before it becomes fully reproductive (Annecke, 1966). This scale species is capable of walking until late in its life-cycle. Both the young and adult scale can produce a great deal of honey-dew that is suitable for the growth of sooty mould (Hely et al, 1982).

1. 5. Life form features of *Coccus hesperidum* L.

1. 5. 1. Eggs

Soft brown scale was formerly considered as viviparous insect by some authors (Comstock, 1916; Lower, 1968). However, this is not correct. Eggs are rarely seen under a female scale because they hatch shortly after they are deposited (Annecke, 1966; Beattie and Gellatley, 1983; Ebeling, 1959). Adult females can produce eggs at an average rate of 70 eggs per day over a two month period (Bodenheimer, 1951 Cited in Hely et al, 1982).

1. 5. 2. Immature stages

Like the black scale, *C. hesperidum* mainly disperses during the immature stages especially the crawler stage. In addition, some agents that may spread *C. hesperidum* over large areas are ants, animals, man and wind (Hely et al, 1982). According to Annecke (1966) crawlers come out from time to time when a parent raises the posterior part of its body. Newly hatched crawlers are unable to organise movement for at least two hours and remain under the female body for 15 hours or more before wandering around prior to settling.

The immature stage of the female *C. hesperidum* moults twice before reaching the adult stage (Annecke, 1966; Ebeling, 1959). Annecke (1966) further found that the second stage nymph forms nine minute columns of glassy wax on the longitudinal dorsal midline of the body.

1. 5. 3. Mature females

Males of the species have not been reported in scale populations in California (Comstock, 1916; Ebeling, 1959), Israel and South Africa (Ben-Dov, 1993), nor in Australia (Hely et al, 1982); however, males were reported to occur in England (Newstead, 1917a Cited in Ben-Dov, 1993) and Russia (Saakyan-Baranova, 1964 Cited in Ben-Dov, 1993). Ben-Dov (1993) also stated that females reproduce parthenogenetically. Therefore, a mated female will not necessarily raise just female progeny (Lower, 1968). The body of the mature female is rather convex, yellow to brown in colour and approximately oval.

1. 6. Feeding effects of scale insect on plant growth and crop yield

The interaction of the host plant with scale insects is very complex (Miller and Kosztarab, 1979) therefore, it is necessary to understand the mechanism of damage and the relationship of pest density to plant yield. This knowledge can help growers to optimise the use of pesticides (Stern, 1973). Direct losses to agricultural crops due to pests are normally associated with a reduction in the quality or quantity of yield (Ridgway, 1980). The quality and quantity of the final yield can be reflected by a number of direct and indirect plant growth responses to the pest (Stern, 1973).

Scale insects (Coccoidea) injure their host plants mainly through removing the sap of the plants (Ebeling, 1959; Kosztarab and Kozár, 1988; Metcalf and Flint, 1939). Smith (1944) reported that their feeding results in three types of injury: (1) mechanical injury resulting from insertion of the rostralis into the tissues of the plants, (2) toxic effects due to injection of saliva into the tissues of the plants, and (3) devitalisation of the plants caused by removing the sap of the plants. They prefer to feed on phloem sap which lacks indigestible tannins, lignins, or cellulose (Weis and Berenbaum, 1989). According to Wigglesworth (1972) scale insects have a special adaptation of the mid-gut to cope with their habit of feeding on the copious watery juices of plants. It enables water and sugars to pass directly to the last part of the mid-intestine thus concentrating the food (protein) entering the mid-gut. Saliva is excreted into plants by piercing-sucking insects while feeding, to facilitate food flow and digestion. The saliva of some scale insects also causes local lesions, tissue malformations or other phytotoxic effects (Carter, 1973 Cited in Cockfield and Potter, 1990). These injuries associated with mechanical feeding damage may interfere with photosynthesis and translocation, ultimately limiting the growth of new tissues such as leaves, stems, and roots (Cockfield and Potter, 1987). Kosztarab and Kozár (1988) noted that vigour of plants is reduced, leaves may drop prematurely, and heavy infestation of scale insects may kill their host plants. Discolouration is often produced on leaves infested by euonymus scale, *Unaspis euonymi* Comstock, and fruit infested by *Quadraspidiotus sp.* (San José scale). In addition, twigs and branches are deformed by pit scale and Italian pear scale. Many Australian coccoids can reportedly produce plant-galls. Splitting of bark, defoliation, dieback of twig terminals and in some cases the death of the host plant may follow heavy infestation of armoured scale (Diaspididae) (Beardsley and Gonzalez, 1975). Feeding of *Unaspis euonymi* on the woody plant could cause chlorosis, reduce photosynthesis and transpiration, and encourage leaf senescence and abscission, especially when the feeding has occurred in combination with water stress (Cockfield and Potter, 1986 ; Cockfield et al, 1987). McClure (1977c) reported that resinosis of red pine at feeding wounds may result from heavy infestation by *Matsucoccus resimosae* Bean and Godwin.

Desiccation of young olive trees occurred on trees heavily attacked by black scale (Bibolini, 1958 Cited in Argyriou, 1963). Podoler et al (1979) found that severe infestation may cause the cull of crops, reduce production of host plants, and cause serious injury to citrus trees. In California a heavy population of black scale can result in defoliation, fruit drop, twig dieback and, in extreme cases, death of the host plants (Ebeling, 1959). Twig dieback occurs in *Dubuisia.* sp. and older plants were worst affected by the black scale (Smith, 1974). The feeding of *C. hesperidum* can cause die-back of young trees and sooty mould which if not removed, induces leaf fall (Steyn, 1954).

1. 7. Crop condition and susceptibility to scale insect infestations

Plants have developed adaptations to insect pest attack such as increasing the content of phenolics and tannins and reducing protein and minerals that are necessary for insects. These adaptations result in reduced growth rates, survivorship or fecundity of insects (Weis and Barenbaum, 1989). Plants have shown varying degrees of susceptibility to particular scale insect infestation (Miller and Kosztarab, 1979; Kodztarab and Kozár, 1988). Kodztarab and Kozár (1988) noted that many host plants have been found to have an environmentally induced or physiological resistance to particular scale species. Flanders (1970) also observed that environmental factors could induce immunity of the host plants to scale insects.

Olive trees were reported as the preferred host for *S. oleae* under various conditions (Quayle, 1938). Compere (1940) found citrus trees completely free of *S. oleae* infestation growing side by side with oleander heavily infested with the black scale in South Africa. According to Flanders (1970) edaphic factors or meteorological changes can modify the physiology of the plant and alter its immunity to scale attack. Thus differences in host immunity through time and geographic differences in host preference can be found. The addition of nitrogen to soil around cacao was found to cause a dramatic increase in the density of *Planococcus sp.* ; however, the addition of potassium caused a decrease in the survival rate of crawlers (Fennah, 1959). McClure (1977b) reported that the survival rate of second stage nymphs of *Fiorinia sp.* was greatly affected by edaphic conditions .

Edmunds and Alstad (1978) found that differences in susceptibility of host-plant, *Pinus ponderosa* Laws, to black pine leaf scale, *Nuculaspis nica* Coleman, were influenced by intra specific variation in pine defences. These defences were likely to be monoterpenes. The different phenology of white oak and red oak can interfere with development of the obscure scale, *Melanaspis obscure* Comstock (Stoetzel and Davidson, 1973). According to Flanders (1970), the fronds of a sago-palm which had been heavily infested with *S. oleae* for several generations became immune to this scale. The immunity of this plant was generated by the secretions injected into the host tissues by the black scale during its feeding.

1. 8. Population dynamics

1. 8. 1. General

A population is defined as organisms of the same species occupying a particular space at a particular time. One characteristic of a population is its size which is affected by natality, mortality, immigration and emigration (Krebs. 1985).

In nature a population of organisms is never truly stable but fluctuates in number (Wallner, 1987). The population dynamics of insects are critically influenced by food resources, weather and competition between themselves or other organisms including natural enemies (Van de Bosch and Messenger, 1973; Nicholson, 1954). Reduction of body size, fecundity, longevity and population growth rate were documented as a result of poor food conditions (Southwood, 1968). However, Nicholson (1954) stated that factors which are only affected by population density tend to stabilise populations in relation to their environments. Such factors are mainly biotic factors, which in their absence can result in destabilizing effects..

Climatic factors such as temperature, humidity and rainfall may affect the abundance of insect populations in different ways; for example: the survival (DeBach, 1965; DeBach et al, 1955; Bateman, 1966; McClure, 1977b) and biology of the insect (Daane and Caltagirone, 1990).

1. 8. 2. Population dynamics of scale insect

1. 8. 2. 1. Populations of *Saissetia oleae* Oliver

The black scale, *S. oleae*, is a potentially explosive and unpredictable pest in a commercial plantation (Daane and Caltagirone, 1990). The population dynamic of *S. oleae* varies from one region to another because of differences in climate between regions and cultural practices. One to three generations per year, have been recorded in many regions (Ebeling, 1959; Hely, 1958; Simmonds, 1951a; McCoy and Selhime, 1971; Peleg, 1965; Argyriou, 1963). The population of *S. oleae* is characterised by considerable fluctuations resulting in periodic outbreaks at a local or regional level (Kapatos and Stratopuolou, 1990). These outbreaks have been associated with a reduction in the populations of natural enemies of the coccid caused by intensive applications of insecticides against other pests (Ehler and Endicott, 1984).

Biotic agents such as parasitoids, predators and pathogens have been recorded as important mortality factors of *S. oleae*. Kapatos and Stratopoulou (1990) reported that predators were the main cause of mortality in the scale population during the spring season. Parasitoids, however, have been reported as the most important factor in keeping the population of *S. oleae* at subeconomic levels in California (Bartlett, 1978; Compere, 1940; Van de Bosch and Messenger, 1973; Flanders, 1942a). It has been noted that natural enemies suppress populations of *S. oleae* to low levels in Florida (McCoy and Selhime, 1971), Israel (Mendel et al, 1984), and in Australia (Wilson, 1960). Thus the preservation of natural enemies could be an important means of maintaining *S. oleae* at a low level. Any measures which disrupt them should therefore be minimised or avoided. Ants which have an association with *S. oleae* have been reported to interfere with the effectiveness of its natural enemies. The removal of ants, mainly the Argentine ant, *Iridomyrmex humilis* Myar, by pesticides was shown to result in an increase in the number of scale parasitised by *Methaphycus helvolus* Compere and as a result, the population of *S . oleae* reduced to a low level (Bartlett, 1961).

On the other hand, abiotic factors especially high temperatures are known to be important factors in the mortality of immature scale. Mortality in the early immature stages is mainly caused by high temperatures combined with low humidity (Kapatos and Stratopoulou, 1990; Ebeling, 1959; Podoler et al, 1984; Simmonds, 1951a; Quayle and Rust, 1911). Peleg (1965) found that under dry conditions and high summer temperatures scale mortality increased.

Besides fluctuations in number, the characteristics of the population of this scale in each habitat, i.e. leaves and wood, differ enormously. The population on the leaves has either higher intrinsic mortality than that on the wood or is more susceptible to injury by high temperatures (Flanders, 1970). Daane and Caltagirone (1990) recorded that the canopy structure of the olive has a considerable influence on the distribution and mortality of the black scale. He further noted that summer weather and cultural practices, especially irrigation, greatly influenced black scale biology. Peleg (1965) found that irrigation affected the development of the black scale.

1. 8. 2. 2. Populations of *Coccus hesperidum* L.

Soft brown scale, *C. hesperidum*, is a cosmopolitan scale species which feeds on numerous host plants (Bartlett, 1978). The distribution of *C. hesperidum* is more or less localised on the plants (Lower, 1968) or in large numbers in isolated spots on trees (Ebeling, 1959). Lower (1968) reported that most soft brown scale prefer to settle along the main veins on the lower surface of leaves. All stages of this scale may occur in a colony due to the fact that there are several generations per year. A settled nymph may need two to four months to produce the next generation (Hely et al, 1982). *C. hesperidum* requires 39 - 40 days at 26.6° C and 65% relative humidity to complete its life cycle (Lewallen, 1955). Bartlett (1978) reported that a generation was completed in about 40 days at 25.6° C.

Ehler and Endicott (1984) found that the regulation of scale populations by natural enemies may be disrupted by the use of pesticides to control other insect pests which kill the natural enemies of this scale. The direct application of parathion or drift from adjoining crops could disrupt natural enemies and as a consequence soft brown scale became a serious pest of citrus in California, Texas, and South Africa (Bartlett and Ewart, 1951). Increased infestation levels of *C. hesperidum* were reported after spraying with parathion in other areas (Annecke, 1959; Cressman et al, 1950; Elmer et al, 1951; Ewart et al, 1951). The same results were reported following the application of DDT (Wilson, 1960). Methyl parathion could accelerate reproduction of this scale so applications of it could lead to outbreaks of soft brown scale (Hart and Ingle, 1971).

Ants have been found in great abundance where C. *hesperidum* colonies occur (Ebeling, 1959). They interfere in the effectiveness of natural enemies of this scale; consequently the infestation level of *C. hesperidum* increase is not controlled (Annecke, 1959; Dean, 1955; DeBach et al, 1951; Myburgh, 1949; Steyn, 1954). Booker (1961) found that *Occophylla sp* was the most dominant ant species. He further noted that *Occophylla sp* gave a protection to *C. hesperidum* from its natural enemies. In laboratory tests, reduction in parasitism of *C. hesperidum* due to the Argentine ant, was 27.4 - 98.4% depending on the parasitoid species (Bartlett, 1961).

1. 8. 3. Life table

A life table can be used to present the results of a study about population density of an insect species in a series of generations in order to gain some understanding of the numerical behaviour of populations (Varley et al, 1973). The life table could be constructed in two ways, as a horizontal or age-specific life table and a vertical or time-specific life table (Dempster, 1975; Bellows et al, 1992; Southwood. 1978). For many animals, such as most insects, recruitment and mortality may vary enormously between generations so that a series of age-specific life tables provides far more information than the other (Dempster, 1975). Furthermore, life tables for insects are generally organised in the terms of a life stage rather than age due to the difficulty of determining the exact age of an insect in the field (Southwood, 1968; Manly, 1990).

Bellows et al (1992) suggested that three dynamic factors of a population must be available if complete life tables are to be constructed: a) the numbers of individuals entering each stage, b) mortality from specific factors in each stage, and c) potential and realised fecundity. Samples for counting the total number of individuals entering different life stages in the field population have to be taken over the life cycle of insects in a series of generations and this data is expressed in a unit measure (Varley et al, 1973). Varley and Gradwell (1970) stressed that sampling routines must be carefully planned to provide information with sufficient accuracy about all factors concerned. The variation in the survival rates in the different stages through generations can then be studied in order to understand which sources of variation are particularly important for population dynamics (Manly, 1990).

1. 8. 3. 1. Key factor analysis

Key factor analysis has been widely used in population studies (Hassell et al, 1987) of both vertebrates and invertebrates (Podoler and Rogers, 1975). The term "key-factor" has been used to describe mortality factors that may be responsible for the changes in population densities (Morris, 1959, Varley and Gradwell, 1960). Varley and Gradwell (1960) stated that key factor analysis has often been used to estimate the contribution of each separate cause of mortality to the overall generation mortality. Calculation of key factor values has to be based on life tables constructed over several generations (Bellows et al, 1992; Kuno, 1991; Manly, 1990; Morris, 1963; Podoler and Rogers, 1975; Varley and Gradwell, 1960; Varley et al, 1973)

Varley and Gradwell (1960) used a graphic technique in which total mortality (K) and each of the component stage-specific k-values were plotted for a series of generations. The k values that contribute most to the total mortality K can be observed by inspection of the graph. However in some cases a visual inspection of the plots of k values and K does not clearly indicate a key factor (Manly, 1977) so Podoler and Roger (1975) suggest a regression technique of individual key and stage mortality, in which the steepest slope of the regression which is closest to 1.0, is the key factor.

Varley and Gradwell (1970) noted that mortality factors can be differentiated into four different effects; density-dependent mortality, inverse density-dependent mortality, delayed density-dependent mortality and density-independent mortality. In practise these effects have to be clearly determined.

1. 9. Biological control

Biological control is the use of biological agents to regulate a pest population at low level (DeBach and Rosen, 1991). Doutt (1974) defines biological control as the study and utilisation of parasitoids, predators and pathogens for the regulation of population densities of pests. Their suppressive effect depends on the density of the pest population. Biological control must have an ecological basis in order for its aims to be achieved. Van de Bosch and Stern (1962) claim that biological controls are a part of the natural control which results in the population density of a pest species being maintained around a general equilibrium level.

1. 9. 1. Parasitoids

A parasitoid is an insect which feeds on other insects and uses a single host to complete its development (DeBach and Rosen, 1991; Davies, 1988). The parasitoids belonging to the order Hymenoptera and Diptera are mainly utilised in biological control (DeBach and Messenger, 1973; DeBach and Rosen, 1991). DeBach and Rosen (1991) noted that the encyrtids and aphelinids specialise in attacking scale insects, mealybugs and white flies, and achieve excellent control. The efficacy of parasitoids is commonly estimated in percentage parasitism (Dent, 1991) and ants can affect it (Flanders, 1951; Way, 1962).

Each of the parasitoid species normally attack different stages of the black scale: *Scutellista ccaerulea* Fonscombe feeds on the scale eggs, *Coccophagus ochraceous* Howard develops on the late first instar, *Metaphycus helvolus* Compere develops on the second instar and *Metaphycus lounsburyi* Howard attacks the third instar (Flanders, 1942a).

When parasitoids were introduced into California to control *S. oleae*, which had been a serious pest of citrus since 1895, one, *S. caerulea,* achieved a result of 75 per cent parasitised scale (Quayle and Rust, 1911). However, the black scale, *S oleae*, still remained an important insect pest until *M. helvolus*, one of twenty eight species, was introduced into California from South Africa in 1937. It has since become the most important parasitoid of *S. oleae* (Flanders, 1942a). In addition, *Diversinervus elegans* Silvestri was also imported from Eritrea into California to control black scale in 1953 as a substitute for existing parasitoids (Bartlett and Medved, 1966). By 1955 thirty-eight species of natural enemies had been introduced into California against *S. oleae* from around the world, including Tasmania. Fifteen species have become established but only one of them, *M. helvolus*, is a most effective parasitoid (DeBach and Messenger, 1974). Periodic release of this reared parasitoid into areas where black scale has one generation per year has resulted in satisfactory biological control for this scale (DeBach and Rosen, 1991). Lampson and Morse (1992a) recorded that fifteen (nine primary and six secondary) parasitoid species were identified from black scale in California. However, four primary species were abundant: *Metaphycus bartletti* Annecke & Mynhardt, *M. helvolus* , *S. caerulea*, and *D. elegans* Silvestri. The most common secondary parasitoids were *Marietta mexicana* Howard, *Cheloneurus noxius* Compere and *Tetrastichus minutus* Howard. Their level of abundance has been found to vary from one region to another.

S. caerulea is the most important parasitoid of *S. oleae* in Florida. McCoy and Selhime (1971) found that *S. cyanea* attacked 90 - 100 % of the mature black scale in August and September. Two *Metaphycus* species and *S. caerulea* were also found as parasitoids of *S. oleae* in Israel (Mendel et al, 1984).

In Australia parasitoids were first utilised to reduce the population of the black scale in 1902 when *Microterys. sp.*, *S. caerulea*, and *Tetrastichus* sp. were introduced into Western Australia from South Africa (Hooper, 1902). In 1904 *S. caerulea* was introduced from California into Western Australia (Compere, 1904; Hooper, 1904). Newman (1907 and 1908) reported that *S. oleae* populations could be further reduced to harmless densities by introducing its natural enemies into Western Australia; on the other hand, *C. hesperidum* became a serious citrus pest. It was also reported that the black scale was kept in check by its natural enemies (Froggatt, 1922).

The last introduction of the parasitoid of black scale, *M. helvolus*, in 1942 was from California and released in Western Australia in 1943, and New South Wales, Queensland and South Australia in 1943-1944 (Wilson, 1960). The Waite Agriculture Research Institute maintained colonies and released *M. helvolus* in South Australia in 1943-1947 (Simmonds, 1951b; Wilson, 1960). Later Simmonds (1951b) recognised some Hymenoptera associated with *S. oleae* : *M.* lounsburyi, *Coccophagus scutellaris*

Dalm, *Microterys flavus* Howard, *Myiocnema comperei* Ashm., *Myiocnema sp.*, *Quaylea whittieri* Gir., *Cheiloneurus* sp.

In general, Wilson (1960) concluded that the natural enemies of *S. oleae* substantially help to reduce the population of the black scale to a level where it can be considered an unimportant pest in Australia.

1. 9. .2. Predators

Stehr (1974) defines a predator as a free-living organism throughout its life; it feeds on prey, is usually larger than its prey, and requires more than one prey individual to complete its development. Both the immature and adult stages of predators are commonly carnivorous (DeBach and Messenger, 1973). The adult predator insects generally deposit their eggs near the prey population, so that soon after hatching the active mobile immatures search out and consume individuals (DeBach and Rosen, 1991). New (1991) noted that many insect predators are polyphagous and others have a more restricted range of prey. Predators often play a significant role in the population dynamic of insects. New (1991) also pointed out that young or immobile stages are particularly vulnerable to insect predator attack because they are more easily captured.

Many insects known to be predators of *S. oleae* have been reported in some areas. In California, *Rhizobium ventralis* Erichson is a coccinellid that most commonly feeds on both eggs and young scale (Quayle and Rust, 1911). Syrphids and chrysopids were also recorded as feeding on the black scale (Ebeling, 1959). Another coccinellid, *Chilocorus sp.* was found to be a common predator of *S. oleae* in Israel (Mendel et al, 1984). The larvae of green lacewings, *Chrysopa* spp., *Rhizobius sp.* and *Cryptolaemus monstouzieri* Mulsant were reported to be predators of *S oleae* in New South Wales (Hely et al, 1982). *Rhyzobius forestieri* Mulsant was introduced into Greece as a substitute for*Exochamus sp.* and *Chilocorus sp.* for the control of *S. oleae.* These predators successfully suppressed populations of scale in Greek olive groves (Katsoyamos, 1984).

Predators, especially coccinellids, are ineffective in suppressing the black scale population due to the lack of synchronisation of the life-cycle between predators and their prey (Richards, 1981). To increase its effectiveness, a predator needs to have several characteristics : 1) a specific feeder, 2) voracious, 3) naturally synchronised in time and space and 4) efficient in the sense of being able to counter the rate of reproduction of prey (New, 1991).

1. 10. Chemicals and integrated control

1. 10. 1. Chemicals and chemical problems

Chemicals have been used for many years to control pests to maintain food and fibre production (Ware, 1989). The modern era of chemical control began in the late 1940s when DDT and other chlorinated hydrocarbons were used in pest control (DeBach and Rosen, 1991; Ware, 1989). Insecticides are generally highly effective, rapid in curative action, adaptable to most situations, flexible in meeting changing agronomic and ecological conditions and economical (Metcalf, 1975 and Matthew, 1984).

Natural products and synthetic analogs are two major sources of pesticides that are used today in pest control management (Casida, 1990). Based on their composition, chemical insecticides can be classified into 4 chemical types; organochlorines, organophosphates, carbamates and pyrethroids. In addition, new insecticides known as insect growth regulators have also been used in pest control (Dent, 1991). In the manipulation of crop pests, chemical substances are still a powerful tool in pest management, being reliable for emergency action when insect pest populations approach or exceed the economic threshold (Metcalf, 1975) and natural enemies cannot regulate pest densities (DeBach and Rosen, 1991).

The use of chemical pesticides without regard to the complexities of the agro-ecosystem has been a major cause of disruption of this system (Smith and Van de Bosch, 1967). Sixty percent or more of spray may fail to impact or it may be retained on foliage and reach the soil surface at the time of application. Therefore it is important to ensure that distribution of the active chemical is as even as possible in order to make direct contact with the target pest (Matthews, 1984).

Insecticides used improperly have caused secondary pest outbreaks (Bartlett, 1963; McClure, 1977b; Smith and Van de Bosch, 1959) due to the elimination of natural enemies that normally keep them at low levels (Pimentel, 1985). Van de Bosch (1973) and Smith and Van de Bosch (1967) pointed out that three ecological phenomena may be generated by using chemicals : 1) large pest resurgence, 2) secondary pest outbreak and 3) pesticide resistance. In addition, chemical sprays could constitute dangers to human health and cause environmental destruction .

Some of the undesired effects which have arisen with using chemicals to control pests are well documented. Readshaw (1971) reported that chemical spray programs using broad-spectrum pesticides could give rise to *Tetranychus urticae* Koch and *Panonychus ulmi* Koch problems as they disrupt the natural balance. Outbreaks of spider mites, scale insects and various lepidopterous larva took place following the use of DDT according to Van de Bosch et al (1973). Bedford (1976) also reported that DDT and parathion sprays on citrus caused an outbreak of *C. hesperidum*. Elmer and Ewart (1954) reported that outbreak of *C. hesperidum* occured following application of parathion for control of other pests. Outbreaks of *C. hesperidum* and *S. oleae* were reported following the application of malathion-bait sprays to control Mediterranean fruit fly, *Ceratitus capitata* Wiedemann since their parasitoids were killed (Ehler and Endicott, 1984). Outbreak of pine needle scale, *Chinaspis pinifoliae* Fitch, was also reported following the application of malathion for controlling mosquitoes (Luck and Dahlsten, 1975). Resurgence of the scale, *F. externa*, on hemlock occurred following incomplete application of dimethoate 2E (McClure, 1977a).

Metcalf (1975) claimed that most chemicals for arthropod species are broad spectrum pesticides which could be damaging not only to target pests but also natural enemies, although in some cases, chemicals such as plictran and dinocap, selectivity is evident (Dent, 1991). The negative impact of broad spectrum pesticides on beneficial insects as an important factor in keeping some pests under an economic threshold in citrus pest management has been well documented (Bellows et al, 1985.; Morse and Bellows, 1986; Morse et al, 1987; Bellows and Morse, 1988). In California population of the Vedalia beetle, *Rodolia cardinalis* Mulsant declined following an application of DDT and as a result the density of *Icerya purchasi* Maskell increased dramatically (DeBach, 1974). Important parasitoids of black scale, such as *M. bartletti, M. helvolus* and *S. caerulea* were found to be very susceptible to most broad spectrum chemical substances (Bartlett, 1953 and 1963)

1. 10. 2. Insect growth regulators (IGRs)

The development of pesticides which do not disrupt the efficacy of beneficial organisms present in crop ecosystems is necessary and widely accepted to support the implementation of integrated pest management (Jackson, 1984). Lampson and Morse (1992) suggested that novel chemicals are now needed for pest control agents to provide economical control without environmental disruption and to combat resistant target pests .

Insect growth regulators (IGRs) are considered to be selective pesticides and have been developed for use in pest control (Jackson, 1984). IGRs which show great promise as effective agents for insect pest control (Staal, 1972) are considered to combat resistant target pests and minimise environmental disruption (Wing and Aller, 1990). Retnakaran et al (1985) also noted that IGRs as chemical agents tend to be more compatible with biological control. William (1956) [cited in Jacobson and Crosby (1971) reported that active hormonal compounds were able to penetrate the unbroken cuticle of insects and produced sufficient morphologenetic damage to preclude normal metamorphosis. However, some IGRs which were introduced into Asia were found to lose their effectiveness rapidly (Guan-Soon, 1990). Teflubenzuron and triflumuron, for example, showed resistant factor (rf) values of 12-16 and 16-18 (Lim et al, 1988); therefore, some insects had developed resistance to these materials.

IGRs as biopesticides generally affect a very specific range of target insect pests (Plimmer, 1993) at certain developmental stages (Lampson and Morse, 1992b). IGRs have been described as a new class of bio-rational compounds with highly selective chemical agents that interfere in the development of certain insects (Staal, 1975; Ishaaya, 1990). Retnakaran et al (1985) also stated that all compounds belonging to IGRs greatly interfere with the normal growth and development of most insects. The IGRs interfere in insect growth and development in three ways: by mimicking juvenile hormone, as precocenes and as chitin synthesis inhibitors (Ware, 1989). Hodosh et al (1985) stated that as a bio-rational pesticide the IGRs, biochemically, must be naturally occurring or identical to the natural chemical and must not act through toxicity. As a consequence, the timing of applications in relation to insect phenology could adversely affect their effectiveness. An example is the application of fenoxycarb, methoprene and teflubenzuron against *S. oleae* (Lampson and Morse, 1992). Riddiford (1972) suggested that due to their specific action both juvenile hormone and its analogues have to be applied at a proper time to disrupt the metamorphosis and embryonic development of the insect pest. Juvenile hormone, furthermore, could interfere with post-embryonic life by preventing the formation of reproducing adults when applied after germ band formation in eggs.

Staal (1975) reviewed IGRs as control agents for a wide range of pests and mites; some were found to be effective against scale insects. Some juvenile hormone analogues were tested against black scale, *S. oleae* (Lampson and Morse, 1992; Peleg and Gothilt, 1981; Peleg, 1988) and soft brown scale, *Coccus hesperidum*, (Virag and Darvas, 1983).

Methoprene as a juvenile hormone to control mosquitoes was registered in 1975 as Altosid® (Ware, 1989). Methoprene is a chemical compound which is nontoxic to mammals and does not upset the development of scale parasitoids (Peleg and Gothilf, 1980 and 1981). Methoprene has been tested on some scale insects, California red scale, *Aonidella aurantii* Maskell (Boboye and Carman, 1975; Peleg and Gothilf, 1981), Florida red scale, *Chrysomphalus aonidum* L., *S. oleae* and Florida wax scale, *Ceroplastes floridensis* Comstock (Peleg and Gothilf, 1981). These researchers reported that nymphs exposed to a high concentration of methoprene failed to transform into the adult stage. Methoprene (0.015 per cent) applied to third stage nymphs of *S. oleae* prevented 97 per cent of them reaching the adult stage. Lampson and Morse (1992) recorded that methoprene at 0.158 g (ai./l) reduced the number of black scale significantly. At higher concentrations (0.03 per cent), it prevented adult emergence from all nymphs treated (Peleg and Gothilf, 1981). Methoprene applied at the proper time inhibited embryogenetic and metamorphosis of *Ephestia cautella* Zeller (Shaaya and Spindler, 1990).

Kinoprene (Entar®) is an effective IGR against adult aphids, white flies, mealybugs and both armoured and unarmoured scale insects. In a glasshouse experiment kinoprene resulted in effective control of scale insects, including *S. oleae* and *C. hesperidum* (Darvas and Virag, 1983). It was produced to combat specific pests which belong to the order Homoptera (Ware, 1989). Kinoprene (Enstar®) does not have negative effects on nontarget organisms nor humans (Anonymous, 1990). Its action is gradual. It reduces populations by inhibiting development, reducing egg-laying, killing eggs already laid, and sterilising mature whiteflies and aphids, rather than by immediate killing of target pests. Kinoprene is classified as a category III pesticide, i. e. is not irritating to skin and eyes (Hodosh et al, 1985).

In addition, some new chitin synthesis inhibitors have been produced which are reported to have a selective effect on sucking insects (Roditakis, 1990). One of them is buprofezin (Applaud) a novel insect growth regulator considered to be a selective control agent through inhibiting incorporation of N-acetyl-1-4ß-glucose-amine into chitin (Izawa et al, 1985; Uchida et al, 1985). It also inhibits biochemical processes leading to prostaglandin formation, that may cause suppression of oviposition (Uchida et al, 1987). Yarom et al (1988) also reported that buprofezin suppressed embryogenesis of *S. oleae* and *A. aurantii.* Buprofezin was found to be a very effective and selective biochemical against some homopterans, for instance whiteflies (Ishaaya et al, 1988; Roditakis, 1990), planthoppers (Ishaaya et al, 1988; Nagata, 1986), planthoppers and leafhoppers (Heinrichs et al, 1984), and some scale insects such as *A . aurantii* and *S. oleae* (Yarom et al, 988), white louse scale, *U. citri* Comstock (Smith and Papacek, 1990). As a selective chemical, buprofezin was reported to be harmless to the parasitoids, *Encarsia formosa* Gahan and *Cales sp.* (Garrido et al, 1984), and the predators, *Lycosa pseudoannulata* Boes. and Str., *Cyrtorhinus lividipennis* Reuter, and *Microvelia atrolineata* Bergroth (Heinrichs et al, 1984). Thus this product could be a new and valuable component of integrated pest control programs (Garrido et al, 1984, Collins et al, 1984; Roditakis, 1990).

1. 10. 3. Integrated control

The problems created by unilateral and excessive use of pesticides in the early 1950s motivated the use of integration of control tactics in crop protection (Glass, 1976). The basic concept of integrated control was offered by Stern et al, (1959) as a combination of biological and chemical control called "applied pest control". Smith and Van de Bosch (1967) described it in more detail. He defined integrated control as an approach which utilises all suitable control measures either to suppress pest populations or keep them at levels under the economic threshold. More recently it has been called integrated pest management (IPM). Basic measures of IPM are the utilisation of indigenous natural agents, management through cultural practices, the use of inherent plant resistance and tolerance, and selective use of chemical pesticides. Their application should be governed by economical and ecological considerations (Apple, 1980). IPM represents a complete change in the philosophy of pest control, away from pest eradication toward pest management (Dent, 1991) and has been being universally adopted (Zalom, 1991). Stern et al (1959) defined economic threshold as the density at which control decisions have to be determined in order to prevent a pest population from reaching the economic injury level. Norton (1992) pointed out that the economic threshold should be used in making the decision whether to apply a treatment against a pest in order to get greater benefit.

An important factor of IPM is the economic injury level (EIL), the lowest density level of pests that causes economic damage. Therefore, the decision to take control measures has to be based on EIL and population dynamics of pests and natural enemies to avoid misuse of insecticides (Stern et al, 1959; Pedigo. 1989; Kogan, 1988) and eliminate environmental contamination and human health problems (Zalom, 1991). The economic injury level is a dynamic factor which is influenced by various aspects; the yield value, the cost of control measures, the environment of the plant and insects (Grunberg, 1969; Ogunlana and Pedigo, 1974) and the variety of crop (Pimentel, 1985).

Technological approaches to assess yield losses which are caused by pest attack can be grouped as artificial infestations, injury simulation through cutting, thinning, or pruning crop plants, determining yield associated with naturally varying levels of pest attack (Norton, 1992), and modification of natural populations (Pedigo, 1989). Apple (1980) stressed that these technologies are the central factor to the successful development of IPM programs. Pedigo (1989) noted that it is very difficult to measure yield losses for some types of pests, such as aesthetic and forest pests because of the difficulty in assessing quantitative values of pest injury. He suggested that the EIL can be assessed using the following equation:

$$P = \frac{C}{V \times I \times D}$$ where

P = density of insect population (insects/unit)

C = cost of management per area ($/acre)

I = injury units per insect per production unit (defoliation/insects/acre)

D = damage per unit injury (bushels lost/acre/percent defoliation)

V = market value per unit of product ($/acre)

The separation of I and D variables is a problem for it is difficult to measure for the effects of piercing-sucking insects. Ruesink and Kogan (1975) also noted that the effect of indirect pests on yield was often more difficult to assess. The product loss per sucking insect can be calculated from statistical regression analyses of data by plotting insect density and yield. The relationship between yield and the number of insects may be linear or non linear. Hosny et al (1972) found that the relationship between mandarin yield and numbers of red scale, *Aonidiella aurantii* Maskell was curvilinear.

The b coefficients represent yield loss per sucking insect. Therefore the EIL can be expressed as follows:

$$EIL = \frac{C}{V \times b}$$

This method was used to assess the EIL of psyllids attacking the commercial plantation of boronia (Mensah, 1990) and the potato leafhopper, *Empoasca fabae* Harris (Ogunlana and Pedigo, 1974).

Insecticides are still needed to minimise losses in crop production from pests (Ware, 1989) but only if pests reach an economic threshold (Metcalf, 1975). DeBach and Rosen (1991) pointed out that 80 percent mortality, rather than 98 percent, may be sufficient to provide immediate control; this lower level would also cause fewer upsets or resurgences and reduce the rate of development of resistances to pesticides. Where natural enemies are scarce or ineffective, complete control of pests with a selective material could lead to disastrous pest resurgences (Stern et al, 1959).

Selective insecticides which kill target pests and preserve natural enemies are necessary in IPM (DeBach and Landi, 1961; Kogan, 1988; Stern et al, 1959 and Ware, 1985). Stern et al (1959) and Ware (1989) stated further that insecticides act as selective agents in several ways: toxicological action, the formulation used, the dose level and the timing of the application. Metcalf (1974) pointed out that decreased dosage has often brought about favourable results in pest control with minimal adverse effects. Van de Bosch and Stern (1962) and Wood (1974) also noted that lowered dosages of broad spectrum insecticides may increase insecticide selectivity through decreasing damage to parasitoids and predators. This would suggest that levels of pesticides should be confined to the pest in question rather than the recommended dose supplied to apply to a wide range of pests.

It is necessary to know the life cycle of the pest in detail and also the relationship between different parts of the life cycle and the stages of the host plant, especially with regard to damage and susceptibility to the pest, in order to determine the accurate application of chemicals (Ashaby, 1979). Metcalf (1974) also noted that use of the life table of the pest showing the key factors affecting it provides valuable information which is required in planning the most effective insecticide intervention, including timing and integration with other key factors. Simple life table data for a generation or two could predict the side effects of insecticides and avoid them in simple cases (Varley et al, 1973).

IPM provides a suitable approach for keeping pest populations under the economic injury level (Glass, 1976). In fact, some IPM programs have been applied to control the crop pests successfully in some regions, such as citrus pests in South Africa (Bedford, 1976) and California (DeBach and Rosen, 1991), the purple scale *Lapidosaphes beckii* Newman on citrus in California (DeBach and Landi, 1961; Bosch and Stern, 1962) and psyllids on boronia in Tasmania (Mensah, 1990).

1. 10. 4. Control of the black scale, *Saissetia oleae* Oliver

Some measures have been tried since the nineteenth of the century to control scales insect, for instance soap, kerosene, tobacco, lye, pyrethrum, alcohol, ammonia, sulphur (Comstock, 1916) and gas treatments with hydrocyanic acid and a mixture of sulphuric acid and dry cyanide of potassium to control *S. oleae*, *A. aurantii* and *I. purchasi* (Craw, 1891). However these chemicals were later replaced with newer chemicals. Petroleum spray oil, and mixtures of white oil and maldison or dimethoate are still recommended to control black scale in Australia. Besides killing the scale insects these oils also loosen sooty mould. Timing of sprays to coincide with vulnerable stages is very important for controlling the black scale and other soft scales if a good result is to be obtained (Beattie and Gellatley, 1983; Brooks and Thompson, 1962; Stafford, 1949).

Petroleum spray oil was reported as one of many chemical agents which adversely affected the cuticle and thus insect survival (Chen and Mayer, 1985). Petroleum spray oil was a relatively selective option for black scale control on citrus (Beattie, 1991 and 1992; Bellows and Morse, 1988; Morse and Bellows, 1986). Nucifora and Nucifora (1978) also suggested that mineral oil treatments should be used to protect the ecology of the citrus orchards. The oil formulations in use today to control pests are based on narrow-range oils. Narrow-range oils are obtained by removing low molecular weight components which reduce the efficacy of oil and high molecular weights which increase the risk of phytotoxicity. The annual ceiling of oil could be increased to at least 3 % annually (Beattie, 1991) due to the low toxicity of modern petroleum spray oils (Beattie et al, 1989). Petroleum oils have become an essential insecticide in integrated pest management in citrus for several reasons. They have little effect on natural enemies, do not stimulate outbreaks of pests, do not develop resistant pests, have low toxicity to vertebrate animals, are broken-down within weeks and are easy to handle. Furthermore, they have to be applied to plants until run-off to achieve an excellent result (Beattie, 1991 and 1992). Banks et al (1993) suggested that the efficiency of pesticide spray was measured not only by its effectiveness but also by its adequate coverage with minimum volume on the target pest. The spreading of oil drops on leaves is a function of the physical properties of the liquid and the nature of the leaf surface (Boize et al, 1976).

Dosages of petroleum spray oils are recommended ranging from 1 - 2% (V/V) ; however a concentration 1 - 1.2% of petroleum spray oil is usually sufficient to control scale insects (Beattie and Gellatley, 1983; Beattie, 1992). The addition of broad spectrum insecticides is only rarely necessary. Beattie (1991) also stated that annual multiple applications of ≤1.2% petroleum spray oils for the control of scale and non scale pests could avoid the risk of phytotoxicity. Petroleum spray oil (2%), applied at 3000 L. ha^{-1}, resulted in high scale mortality of Chinese wax scale on citrus and was the most cost-effective treatment (Beattie et al, 1991).

Phytotoxicity or burns to trees and loss of yield are major disadvantages of petroleum spray oils. However, with new formulation and correct application phytotoxicity and loss of yield could be avoided (Beattie, 1992). Gudin et al (1976) pointed out that stomata were considered to be one of the most important routes of oil penetration into leaves.

In Fillmore, California, before the 1940s *S. oleae* attacking citrus was fumigated with hydrogen cyanide gas or sprayed with broard-range white oil annually before it was controlled by its natural enemies. Between 1960 and 1970 five percent of citrus groves needed only oil spray to control *S. oleae* (Debach and Rosen, 1991).

The insecticides gusathion (azinphos methyl), parathion, oil and a combination of parathion and oil, when tested against *S. oleae* reduced the number of this scale significantly. Gusathion gave the best result and reduced the sooty mould infestation (Brooks and Thompson, 1962).

In Israel, fenoxycarb as an insect growth regulator has been recommended in integrated pest management to control *C. floridensis* and *S. oleae* infesting citrus because it has specific effects and is harmless to beneficial insects (Peleg, 1988). D'anna and Leonardi (1990) also noted that fenoxycarb gave control of *S. oleae* comparable to that achieved with carbaryl and methadathion, although its effect was not so immediate.

As previously mentioned, biological agents, parasitoids and predators, have been used to control the black scale and these could play an important role in keeping its population at a low level. So insecticides applied for control of other pests should not kill the parasites of black scale that maintain its population under the economic threshold (Debach and Rosen, 1991). Katsoyannos and Laudeho (1976) also suggested that chemicals used to control olive fruit fly, *Dacus oleae* (Gmel), have to be applied carefully to avoid adverse effects on the natural enemies of *S. oleae*.

Daane and Caltagirone (1990) found that a monitoring program based on cultural practices and adult scale density surviving into the next generation and summer temperatures could be used for guidance in regular management practices.

Chapter 2

Biology and taxonomy of *Saissetia oleae* Oliver and *Coccus hesperidum* L. and the damage of boronia plants

2. 1. Introduction

The biology and morphology of pest scale insects such as *S. oleae* (Argyriou, 1963), *C. hesperidum* (Annecke, 1966) and *Saissetia nigra* Nietner (Smith, 1944) have been studied intensively. Biological information of insect pests is valuable in ecological studies and the development of pest management programs. Some studies have shown that the biology and morphology of insect pest may be altered according to the host plant. Therefore the taxonomy and biology of *C. hesperidum* and *S. oleae* on boronia plants have to be known as a base for further studies.

The relationship between the numbers of insects and yield loss is a most important factor to be measured in order to determine an economic injury level. The relationship between *S. oleae* and the effect of its damage of *Boronia megastigma* in the commercial plantations needs to be assessed.

This chapter describes the numbers of eggs deposited, characteristics of each stage of both scale species, *S. oleae* and *C. hesperidum*, and the settling preference of crawlers of black scale on host plants. In addition, the relationship between the numbers of *S. oleae* and plant reproductive and vegetative growth is presented.

2. 2. Study area

The study of the taxonomy and biology of both scale species was conducted in a glasshouse and the entomological laboratory, Department of Agricultural Science, University of Tasmania in 1992. Temperatures in the glasshouse ranged from 18 -25 ^{o}C and 60 - 75 % relative humidity. However, the assessment of scale damage and the relationship between numbers of black scale and plant reproductive or vegetative growth were conducted on a boronia farm owned by Mr Greg Pullen at Cygnet, in 1993 and 1994.

2. 3. Material and methods

2. 3. 1. Life form characteristics of *Saissetia oleae* Oliver and *Coccus hesperidum* L.

Specimens of *S. oleae* and *C. hesperidum* used in this study were collected from the boronia farm. Chemicals used in this study were as follows : lacto-alcohol, alcohol, potassium hydroxide and Euparal.

Twenty adult*S. oleae* female were randomly selected to assess their fecundity. Adhesion of the posterior region of the female scale to leaf or stem surfaces indicated that no crawlers had as yet escaped. Each female was removed from the boronia shoot and placed in a petri dish with diameter 9.5 cm and 1.5 cm in height. Eggs, which were deposited beneath the female scale, were counted using a stereomicroscope. Then each female scale was dissected to count eggs which remained in the body of the scale. Twenty reproductive female scales of *C. hesperidum*, which had just commenced laying their eggs, were selected at random were dissected to estimate numbers of eggs produced.

Specimens of all stages of both scale insects, *S. oleae* Oliver and *C. hesperidum* L., were collected and placed in lacto-alcohol before the mounting process was commenced.

The mounting of both scale species on a glass slide for examination under a microscope consisted of several steps. First, a specimen was placed in a 10 per cent solution of potassium hydroxide for 10 - 30 minutes depending on the stage of the scale species. Heating the specimen with care in the potassium hydroxide in a water bath with care was helpful in this study. The specimen was then transferred from the potassium hydroxide to water washes for 5 - 10 minutes to remove the potassium hydroxide. Next the specimen was transferred from the water first to 25 then 50, 75 and 95 per cent ethanol in that order, each for five minutes. The next step was to take a microscope slide and place a small drop of Euparal in the centre. A specimen was transferred to the drop of Euparal and arranged in the required position. A cover slip was then placed over it. This was done by placing one edge of the cover slip on the slide and supporting it with a needle and gently lowering it over the specimen to settle down of its own accord. The slide was kept horizontal until the Euparal dried out and then examined under the microscope with 45 to 400 x magnification .

The time required for a crawler to wander around on a host plant and to settle was determined in a glasshouse experiment. A hundred crawlers were collected from beneath reproductive females and placed on a boronia plant (7 months old) with fine brush. Counts of settled crawlers (1st nymphal stage) were made at 12, 24, 36 and 48 hours after infestation. The experiment of settling preference was also conducted in the glasshouse. Five boronia plants (7 months old) were infested with crawlers on either leaves or shoots. Counts of the 1st stage nymphs which settled on both leaves and shoots were made three days after infestation.

Measurements of the stylet length of both scale species were also made in this study. Sample shoots with the scale species attached were kept for three days in a plastic bag to make it easier to remove the scale from the sample shoot. Individual scale insects were put on the edge of a glass-slide after they were removed from the sample shoot and the length of the stylets of each scale insect was measured under a stereomicroscope.

2. 3. 2. Host plant damage and yield loss due to *Saissetia oleae* Oliver

Observations on 100 boronia plants about 6.5 years old which had died were made in February, 1993 at Cygnet to establish the cause of the death. In this study the dead boronia plants were classified into two categories: 1) plants that were attacked by black scale only and 2) plants that were attacked by black scale combined with mechanical injuries.

A second study was conducted at the same farm from February to October, 1994 to establish the effect of black scale infestation on boronia growth and flower yield per plant. Twenty boronia plants of similar height and planted at 50 cm spacing in the row were selected at random and used in this study. Half of these plants were left unsprayed and the remaining plants were sprayed with petroleum spray oil (D-C-Tron NR) at a concentration of 1.2 % until run-off (0.12 L/plant) using a knapsack sprayer. Sample shoots that were later used to measure the number of new nodes and shoot length extension were marked with long-life gloss enamel paint (Dulux Australia Limited, Clayton, Victoria). Mensah (1990) claimed that this type of paint had no effect on the growth of the plant. Counts of additional new nodes were made at 14, 28, 56, 140 days and at harvest time. Shoot length, numbers of new nodes and the weight of flowers were assessed at harvest time on October 5, 1994. The flowers were harvested by hand at about 65 % flowering.

2. 3. 3. Assessment of an economic injury level

The economic injury level for *S. oleae* was assessed in the field conducted from February to October, 1994 at the boronia farm of Mr Greg Pullen, Cygnet. Fifteen boronia bushes 6.5 years old that were comparably infested with scale to the same degree were sprayed with petroleum oil (D-C-Tron NR) at a concentration of 1.2 % in water. Individual bushes were sprayed with either 120 or 60 mls to provide "complete' and 'partial' coverage respectively. These treatments were aimed to reduce the numbers of black scale to various levels. In addition, forty-two boronia plants that were similar in size and vegetative growth were selected and used to determine the relationship between the numbers of *S. oleae* and flower yields.

To estimate the density levels of *S. oleae* two infested shoots were selected randomly from each test and control plants and placed in a plastic bag for counting in the laboratory under a stereomicroscope. Counts of the numbers of *S. oleae* were made on February 20, 1994 as it was considered the best time to measure the level of the scale population so that a decision either to spray or not spray could be made. In addition, the vegetative growth, additional nodes and new shoot length, were measured on two shoots/plant at the end of the study. The sample shoots used to assess the numbers of new nodes and shoot lengths and harvesting of boronia flowers were those mentioned above.

2. 4. Results and observations

2. 4. 1. Life form characteristics of *Saissetia oleae* Oliver

Eggs

The egg is pale white and becomes a golden honey to reddish in colour near hatching time. Its length ranges from 0.25 mm to 0.33 mm with an average of 0.290 ± 0.018 mm and width from 0.13 mm to 0.18 mm with an average of 0.150± 0.007 mm. It is oval in outline. The eggs are covered with "a thin layer of white waxy substance" assumed to prevent their sticking together as deposited beneath the female scale. Brown specks or eyes of the embryo can be seen in the anterior section of the egg just before hatching time occurs; a segmented body can be recognised.

Female scales were recorded to lay 665 - 2234 eggs with an average of 1208 eggs (N = 30). A white mass of empty egg shells are found beneath the parent female scale after hatching.

Crawlers

The colour of the crawler stage is golden honey and it is oval in outline. Its length ranges from 0.35 to 0.40 mm with an average of 0.370 ± 0.016 mm and width from 0.18 to 0.20 mm with an average of 0.200 ± 0.006 mm. The antennae are six-segmented. The metatarsus bears a relatively long and strong claw equipped with four bristles comprising the empodium. The body is eleven-segmented with 16 marginal and 4 stigmatic setae. Each stigmatic seta is set between two short spiny setae.

The anal ring of this stage bears six setae. Two anal plates, which are triangular in outline, are easily recognised. Each of them bears one long "archy caudal seta" with a length about 0.180 ± 0.010 mm and three apical setae. Two of these setae occur between the archy caudal seta and one setae sits on the inner side of the anal plate next to the other anal plate. In addition, each anal plate bears two setae, one of which grows near the apex and is known as the "subapical seta" and the other grows near to the anal opening and is known as the "fringe seta".

Table 1. Number of active black scale crawlers after infestation of boronia plants in glasshouse experiment

	Total of scale released	Number of active crawlers after infestation (hours)			
		12	24	36	48
Boronia plant	100	75	49	26	0

As seen in Table 1, all crawlers used in the study settled on the boronia before 48 hours. Results of the settling preference study in the glasshouse show thät crawlers preferred to settle on leaves rather than on stems. The percentage of crawlers settling on leaves was 69.37% (1101 nymphs) and that on stems 30.63 % (486 nymphs). No mortality was recorded.

First settled stage nymphs

After wandering around for a approximately 12 - 24 hours the immature scale settles by inserting its stylets into either leaves or shoots of the host plant. The body of the scale is elongate-oval in outline with dark brown eyes. The scale ranges from 0.51 to 0.96 mm in length and from 0.29 to 0.49 mm in width. Its colour is golden honey.

The antennae are six-segmented and their length ranges from 0.11 to 0.13 mm. The anal ring bears six setae. The number of marginal setae of this stage on each half of its body is 16 - 17 setae (Fig. 1). Each anal plate bears three apical setae, with the long apical setae still remaining at this stage. In addition, each anal plate bears two subapical setae and one fringe setae on the anal tube.

Second stage nymphs

The second stage scale is light brown to brown with an elongate-oval outline similar to the previous stage. The length of the body is 0.830 ± 0.102 mm ranging from 0.63 to 1.05 mm and the width ranges from 0.35 to 0.60 mm with an average 0.570 ± 0.640 mm. A longitudinal ridge with 11 waxy formations can be observed along the median line of the body. Four brown specks are set on both sides of the ridge where two transverse ridges form later on.

The antennae are six-segmented. Antennal length is 0.130 ± 0.019 mm ranging from 0.08 to 0.15 mm. Each of the anal plates bears four apical setae, one subapical setae and two fringe setae on the anal tube. Half of the body bears 17 to 20 marginal setae. The anal ring bears the six setae of the anal tube the same as the previous stages. However, the scale entering this stage does not carry the long apical setae.

Third stage nymphs

The third stage scale is brown with the longitudinal ridge more clearly defined. The transverse ridges are developed and easily seen from the dorsal view. The size of the scale is 1.150 ± 0.20 mm in length ranging from 0.73 to 1.50 mm and 0.770 ± 0.14 mm in width ranging from 0.55 to 0.90 mm.

The antennae are seven-segmented and their length is 0.190 ± 0.04 mm ranging from 0.15 to 0.28 mm. The third stage scale bears 20 - 22 marginal setae on each half of the body. The anal ring bears eight setae of which two are shorter. Each of the anal plates bears four apical, two subapical and three fringe setae.

Pre-reproductive stages

Soon after entering this stage the scale gradually changes colour to grey and becomes dark grey later. The size of the body increases dramatically ranging from 1.33 to 2.83 mm in length with an average of 2.170 ± 0.390 mm and 0.90 to 2.27 mm in width with an average of 1.620 ± 0.350 mm. The longitudinal and the transverse ridges are distinctly formed so they are clearly seen from a dorsal view.

The antennae are eight-segmented with a length of 0.290± 0.031 mm ranging from 0.23 to 0.33 mm. The anal ring bears eight setae similar to the previous stage. Each of the paired anal plates bears four apical, four subapical and the four fringe setae of the anal tube (Fig. 2).

Reproductive stages

When full size the scale starts to deposit its eggs. The size of the scale is now from 2.20 to 4.00 mm in length with an average of 3.130 ± 0.352 mm, 1.80 to 3.10 mm in width with an average of 2.520± 0.325 mm and 1.20 to 2.50 mm in height with an average of 1.800 ± 0.297 mm. The scale is dark grey becoming dark brown or black (Fig. 8).

Adult male scales are brown in colour and have nine-segmented antennae. The length of the antennae is 0.560 ± 0.056 mm. The size of the head is 0.520 ± 0.029 mm in width and 0.560 ± 0.058 mm in length. The length of the body is 1.620 ± 0.076 mm. 0.630 ± 0.115 mm of cercus and the length of the hind femur is ca. 0.41 mm (Figs. 3 and 4).

2. 4. 2. Life form characteristics of *Coccus hesperidum* L

Eggs

The average number of eggs produced by an adult female is 80.700 ± 20.400. The egg is oval in outline and transparent and becomes reddish-brown later. Its size ranges from 0.25 to 0.30 mm in length with an average of 0.270 ± 0.019 mm and 0.13 to 0.18 mm in width with an average of 0.150 ± 0.009 mm. In the anterior part of the egg two dark brown specks occur which later develop into eyes and embryo segmentation can be observed as the deposited egg is about to hactsh. The egg hatches shortly after it is deposited by the female scale.

Crawlers

The crawler emerges from beneath the adult female scale in the posterior region of the body and especially from under the anal plate.

The crawler is oval in outline and lightly reddish-brown in colour. The antennae is six-segmented with a length ranging from 0.10 to 0.12 mm. The body length ranges from 0.34 to 0.42 mm and 0.20 to 0.22 mm in width. Two anal plates, which are triangular in outline, are easily identified. Each of them bears one long "arched caudal

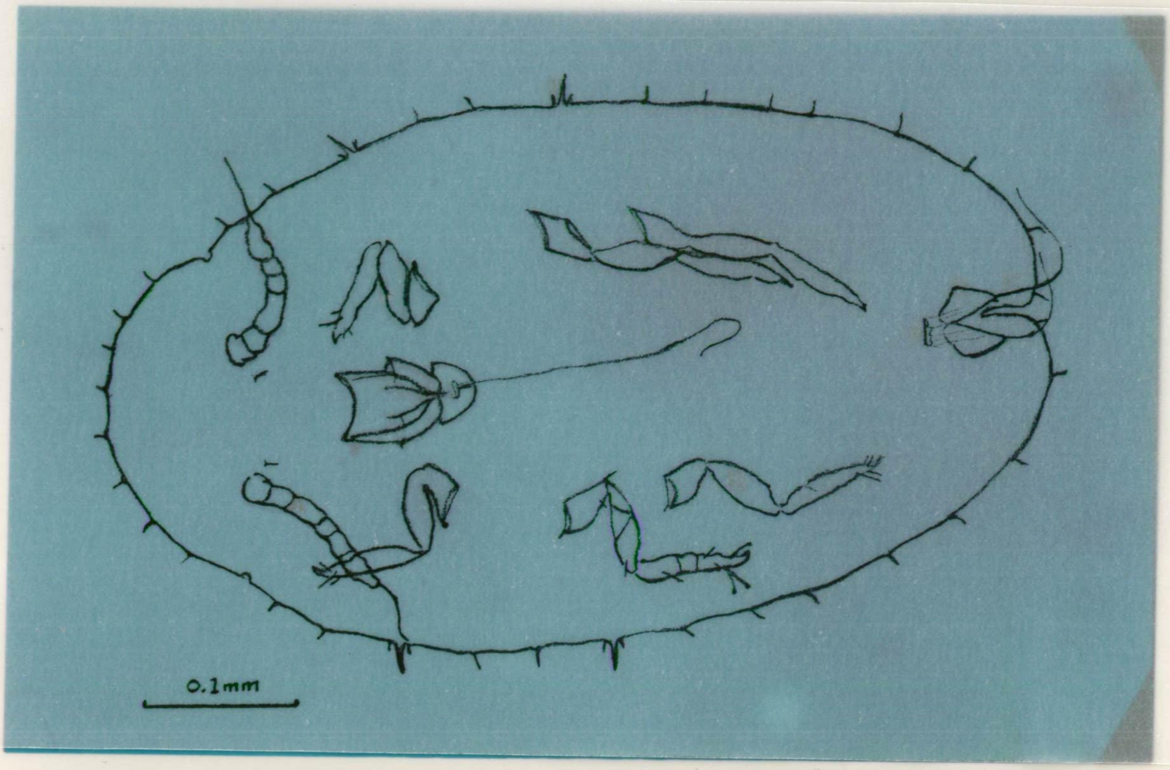


Fig. 1. First stage nymph of *S. oleae* at magnification of 200X (above) and anal plate (below); A) antennae, B) hind leg, C) archy caudal setae, D) anal plate, E) stigma setae, F) anal ring, G) apical setae, H) subapical setae, I) fringe setae and J) anal ring setae.

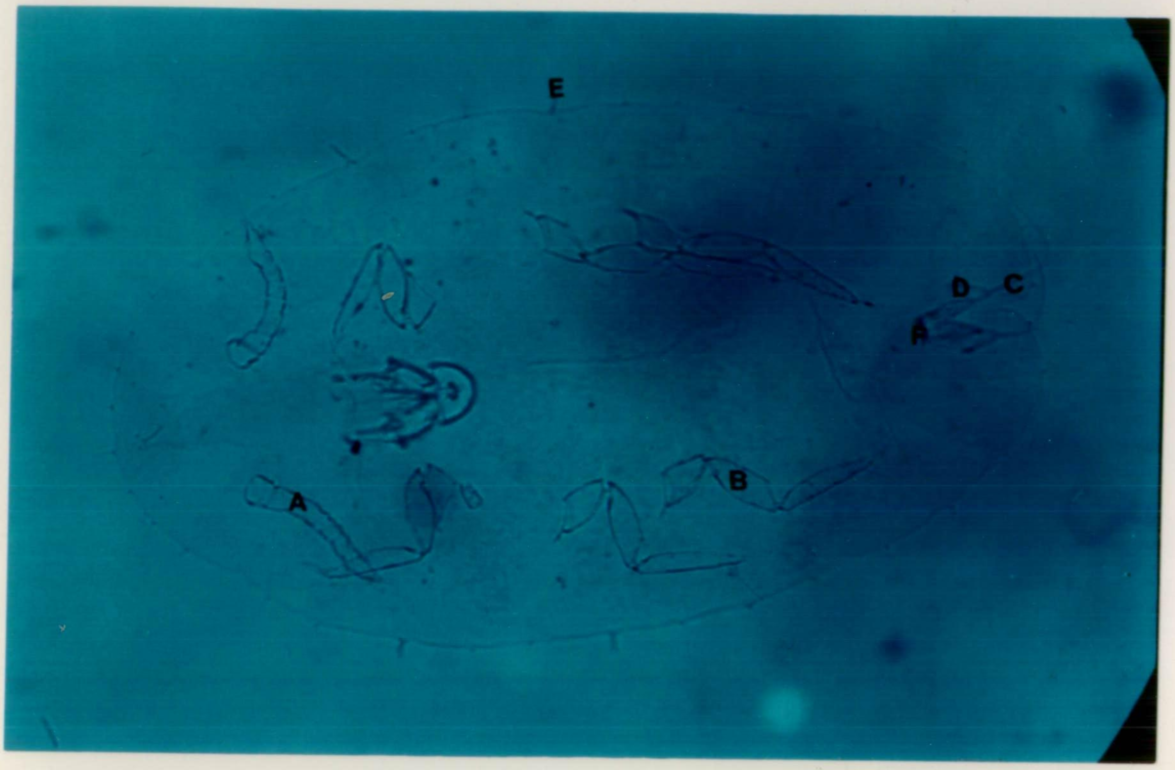


Fig. 1. First stage nymph of *S. oleae* at magnification of 200X (above) and anal plate (below); A) antennae, B) hind leg, C) archy caudal setae, D) anal plate, E) stigma setae, F) anal ring, G) apical setae, H) subapical setae, I) fringe setae and J) anal ring setae.

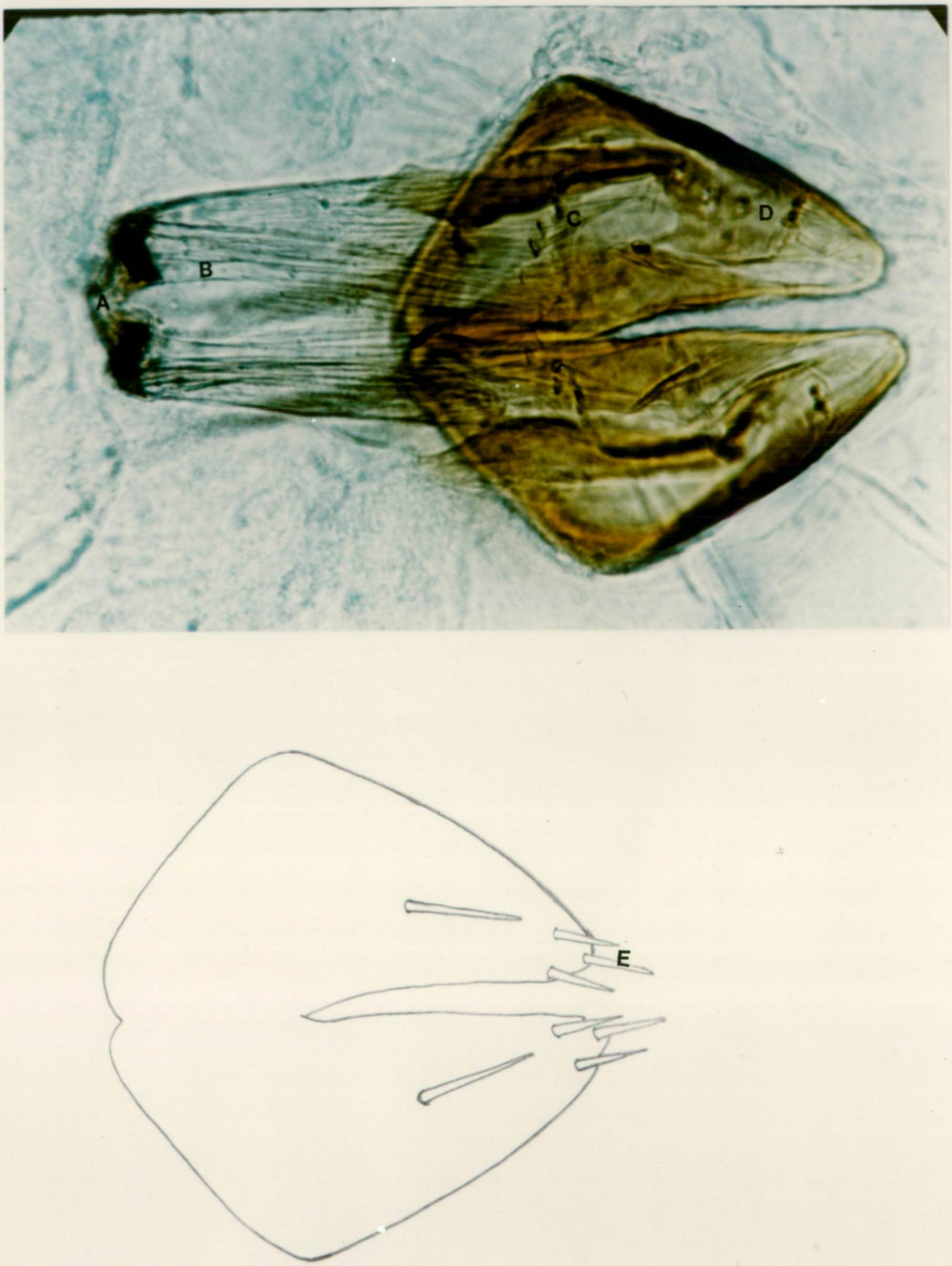


Fig. 2. Anal plate of reproductive stage of *S. oleae*: (200X); A) anal ring, B) anal ring setae, C) fringe setae, D) subapical setae and E) apical setae.

Fig. 3. Male of *S oleae* with its single pair of wing (45X) and the wing of male scale (100X); A) antennae, B) wing, C) hind leg and D) style.

Fig. 4. Head and abdomen of male scale (100X); A) antennae, C) hind leg, D) style and E) eye.

seta" with length about 0.16 ± 0.01 mm and three apical setae. Two of them sit near the arched caudal setae and one seta sits on the inner side of the anal plate next to the other anal plate. In addition, each of the anal plates also bears two setae, one of them attached near the apex known as the "subapical seta" and the other attached near the anal opening and known as the "fringe seta".

The metatarsus supports a long and strong claw equipped with four bristles comprising the empodium.

First settled stage nymphs

After initial wandering around the plant crawlers settle on boronia by inserting their stylets into the tissue of the boronia plant to feed. This stage is oval to elongate oval in outline. The colour of the scale is green-yellow and semi-transparent inside from the margins. Its width 0.390 ± 0.060 mm ranging from 0.26 to 4.90 mm and its length 0.750 ± 0.110 mm ranging from 0.56 to 0.90 mm.

The antennae are six-segmented and length ranges from 0.11 to 0.13 mm with an average of 0.130 ± 0.010 mm (Fig. 5). Each of the anal plates bears two apical setae and one long apical setae which sits between the two apical setae. In addition, each of the anal plates bears one subapical and one fringe seta. The anal ring also bears six anal ring setae. The body of this scale has nine segments that can be seen clearly under the microscope.

Second stage nymphs

The antennae of the second nymphal stage are six-segmented as in the previous stage. Antennal length is 0.190 ± 0.012 mm ranging from 0.14 to 0.21 mm. The scale is elongate oval in outline and 0.92 to 1.76 mm in length with an average of 1.250 ± 0.180 mm and 0.56 to 0.88 mm in width, average 0.670 ± 0.010 mm. The colour of the scale is yellow with longitudinal, mediodorsal rows of nine minute vertical columns of wax (Fig. 6). These waxy formations remain attached to the body until the adult stage.

Each of the anal plates bears four apical setae and one subapical seta and two fringe setae. The anal ring still carries six anal ring setae.

Pre-reproductive stage

The scale at this stage is elongate oval in outline and rather convex. The colour of the body is yellow-brown with a dark brown spot usually on the dorsum. In some cases the dark brown areas are irregularly arranged as streaks running from the midline to the lateral body-margin. The body length ranges from 1.05 to 3.15 mm and width from 0.67 to 1.93 mm.

The anal ring has eight setae as does the second instar. Each of the anal plates bears four apical and two fringe setae. However, to distinguish them from the second instar each of the anal plates has two subapical setae (Fig. 7). In addition to that, the antennae have seven-segments and range from 0.23 to 0.33 mm in length.

A dark area can be observed later on the ventral side near the anal tube and the nine wax columns still remain attached to the dorsal surface of the scale.

Reproductive stage

In this stage the ventral dark area clearly appears near the anal tube and sometimes can be seen from a dorsal view (Fig. 8). The scale is convex with a dorsal dark brown spot usually spreading in an irregular pattern with dark brown areas irregularly arranged as streaks running from the midline to the lateral body-margins. The body length is 3.11 ± 0.34 mm ranging from 2.75 - 3.70 mm and the body width is 2.39 ± 0.21 mm ranging from 1.80 - 2.60 mm. The antennae are seven-segmented and range from 0.48 - 0.63 mm in length.

The length of the stylets of both scale species were measured and are presented in Figures 8 and Figures 9. Results show that relationship between stylet length and the body width was linear with value of $r^2 = 0.82$ for *S. oleae* and 0.82 for *C. hesperidum*. Therefore increases in the width of body scale were associated with increases in stylet length for both of scale species.

Fig. 5. First stage nymphs of *C. hesperidum* (200X); A) antennae, B) leg, C) apical setae, D) anal plate, E) stigma setae, and F) anal ring.

Fig. 6. The nine formations of wax on the mediodorsal surface of *C. hesperidum* (40X); A) the nine formations of wax and B) boronia leaf.

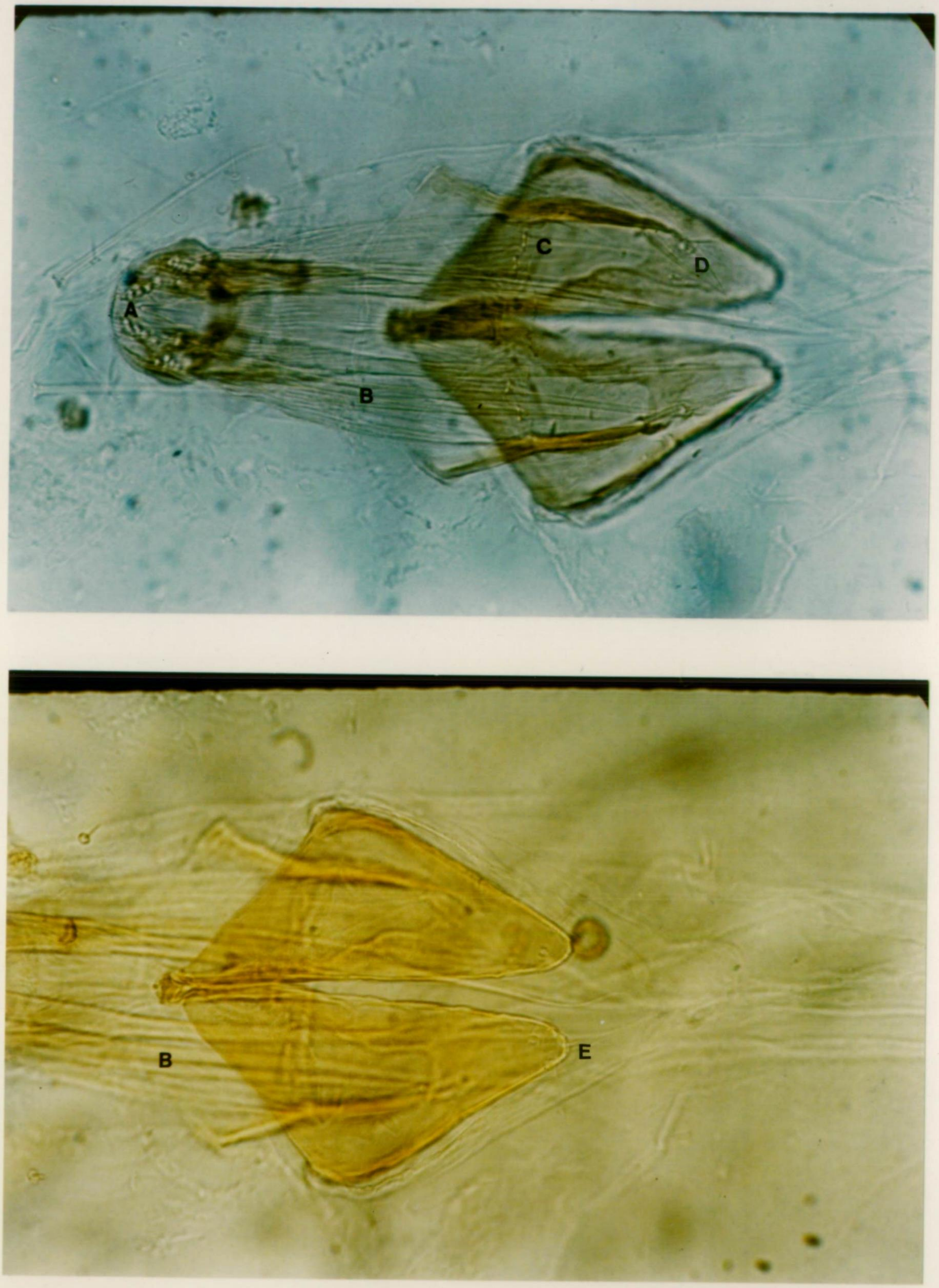


Fig. 7. Anal plates of pre-reproductive of *C. hesperidum* (200X): A) anal ring, B) anal ring setae, C) fringe setae, D) subapical setae and E) apical setae.

Fig. 8. Reproductive stage of *S. oleae* (10X) (above) and *C. hesperidum* (10X) (below).

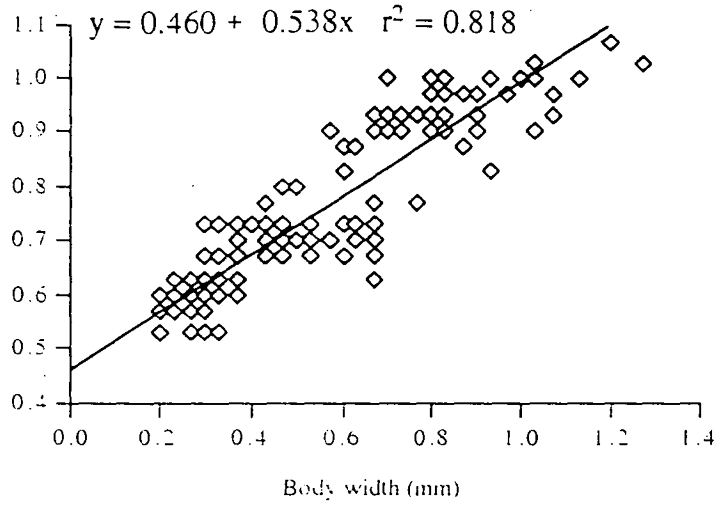


Fig. 9. Relationship between stylet length and the width of *S. oleae* on boronia plants.

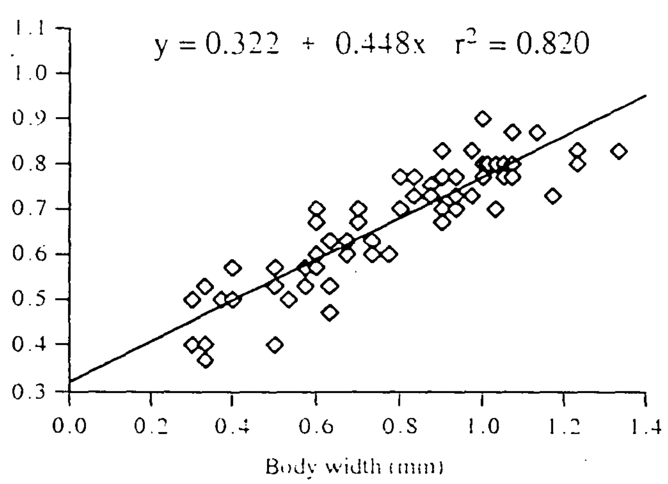


Fig. 10. Relationship between stylet length and the width of *C. hesperidum* on boronia plants.

2. 4. 3. Damage and yield relationships

2. 4. 3. 1. Plant damage and yield loss

Examination of sample of 100 scale infested boronia plants (HC 17) which had died in February, 1993 at Cygnet indicated that a combination of both mechanical damage during harvesting and black scale infestation contributed significantly to these deaths. Mechanical damage and scale infestation occurred on 88 plants and only 12 plants were undamaged but still heavily infested. All plants were heavily infested with sooty mould.

Fig. 11. Mechanical damage of boronia plant.

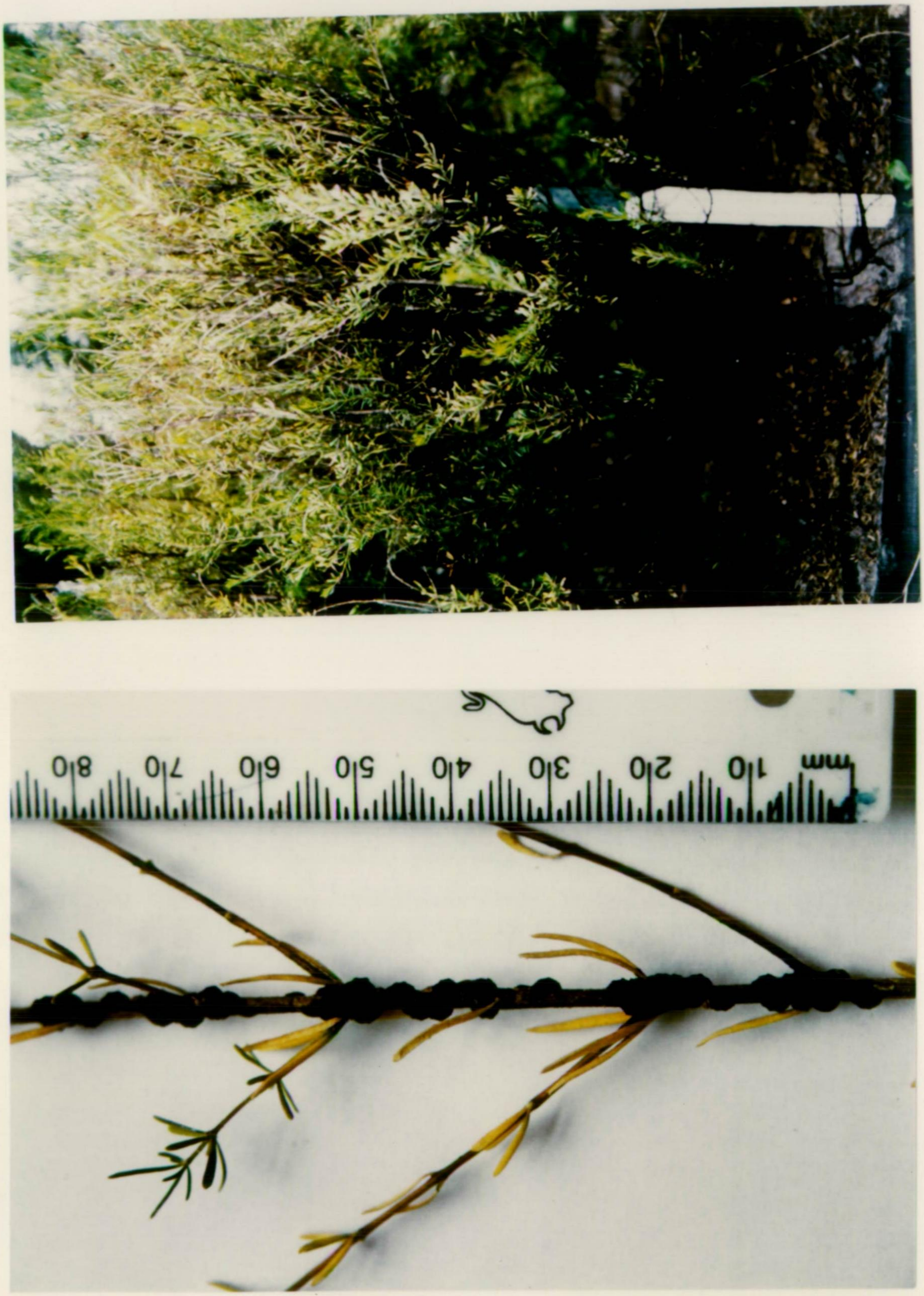


Fig. 12. Heavy infestation of boronia plant by *S. oleae* (above) in summer and boronia shoot was heavily infested by *S. oleae* (below).

The mean yield of boronia flowers from ten randomly selected plants sprayed with petroleum oil at 1.2 % and ten unsprayed control plants are presented in Table 2. The ANOVA analysis showed that the mean yield per plant between treated and untreated plants was significantly different (P = 0.0013) . The mean yield of flowers from boronia bushes initially carrying comparable infestations of scale were 229.1 and 144.1 grams from the petroleum oil spray treated bushes and unsprayed control bushes respectively. According to LeClerg (1971) yield loss due to insects can be calculated using the following equation:

$$Y = \frac{B - A}{B} \times 100\%$$

$$Y = \frac{229.1 - 144.1}{229.1} \times 100\%$$

Y = 37.1 %

where Y = yield loss

A = yield on untreated plants

B = yield on treated plants

Yield loss of boronia due to black scale infestation was 37.10 %.

Table 2. The weight of boronia flowers on treated and untreated plants (cultivar HC 17) harvested by hand at Cygnet 1994.

Plants as Replicates	Weight of flowers per sample plant			
	Sprayed plants		Unsprayed plants	
	X (gram)	Log (X +1)	X (gram)	Log (x +1)
1	220	2.344	106	2.029
2	209	2.320	152	2.189
3	197	2.297	135	2.130
4	250	2.400	194	2.290
5	311	2.494	94	1.977
6	216	2.337	178	2.250
7	182	2.260	148	2.170
8	195	2.292	117	2.072
9	280	2.447	133	2.127
10	231	2.265	184	2.267
Total	2291	23.456	1441	21.501
Mean	229.1	2.346 ± 0.078	144.1	2.150 ± 0.104

Analysis of variance (ANOVA) for the weight of flowers per plant

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	36125.000	36125.000	21.274	.0013
Replication	9	9736.800	1081.867	.637	.7438
Residual	9	15283.000	1698.111		

Dependent: Weight of flowers

lsd(0.01) = 59.891 and lsd(0.05) = 41.689.

Numbers of new nodes and shoot extension growth lengths on treated and untreated plants were recorded and are summarised in Table 3 and Figure 13. The numbers of black scale were also counted before and after treatment and are presented in Figure 14. ANOVA for the numbers of new nodes and shoot extension growth length were also calculated. The numbers of new nodes per sample shoot produced on untreated plants were significantly fewer (8.05 new nodes) than those on treated plants (11.45) at P = 0.005

Table 3. Numbers of new nodes and shoot extension growth lengths per sample shoot on treated and untreated boronia plants (HC 17) in Cygnet Huonville 1994.

Plants as replicates	Numbers of new nodes per sample shoot		Shoot extension per sample shoot	
	Sprayed plants	Unsprayed plants	Sprayed plants	Unsprayed plants
1	11.00	5.00	8.00	5.45
2	13.00	10.50	13.80	6.60
3	13.50	6.50	13.90	8.80
4	10.50	6.00	9.30	5.85
5	12.50	5.50	7.05	5.50
6	8.50	10.50	10.90	10.00
7	12.00	8.00	12.40	6.90
8	9.00	8.50	9.15	6.90
9	12.00	10.50	12.00	10.50
10	12.50	9.50	9.65	9.30
Total	114.5	80.50	106.15	75.80
Mean	11.45 a ± 1.67	8.05 b ± 2.18	10.612 a ± 2.37	7.58 b ± 1.90

lsd(0.01) = 2.994 and lsd (0.05) = 2.084.　　lsd(0.01) = 2.994 and lsd (0.005) = 2.084.

ANOVA for the number of new nodes

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	57.800	57.800	13.618	.0050
Replications	9	29.750	3.306	.779	.6422
Residual	9	38.200	4.244		

Dependent: Number of new nodes

ANOVA for the shoot extension

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	46.056	46.056	18.406	.0020
Replications	9	60.526	6.725	2.688	.0785
Residual	9	22.520	2.502		

Dependent: Shoot extension

The numbers of new nodes produced and shoot growth between treatments were significantly different (P = 0.005 and P = 0.002 respectively). The number of black scale counted at pre-treatment was 93.7 per sample shoot on treated plants and 78.6 on untreated plants. At the end of the study the mean number of black scale was 40.9 per sample shoot on untreated plants and 0.2 on plants treated with petroleum spray oil. That is in the control plants scale density was 204.5 fold over that of sprayed plants (Fig. 14). The difference between treatments was highly significant (P = 0.0025).

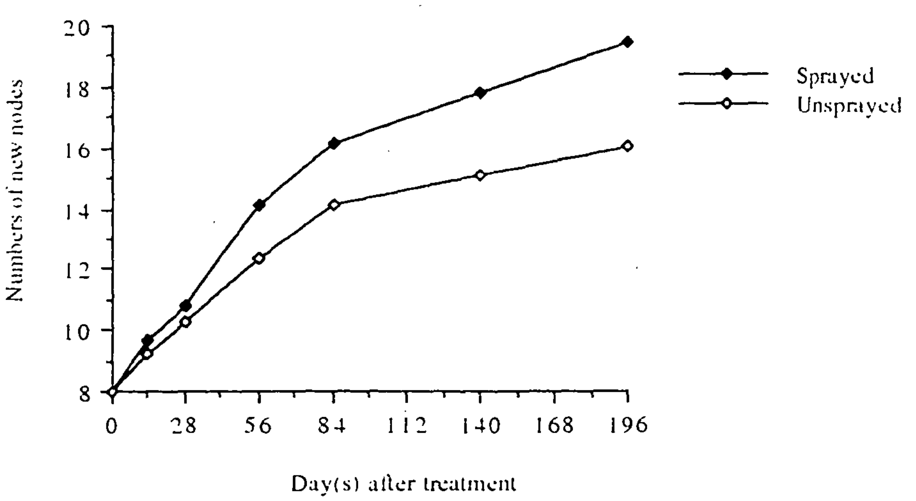


Fig. 13. Number of new nodes on boronia plants sprayed with petroleum spray oil at 1.2% on February 21, 1994 and unsprayed plants at Cygnet

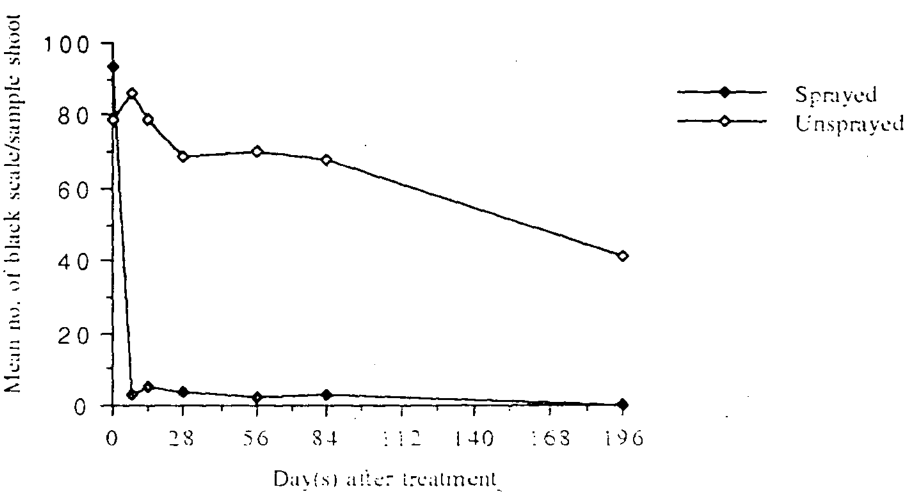


Fig. 14. Average number of black scale, *S. oleae*, on sample shoots of boronia plants sprayed with petroleum oil at 1.2 % on February 21, 1994 and unsprayed plants at Cygnet.

2. 4. 3. 2. Assessment of an economic injury level

The relationship between the number of black scale on the boronia plants in February and the flower yield of the plants in October was curvilinear (Fig. 15) with a negative slope ($r^2 = 0.868$).

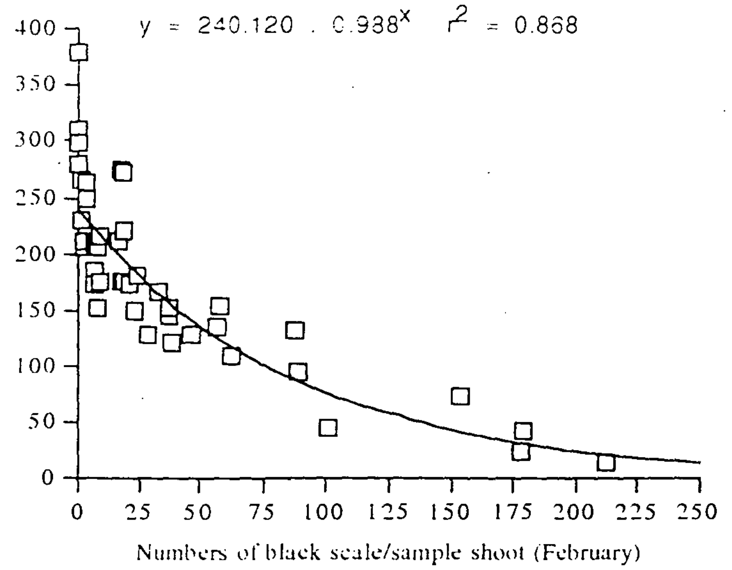


Fig. 15. Relationship between the flower yield (g/plant) of boronia plants on October 5 and levels of black scale density counted on two sample shoots (15 cm) on February 21, 1994 at Cygnet.

Using the relationship between the yield and numbers of *S. oleae* an economic injury level for black scale, *S. oleae*, was determined. However, to do so, it was necessary to know the rate of yield reduction per insect, market price per unit of yield and management cost per area for controlling an insect pest. Petroleum oil at 1.2 % was used to control *S. oleae*. The average cost of each application was $ 122.35/ha including petroleum spray oil, labour and tractor rent. The market value of boronia flowers paid by "Essential oil of Tasmania Pty. Ltd." was $ 16.85 per kg fresh flowers which contain ca. 60 % oil.

The gain threshold has to be calculated as the amount of yield loss which constitutes minimum economic damage (Stone and Pedigo, 1972). It is expressed as follows:

Gain threshold (kg/ha) = Cost of pest control ($/ha) / market price of flowers ($/kg)
Gain threshold (kg/ha) = 122.35 ($/ha) / 16.85 ($/kg)
Gain threshold (kg/ha) = 7.261 kg/ha

The reduction in the rate of yield per individual insect is represented by the value of b on the regression equation (Pedigo, 1989). Therefore, the coefficient, b, in the curvilinear equation (Fig. 15) expresses the increase in the rate of loss of boronia flowers per *S. oleae* stage on boronia in February, 1994 as about 0.988. The economic injury level was, therefore, the average number of *S. oleae* per terminal shoot (15 cm) that can reduce the boronia flowers by 7.261 kg/ha. The average number of *S. oleae* can be assessed as:

X = Gain threshold / b
X = 7.261 / 0.988
X = 7.35 nymphs

Consequently, the economic injury level for boronia plants (cultivar HC 17) at six years old based on this experiment was ca. 7 nymphs per terminal shoot in February.

The relationship between shoot extension measured at the harvest time and levels of black scale density in February was also curvilinear with a negative slope with a r^2 value of 0.614 (Fig. 16). That is, the infestation of black scale also affected the length of boronia shoot.

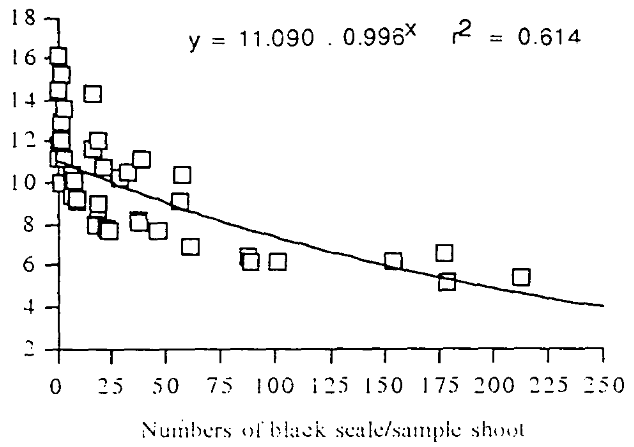


Fig. 16. Relationship between shoot extension length on October 5 and the numbers of black scale counted on February 21, 1994 at Cygnet.

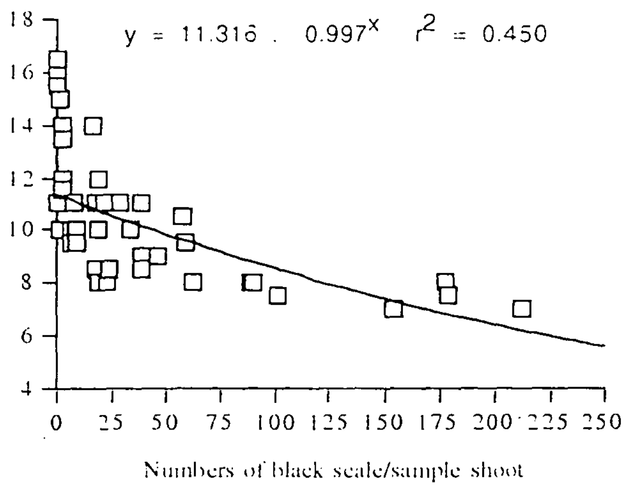


Fig. 17. Relationship between the numbers of new nodes on October 5 and the numbers of black scale counted on February 21, 1994 at Cygnet.

However, the correlation between the numbers of new nodes and levels of black scale density on boronia, although curvilinear and with negative slope, had a low r^2 value of 0.45 (Fig. 17). That is, the reduction in the numbers of new nodes was only slightly affected by increased numbers of black scale.

The relationship between yield and the length of shoot growth of boronia plants (HC 17) was linear with a r^2 value of 0.533 ($F = 45.541$; $p = 0.0001$) and presented in Figure 18. A linear regression with a r^2 value of 0.520 ($F = 43.364$; $p = 0.0001$) (Fig. 17) also expressed a relationship between yield and additional new nodes of boronia plant (cultivar HC 17). Flower yield decreased proportionally in relation to both additional new nodes and shoot growth.

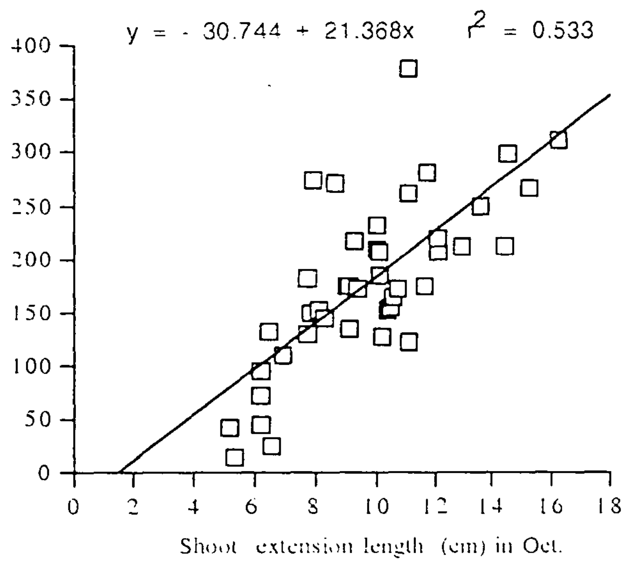


Fig. 18. Relationship between flower yield and shoot extension length of boronia plants (cultivar HC 17) on October 5, 1994 at Cygnet.

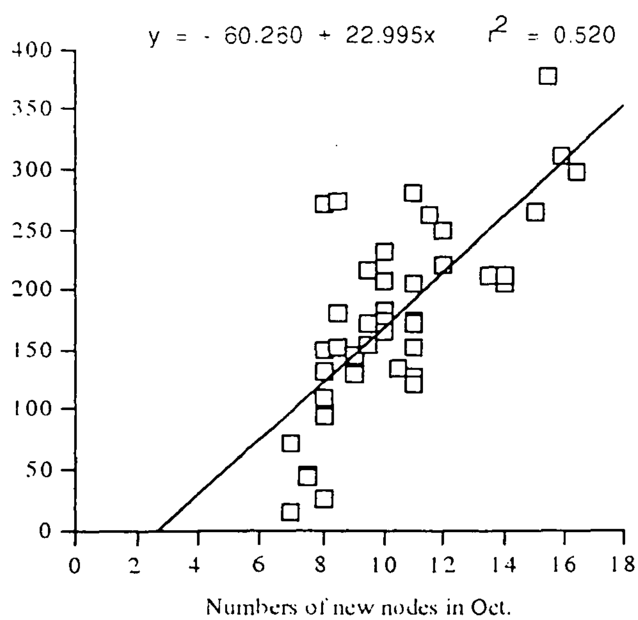


Fig. 19. Relationship between flower yield and the numbers of new nodes of boronia plants (cultivar HC 17) on October 5, 1994 at Cygnet.

2. 5. Discussion

Variation in numbers of eggs deposited by both scale species, *S. oleae* and *C. hesperidum* was observed. Hinton (1981) stated that the numbers of eggs produced by an insect depends on the size of the adult female which is affected by the availability of either the quality or quantity of food. The eggs of *S. oleae* are deposited beneath the reproductive female then hatch later; however, eggs of *C. hesperidum* hatch shortly after they are deposited. Consequently, eggs are rarely to be found beneath the adult scale. Males of *S. oleae* occurred in the scale population but were rarely found and female *S. oleae* reproduce parthenogenetically. Crawlers of *S. oleae* settled within 48 hours and preferred to settle on the under-side of boronia leaves rather than on shoots in the glasshouse experiment. In the field their behaviour, however, is affected by several factors such as temperature and structure of canopy.

When this study first commenced it was believed that only one species, *S. oleae*, occurred in the field. Subsequently,*C. hesperidum* was found. In the adult stage both thesespecies are easily recognised. However the first stage nymphs of *S. oleae* and *C. hesperidum* have to be differentiated under a stereomicroscope using differences in colour and size of body and antennae. Furthermore, each stage of both scale species bear different numbers of fringe and subapical setae. Argyriou (1963) used these characteristics to separate the stages.

Results from field observations indicate that a combination of mechanical damage of boronia plants (cultivar HC 17) and *S. oleae* infestation resulted in the death of many plants. The mechanical damage of boronia plants was mainly caused by the movement of a tractor over the plant and also equipment used to harvesting flowers. Retaining the boronia plants' height at a certain level could possibly reduce the mechanical damage which provides settling sites for crawlers by minimizing any leverage or bending effect. This type of damage, such as broken branches could affect the amount of nitrogen available in the tissues to phytophaguous invertebrates (White, 1984). However, heavy infestation of *S. oleae* alone can cause the death of boronia plant. Ebeling (1959) reported that in extreme cases, citrus trees could die due to *S. oleae* infestation. Smith

(1954) found that twig dieback of *Dubuisia* sp. could occur following heavy infestation of black scale. In addition, the local plants which died were heavily covered by sooty mould especially on the bottom half of plants. Covering parts of the plants with excessive sooty mould must contribute to the death of the boronia plants by interfering with photosynthesis. Mensah (1990) observed that the contamination of boronia plants with black sooty mould could suppress plant growth and excess honey dew joined terminal leaves and prevented shoot growth.

S . oleae feeding significantly reduced flower yield of boronia plants (Table 3) and affected the vegetative growth by suppressing the numbers of new nodes and shoot extension (Table 4). As a result, the reduction of boronia flowers caused by black scale is through initial suppression of vegetative growth. Vranjic and Gullan (1990) found similar results that *Eucalyptus blakelyi* Maid. growth (3 months) was affected by *Eriococcus coriaceus* Maskell. infestation. Pedigo (1989) stated that piercing-sucking insects remove plant carbohydrates and nutrients after carbon is taken up and before the plant can convert it to tissue. Furthermore, Cockfield and Potter (1987) and Mills (1984) reported that scale feeding may interfere with photosynthesis and translocation, consequently limiting the growth of new tissues. The percentage yield loss of boronia (cultivar HC 17) attacked by *S. oleae* in 1994 was approximately 37%. This means that inappropriate control of *S. oleae* infestations can result in significant reductions of yield and, hence, profit to growers.

The economic injury level was assessed on the basis of plant damage and insect pest intensity trials in the field. The results indicate that the relationship between boronia flower yield of boronia plants (cultivar HC 17) and the numbers of *S. oleae* was curvilinear with a negative slope which means that yield reduction progressively increased with the increase in the number of *S. oleae* on the plant in February, 1994. A similar relationship was reported between California red scale and citrus yield in Egypt (Hosny et al, 1972). According to the relationship the economic injury level was determined at an average 7 nymphs of *S. oleae* per terminal shoot of boronia plant (cultivar HC 17) at six years old. The economic injury level is a dynamic parameter which is influenced by several factors such as market value of product yield and cost of pest control; and it is imperative to continually update market data.

As shown previously flower yield reduction may be affected by *S. oleae* through the suppression of vegetative growth resulting in fewer new nodes and shorter shoot extension. Plotting the new nodes and shoot extension against yield results shows that a relationship between the two parameters on flower yield was positive and linear (Figs. 14 and 15).

Chapter 3

The life history and population performance of *Saissetia oleae* Oliver and *Coccus hesperidum* L.

3. 1. Introduction

Black scale and soft brown scale have recently infested commercial boronia plantations in Tasmania and *S. oleae* has become a serious pest in certain areas. In general, populations of both scale species in Australia are kept at low levels by natural enemies (Wilson, 1960; Helly et al, 1982). In some instances high temperatures during summer have been shown to be a major mortality factor of scale insect in the immature stages. Although these insect have been intensively studied previously, the life cycles and population dynamics of both species on boronia have not been examined previously. It is important to know the population dynamics and mortality factors affecting scale on this plant in order to develop appropriate control strategies This study emphasises the black scale as the most dominant species. Observations were commenced at Kingston in November, 1991 and Cygnet in October, 1992 to gain this information. In addition, the effect of cultural practices, pruning and harvesting, on the populations of both scale species were assessed.

3. 2. Study areas

A boronia farm owned by Mr. Scott Innes, at Kingston (Figure 20), was used in the study of the populations of *S. oleae* and *C. hesperidum* . Boronia plants used in the study had not been sprayed with pesticides since 1990. The plants were similar in height and planted with 0.5 m spacing in rows and 1 m between rows. Soil was a sandy loam. Fluctuations of black scale populations due to insecticide applications were monitored at Cygnet (Fig. 20). Boronia plants at Cygnet were intensively managed.

The effect of pruning was assessed at both boronia farms, Kingston and Cygnet, in 1993. The effect of mechanical harvesting was only assessed at Cygnet in 1994.

3. 3. Material and methods

3. 3. 1. Populations of black scale, *Saissetia oleae* Oliver and soft brown scale, *Coccus hesperidum* L.

Sampling of infested terminal shoots (15 cm long) for both scale species, *S. oleae* and *C. hesperidum* commenced on November 18, 1991 at Kingston. One infested terminal shoot per plant was selected at random from each of 88 randomly selected plants at each sample date. Each sample shoot was placed in a plastic bag (25 x 35 cm) for counts of the numbers of both scale species on return to the laboratory. Populations of both *S. oleae* and *C. hesperidum* were assessed at monthly.

Observations on the populations of black scale at Cygnet commenced on October 16, 1993. Selected sample shoots were taken from above the last season's growing point in summer and autumn and 2 - 3 cm below this point in winter and spring because black scale tend to migrate to the lower parts of boronia plants during this time.

Counts of the number of both scale species were separated according to their developmental stages and settlement on both stems and leaves. The developmental stages of black scale recorded in these observations were as follows: crawler and settled first, second, and third stage nymphs. Furthermore, the mature stage was divided into two stages: pre-reproductive and reproductive females.

The developmental stages of soft brown scale recorded in these observations were as follows: crawler and settled first, second stage nymphs, pre-reproductive and reproductive females.

Parasitised black scale and soft brown scale and predators were recorded also. Predators were counted for 100 sweeps as described by Mensah (1990).

Fig. 20. Locations of study areas at Kingston (above) and Cygnet (below) in autumn.

3. 3. 2. Analysis of the sampling data

3. 3. 2. 1. The expression of sampling results

Populations estimation of *S. oleae* and *C. hesperidum* and their distribution on stems and leaves were expressed as total numbers per 100 sample shoots. The incidence of potential scale predator was expressed as the average numbers per 100 net sweeps (1 sweep/bush) and the average number of scale per sample shoot that was determined by the total numbers of scale per 88 sample shoots multiplied by 100/88. This was regarded as an estimate of the average numbers per plant.

3. 3. 2. 2. Construction of life table

Life tables were constructed for population of black scale, *S. oleae* for two generations at Kingston. Population estimates of each stage of black scale were expressed as the average numbers per terminal shoot per generation. Eggs of black scale were estimated by multiplication of the number of reproductive females per sample shoot by the average number of eggs deposited by mature female scales, ca. 1208 eggs. Percentage of eggs hatching was assessed in the laboratory. Numbers of crawler stages per sample shoot were therefore determined by multiplication of numbers of eggs per shoot by the average percentage of hatch (97%).

The generation life tables were examined using Varley and Gradwell's (1968) key factor method that is able to recognise key factors acting on populations and the period over which they act. For this analysis, the estimation of scale numbers at different stages were transformed into logarithmic values and the differences between successive stages termed k_i, and the total of all k_i values as K (total generation mortality).

3. 3. 3. Effect of pruning and harvesting on scale insect population

Both pruned and remnant sample shoots were put in plastic bags and brought to the laboratory for counting. The numbers of both scale insects removed by pruning and remaining on the plant were estimated on 100 randomly selected shoots. Sample shoots were initially tagged above and below the potential point of pruning. The numbers of both scale insects removed were counted on these pruned sample shoots. Counts of both scale species remaining on the tagged sample shoots were also made.

Because soft brown scale, *C. hesperidum*, only occured at low levels, the effect of harvesting chiefly involved the black scale, *S. oleae*. The effect of harvesting on the numbers of black scale was assessed on one hundred selected shoots before and after the harvesting of boronia plants.

3. 3. 4. Black scale settling on weeds in boronia farms

The number of immature black scale which settled on weeds was assessed. Weeds which are commonly found in boronia were *Trifolium repens* L.(white clover), *Leotnondon taraxacoides* (Vill.) Merat. (hawkbit), *Rumex acetosella* Fours. (Sorrel) and *Stylidium graminifolium* Swartz. (trigger plant). Individual plants were sampled at distances of 10, 20, 30, 40, and 60 cm from individual boronia plants. Counts of black scale on each weed species were assessed on five occasions.

3. 4. Results

3. 4. 1. Populations of *Saissetia oleae* Oliver

Fluctuations of the numbers of black scale were recorded from November, 1991 to June, 1994 at Kingston and are summarised in Figure 21 in terms of the logarithm of numbers of survivors. Results indicated that *S. oleae* had only one generation per annum ie. in Tasmania where temperature ranged from -4 ^{O}C to + 41 ^{O}C, rainfall 12-32 mm per month and moderately low to high humidity. New crawler emerged from the end of January through to September / October

The distribution of *S. oleae* immature stages, first settled, second and third stage nymphs, were similar on both shoots and leaves (Fig. 22). It was observed that adults of this scale preferred to settle on shoots rather than leaves. Migration from leaves to stems was observed for the black scale at the third stage nymphs. Development of black scale during winter was slow (Fig. 21).

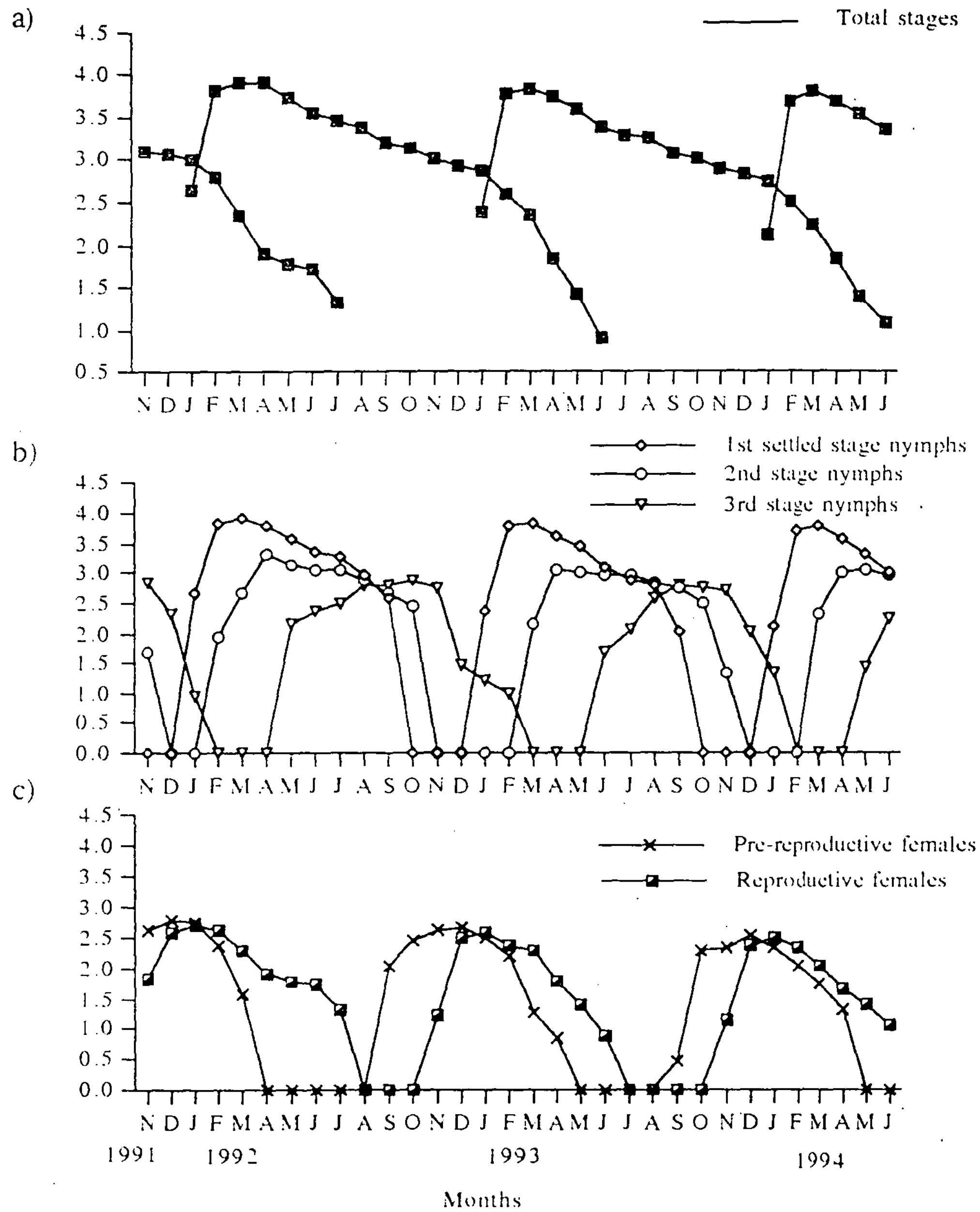


Fig. 21. Population curves for *Saissetia oleae* counted on 88 sample shoots; a) total stages, b) 1st settled, 2nd and 3rd stage nymphs and c) pre-reproductive and reproductive females on boronia at Kingston 1991 - 1994.

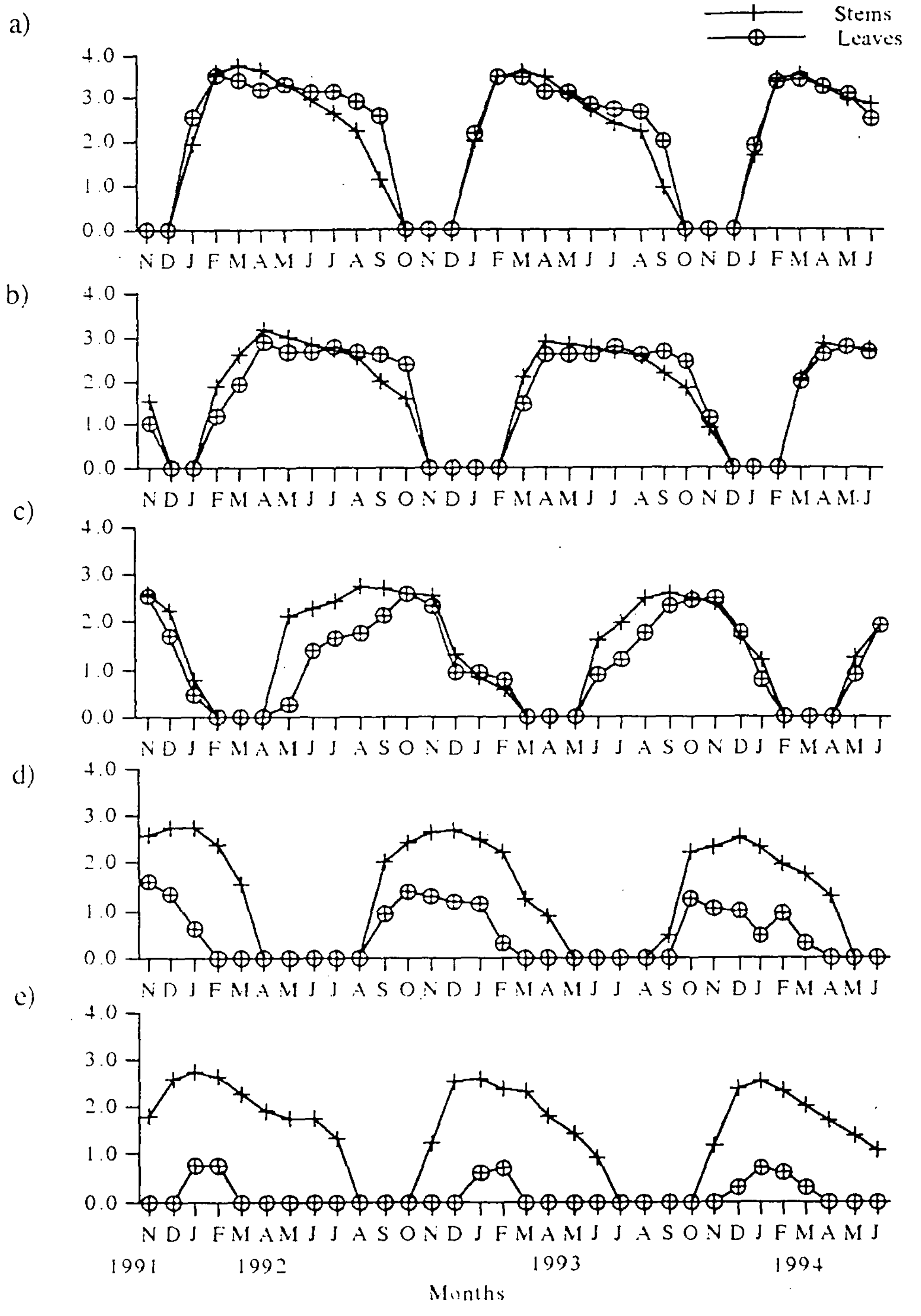


Fig. 22. Distributions of each stage of *S. oleae* on both stems and leaves of boronia plants counted on 88 sample shoots at Kingston, 1991 - 1994; a) first settled, b) second, c) third stage nymphs, d) pre-reproductive and e) reproductive females.

Table 4. The life table of *S. oleae* for two generations at Kingston 1992-1993.

Years	Stages	Average no. of black scale per sample shoot /generation	Log. of average no. of black scale per sample shoot /generation	k value	kp
1992 - 1993	Eggs	24214.91	4.384	$k_e = 0.013$	
	1^{st} stage nymphs			$k_1^* = 2.426$	
	crawlers+	23488.46	4.371	$k_c = 1.830$	
	settled	347.30	2.541	$k_{1st} = 0.596$	
	2^{nd} stage nymphs	88.11	1.945	$k_2 = 0.364$	
	parasitism				$kp_2 = 0.001$
	3^{rd} stage nymphs	38.10	1.581	$k_3 = 0.268$	
	parasitism				$kp_3 = 0.004$
	Pre-reproductive females	20.41	1.310	$k_4 = 0.156$	
	parasitism				$kp_4 = 0.001$
	Reproductive females	14.26	1.154		
				$K = 3.227$	$kp = 0.006$
1993 - 1994	Eggs	17226.08	4.236	$k_e = 0.013$	
	1st stage nymphs			$k_1^* = 2.398$	
	crawlers+	16709.31	4.223	$k_c = 1.817$	
	settled	254.671	2.406	$k_{1st} = 0.581$	
	2nd stage nymphs	66.86	1.825	$k_2 = 0.388$	
	parasitism	66.77	1.824		$kp1 = 0.001$
	3rd stage nymphs	27.35	1.437	$k_3 = 0.324$	
	parasitism				$kp2 = 0.002$
	Pre-reproductive females	12.97	1.113	$k_4 = 0.063$	
	parasitism				$kp3 = 0.002$
	Reproductive females	11.21	1.050		
				$K = 3.186$	$kp = 0.005$

k_1^* = total of k_c and k_{1st}

+ = assessed from egg counts and percent hatch

The life table for *S. oleae* was made according to the average number of *S. oleae* per sampled shoot per generation and is presented in Table 4. Total mortality expressed by the K value for the 1992-1993 generation was 3.227 and 3.186 for the 1993-1994 generation. The highest mortality occurred during the first nymphal stages (k_1) in both generations and consisted of mortality of first stage crawler (k_c) and of first settled stage nymphs (k_{1st}). Mortality of crawler stages was significantly higher than that of first stage settled nymphs. The second highest mortality occurred in second stage nymphs with the k_2 values of 0.364 and 0.388 and this was followed by mortality of third stage nymphs with k_3 values of 0.268 and 0.324 per generation respectively. Mortality of adult stages was considerably lower with k_4 values of 0.155 and 0.061.

Mortality of *S. oleae* due to parasitoids was at an average less than five per cent with kp vakues of 0.006 and 0.005. This finding indicates that the impact of parasitoids contributed on this study was insignificant which contrasts to their reported effectiveness in controlling scale populations. The lack of effectiveness may reflect the more variable and extreme climate experienced in Tasmania.

Populations of *S. oleae* were monitored at Cygnet in 1992 - 1994 to determine the effect of commercial applications of insecticide against scale insects. The insecticides employed against black scale were petroleum oil or a mixture of petroleum oil and maldison. It can be seen in Figures 23 a and b that applications in February reduced the population of *S. oleae* significantly. Reduction of *S. oleae* population in 1993 differed to that in 1994. This was caused by only a partial application of insecticide. Petroleum oil (1.25 %) mixed with maldison (0.02%) was applied against black scale at about 800 L/ha in March and April, 1993 to the top half of boronia plants. According to field observations this application only resulted in reduction of scale population on the top half of boronia plants. However when 1.2 percent petroleum oil (D-C-Tron NR) alone was sprayed onto bushes at approximately 2650 L/ha after ensuring that the spray nozzle was directed to give good coverage to inside of the bush and excellent control was achieved.

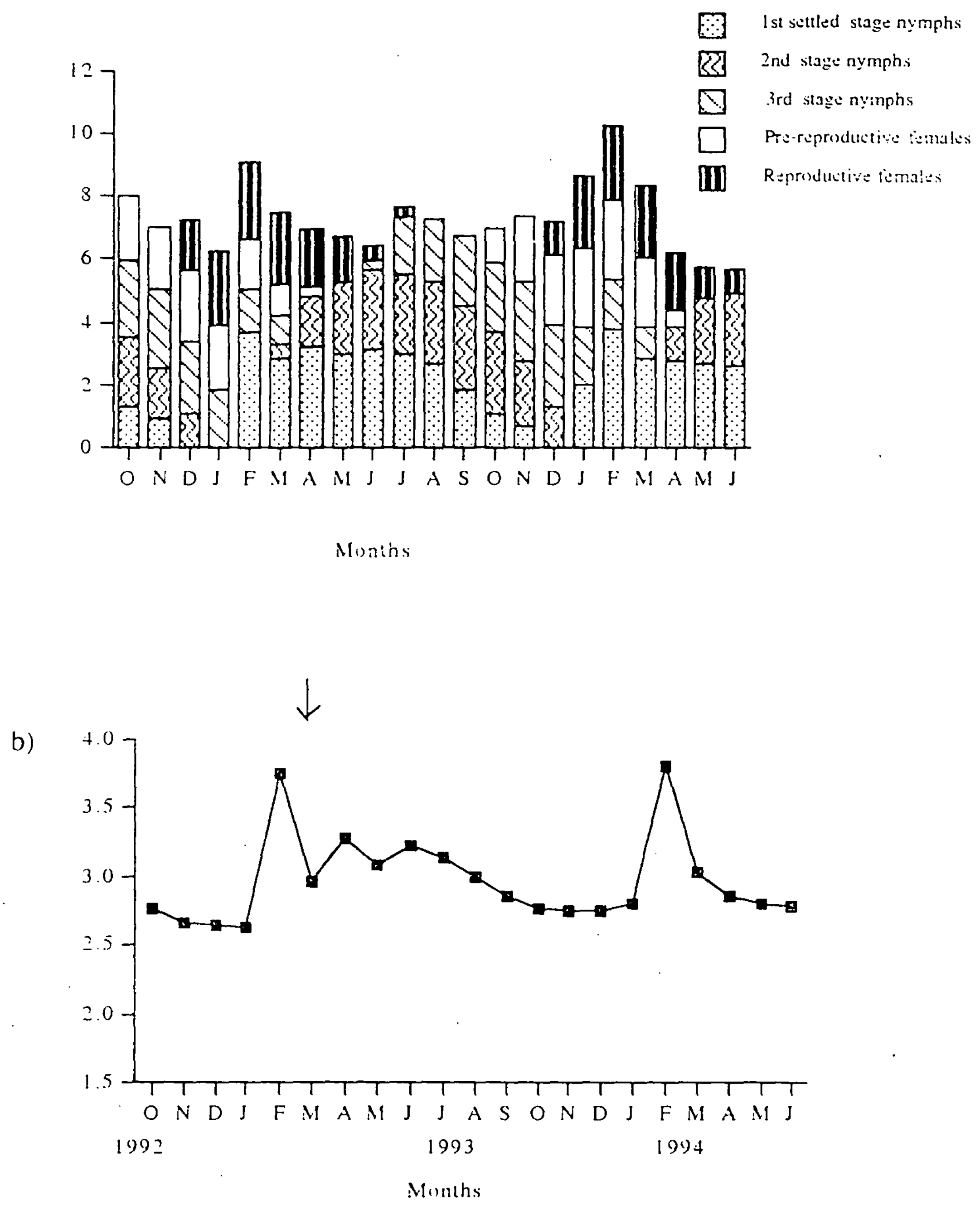


Fig. 23. a) proportion of each stage of *S. oleae* and b) population curve of all stages of *S. oleae* counted on 88 sample shoots at Cygnet, 1992 - 1994 (= insecticide applications).

3. 4. 2. Populations of *Coccus hesperidum* L.

Numbers of *C. hesperidum* on boronia plants were recorded in this study and are presented in Figures 24, 25 a and b. Results show that all stages were present in the field during the study. First stage nymphs were more abundant in summer and autumn and second stage nymphs in autumn through spring. Pre-reproductive females were more abundant in spring through early summer and reproductive females in spring through summer. Third stage nymphs were not found in the field study. The distribution of *C. hesperidum* on both stems and leaves were assessed and are presented in Figure 25b. It can be seen from Figure 25b that all stages of *C. hesperidum* settled on both stems and leaves; however, stems carried more scale than leaves in the spring to summer season.

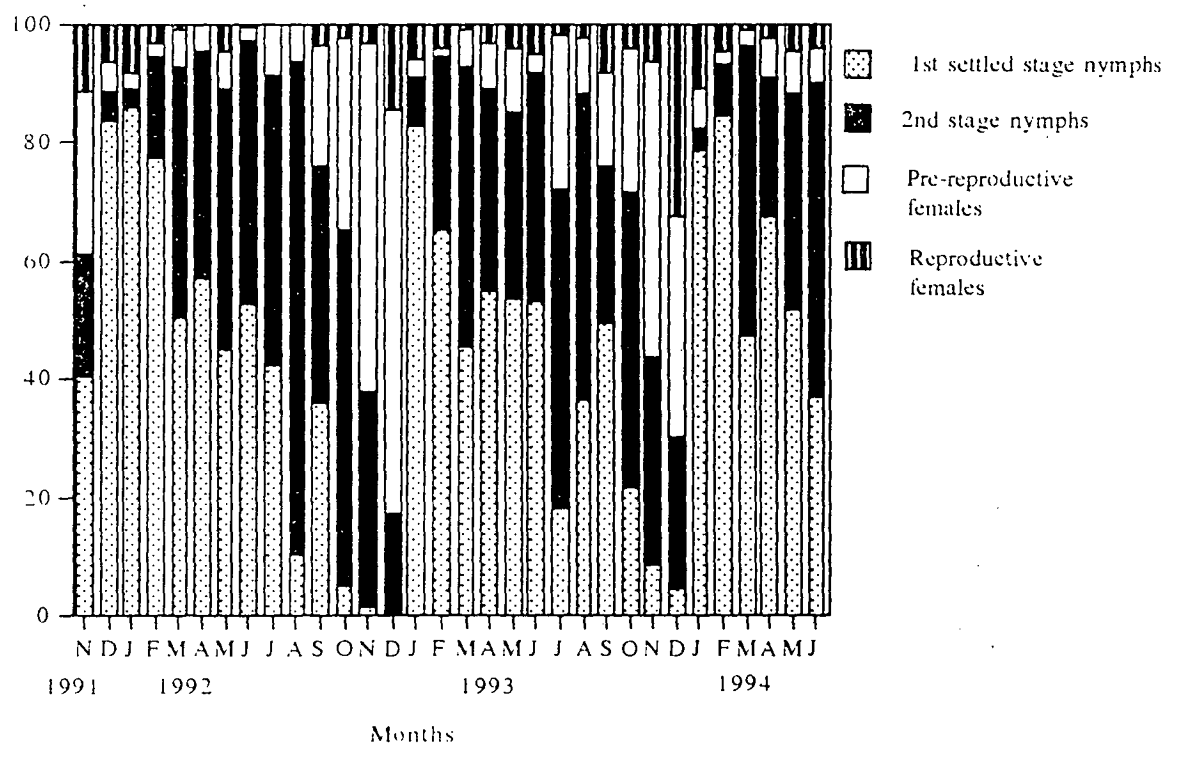


Fig. 24. The proportion of stages of soft brown scale, *C. hesperidum*, recorded in this study at Kingston, 1991 - 1994.

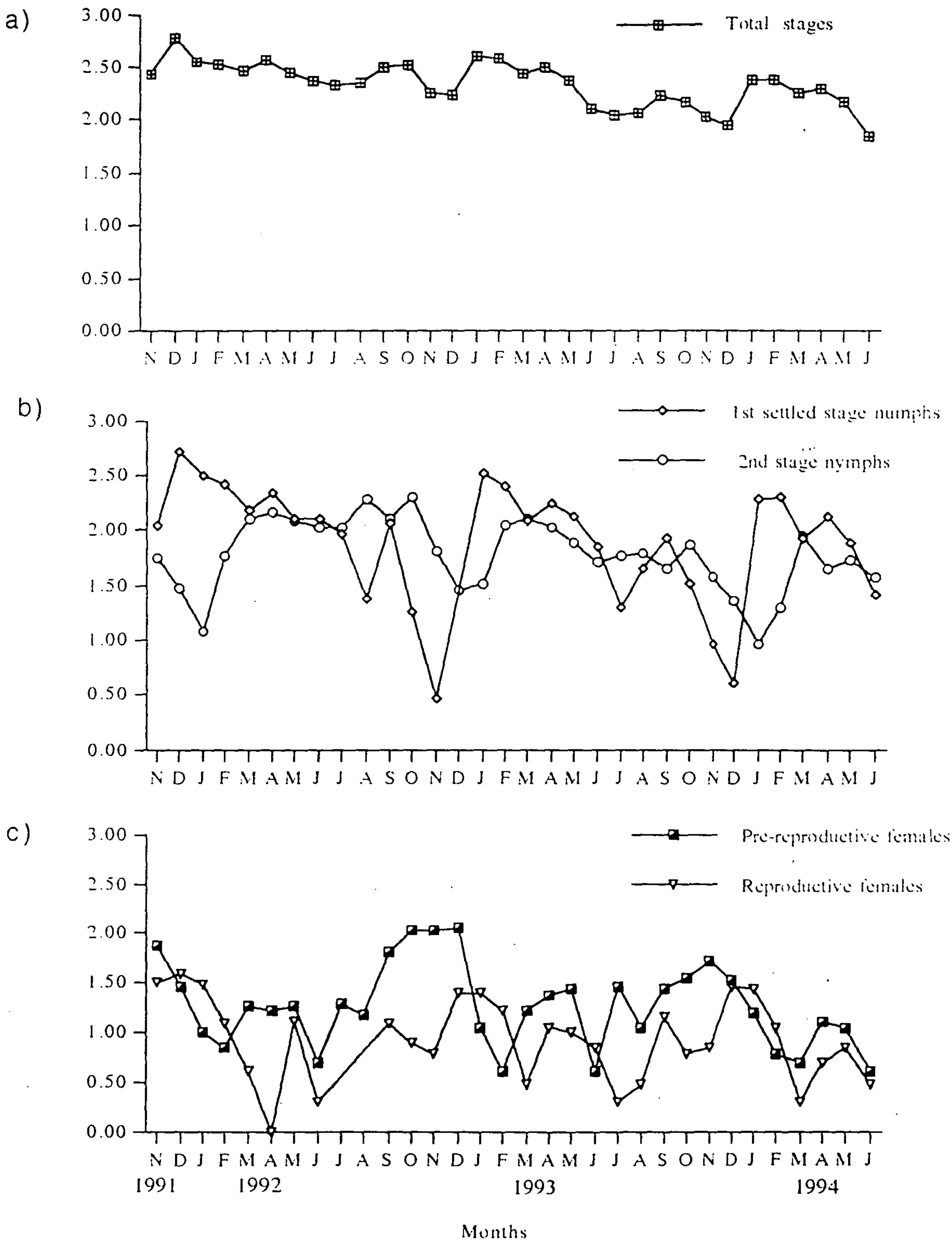


Fig. 25 a. Population curves for *Coccus hesperidum* counted on 88 sample shoots; a) total stages, b) 1st settled and 2nd stage nymphs and c) pre-reproductive and reproductive females on boronia at Kingston 1991 - 1994.

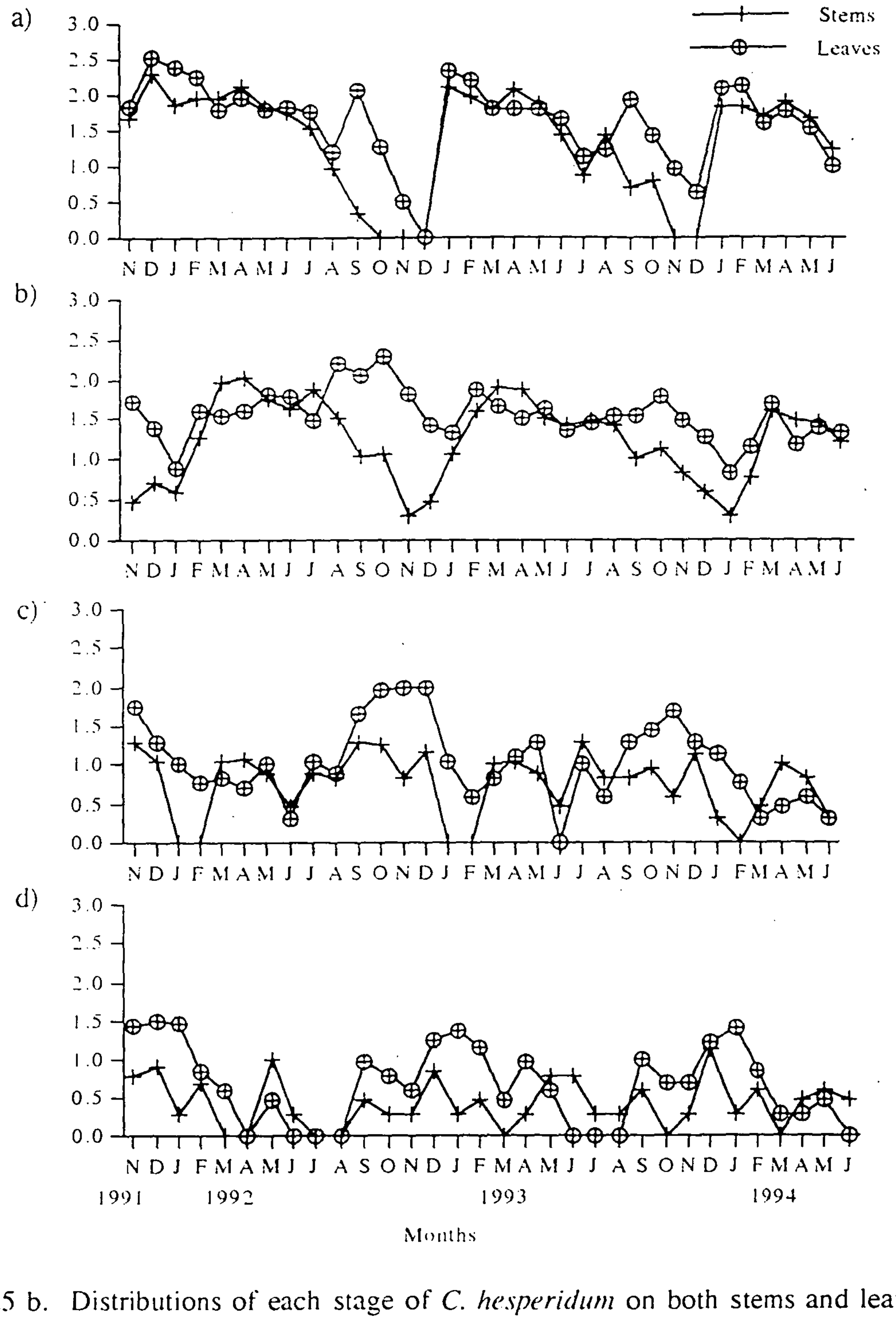


Fig. 25 b. Distributions of each stage of *C. hesperidum* on both stems and leaves of boronia plants counted on 88 sample shoots at Kingston, 1991 - 1994; a) first settled, b) second, c) third stage nymphs, d) pre-reproductive and e) reproductive females.

3. 4. 3. Natural enemies

Five species of parasitoids recovered from rearing parasitised black and soft brown scale were identified as belonging to the families Aphenilidae (two species), Encyrtidae (two species) and Pteromalidae (one *Moranila* sp.). Parasitism occurred in the second and third stage nymphs and the pre-reproductive females. Parasitism of *S. oleae* populations is summarised in Figure 26 and 27 and Figure 28 shows parasitism of *C. hesperidum*. In addition to the parasitoids, four coccinellid (*Harmonia conformis* Boisduval, *Rhizobius* sp., *Cleobora mellyi* Mulsant, and *Stethorus* spp., a predatory mite (*Anystis* sp.) and green and brown lacewing (*Chrysopa* sp. and *Micromus* sp.) have been observed preying on scale populations. Mortalities of both scale species which were caused by predators were difficult to measure. However, the seasonal abundance of predators that occurred in the field, as recovered by sweeping boronia plants, was related to the abundance of both scale species per sample shoot. Comparison of the time of occurrence of predators with *S. oleae* at Kingston are presented in Figure 29 and that with *C. hesperidum* in Figure 30. Comparison of the time of occurrence of predators with *S. oleae* at Cygnet is presented in Figure 31

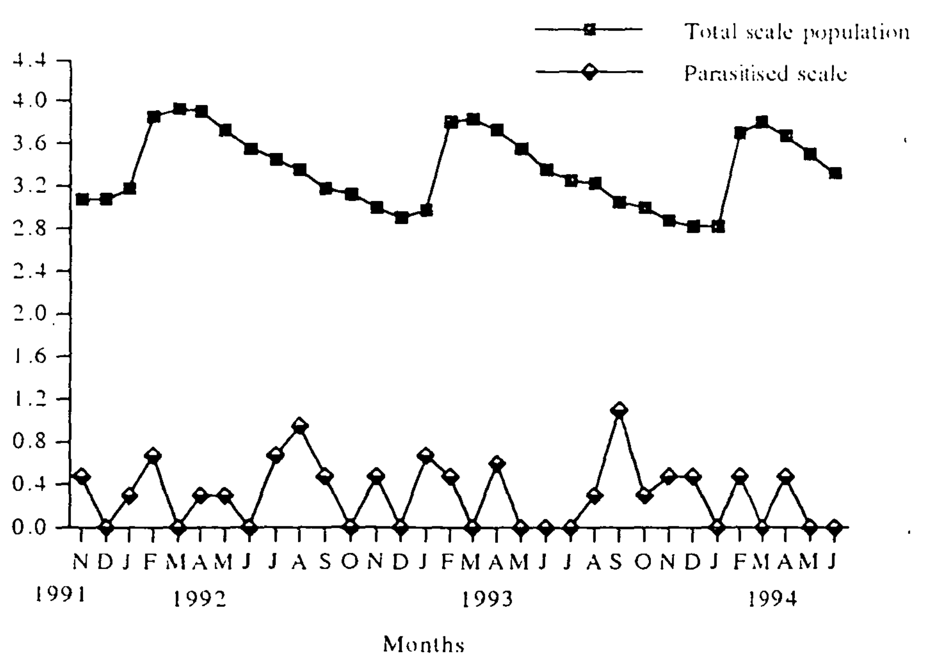


Fig. 26. Total population of all stages of *S. oleae* on boronia bushes and numbers parasitised counted on 88 samples shoots at Kingston (1991 - 1994).

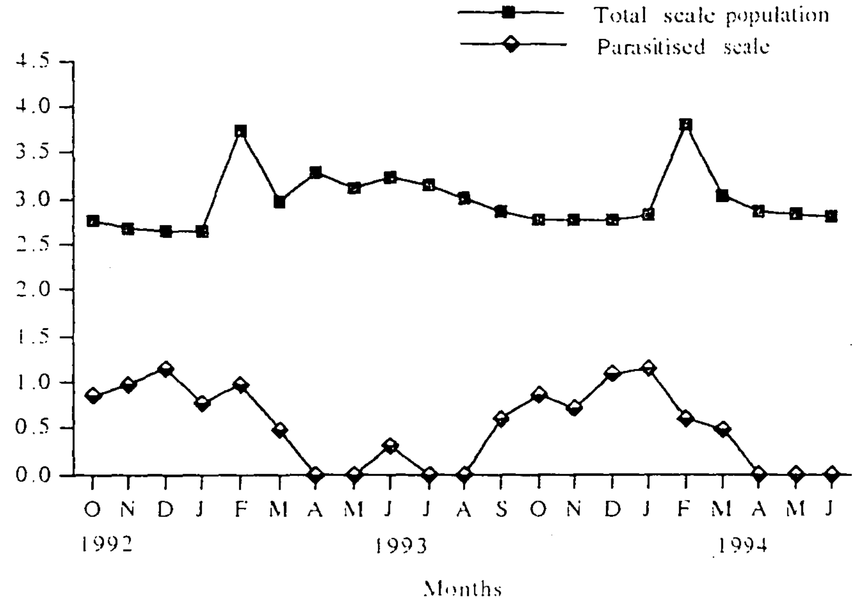


Fig. 27. Total population of black scale, *S. oleae*, on boronia bushes and numbers of parasitised counted on 88 sample shoots at Cygnet, 1992 - 1994.

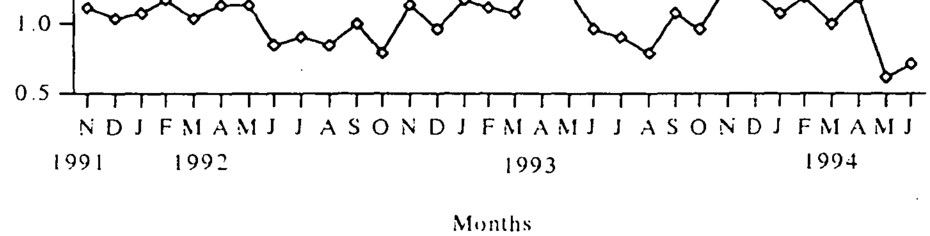


Fig. 28. Total population of soft brown scale, *C. hesperidum* on boronia bushes and numbers of parasitised counted on 88 sample shoots at Kingston, 1992 - 1994.

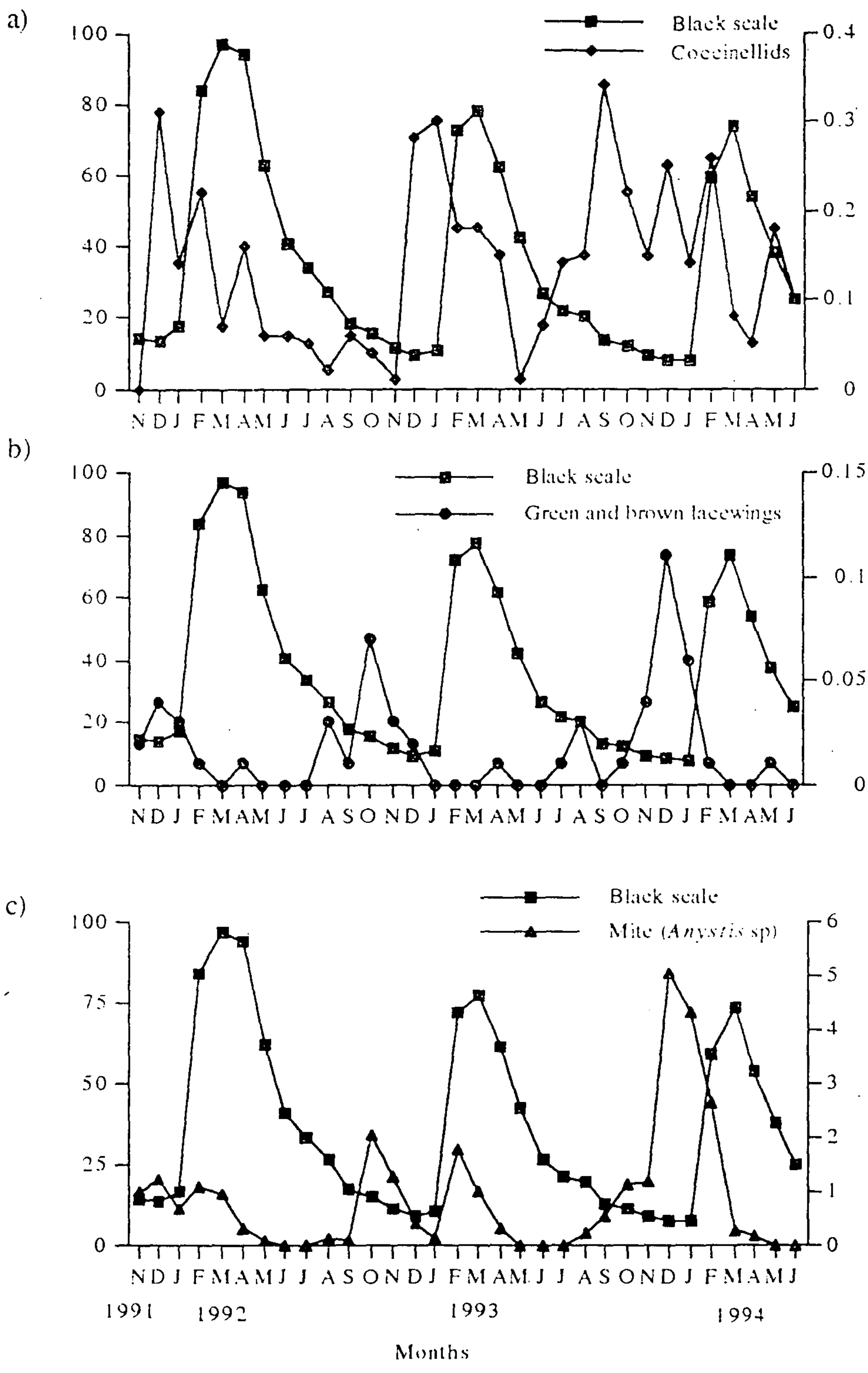


Fig. 29. Comparison of the relative occurrence of coccinellids (a), Green and brown lacewings (*Chrysopa* sp. and *Micromus* sp.) (b) and mite *Anystis* sp. (c) with black scale, *S. oleae*, on boronia plants at Kingston, 1991 - 1994.

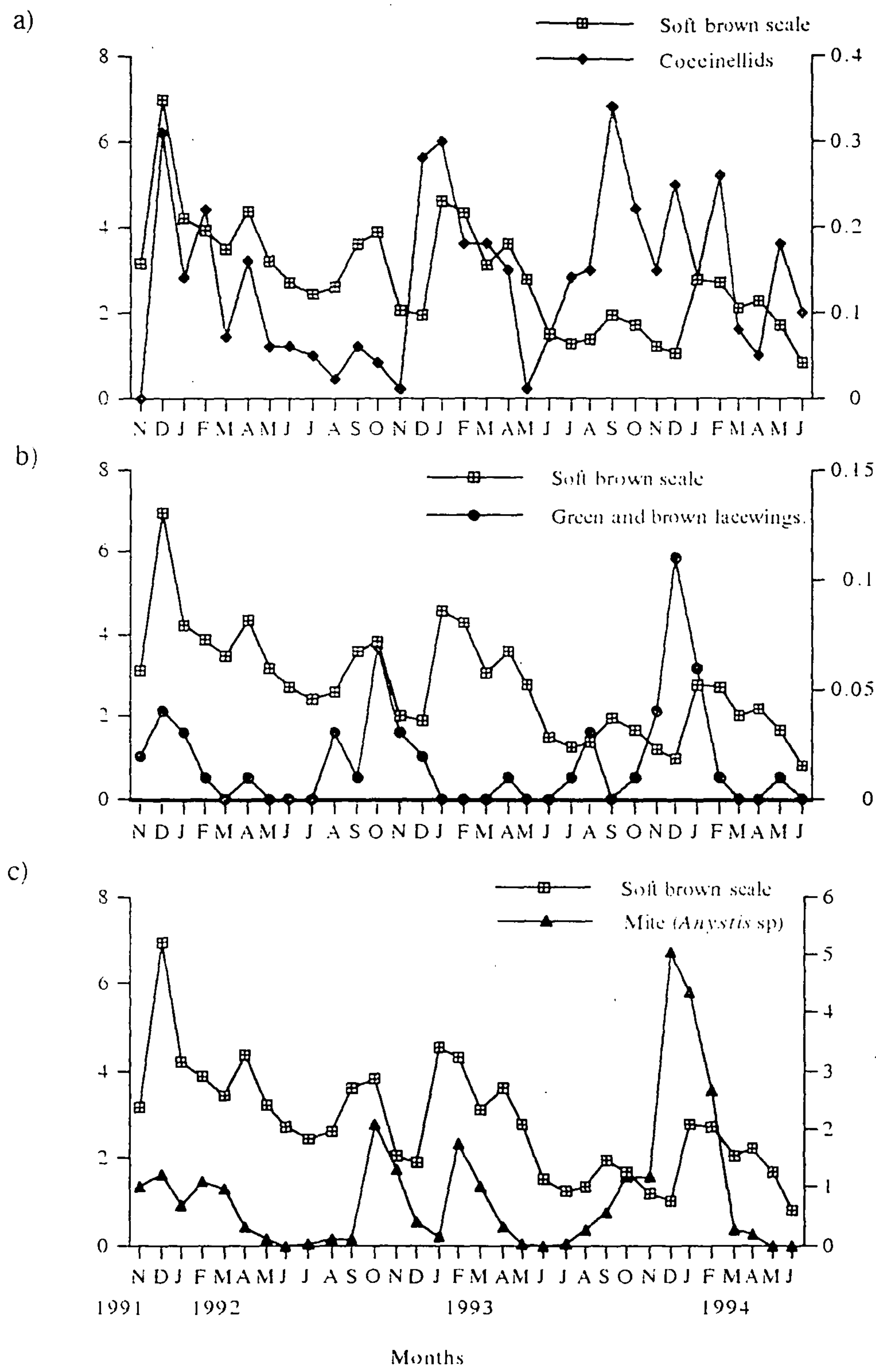


Fig. 30. Comparison of the occurrence of coccinellids (a), green and brown lacewings (*Chrysopa* sp. and *Micromus* sp.). (b) and mite *Anystis* sp. (c) with soft brown scale, *C. hesperidum*, on boronia plants at Kingston, 1991 - 1994

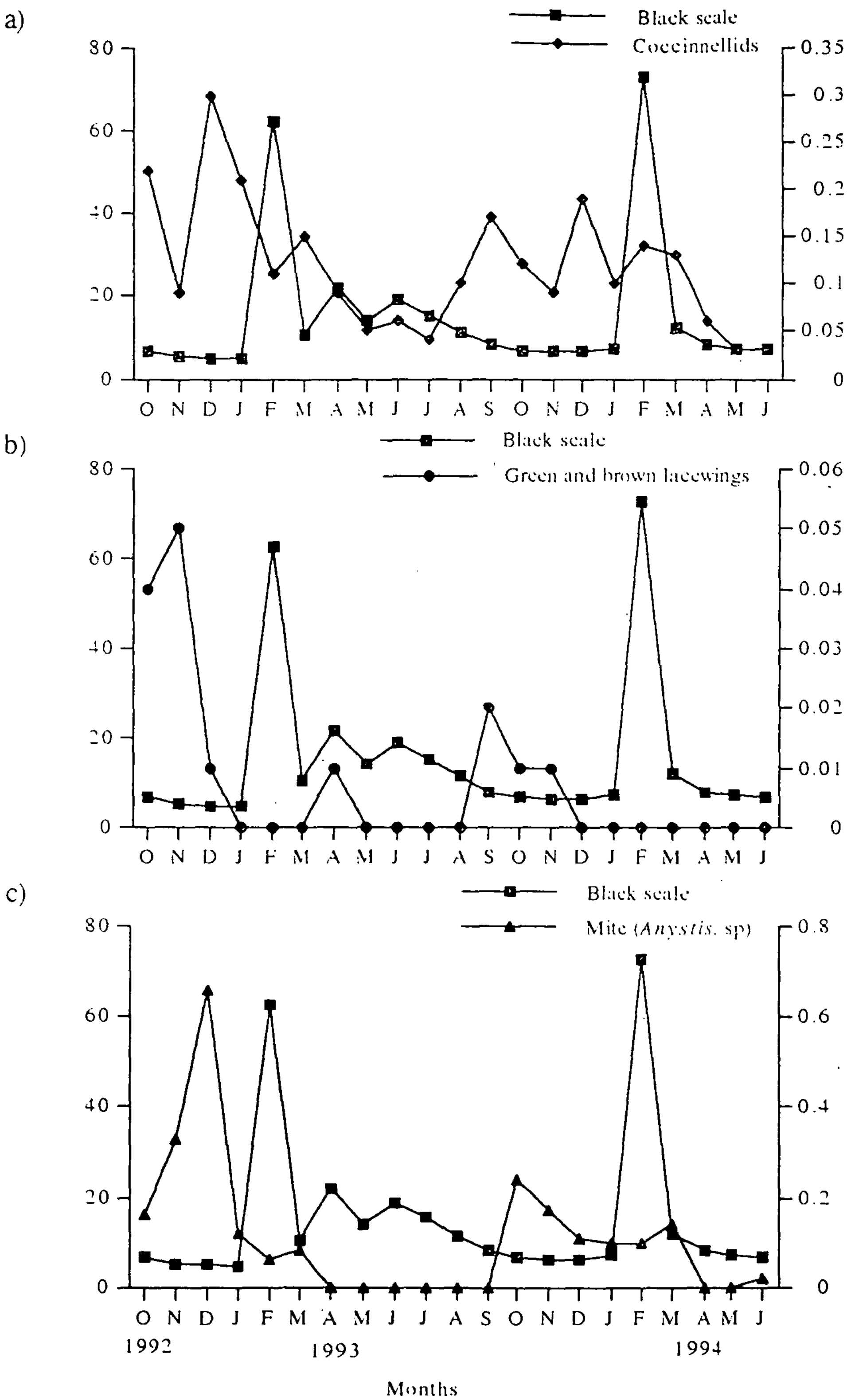


Fig. 31. Comparison of the relative occurrences of coccinellids (a), green and brown lacewings (*Chrysopa* sp. and *Micromus* sp.) (b), mite *Anystis.* sp (c) with black scale, *S. oleae*, on boronia at Cygnet, 1992-1994.

3. 4. 3. Effect of pruning and harvesting on scale insect population

The effect of prunning on the populations of *S. oleae* and *C. hesperidum* is presented in Tables 5 and 6. These results show average numbers of *S. oleae* per sample shoot was reduced by pruning by ca. 15% and 34% at Cygnet and Kingston in 1993 respectively.. Pruning also affected numbers of *C. hesperidum* by ca. 20% at Huonville and 55% at Kingston respectively.

Table 5. The effect of pruning on the population of black scale, *S. oleae* at Cygnet and Kingston, 1993.

Locations	Number of black scale/sample shoot		Total
	removed from boronia plants	remaining on boronia plants	
Kingston	98 (34.5%)	186 (65.49%)	284
Cygnet	121 (15.4%)	662 (84.6%)	783

Table 6. The effect of pruning on the numbers of soft brown scale, *C. hesperidum*, at Cygnet and Kingston, 1993.

Locations	Number of soft brown scale/sample shoot		Total
	removed from boronia plants	remaining on boronia plants	
Kingston	86 (55.5%)	69 (44.5%)	155
Cygnet	1 (20%)	4 (80%)	5

On the other hand the effect of mechanical harvesting was only evaluated on black scale as soft brown scale occurred at very low levels throughout this study. Reduction of black scale numbers due to mechanical harvesting is presented in Table 7. This results indicated that mechanical harvesting reduced numbers of black scale on all sample shoot s by 13 percent.

Table 7 . Effect of mechanical harvesting on black scale numbers at Cygnet in 1994.

	before harvesting	after harvesting	removed by harvesting
Numbers of black scale/sample shoots	2640	2303	337 (12.77%)

3. 4. 4. Black scale settling on weeds

Only immature stages of black scale were observed to move across the ground from wee to weed. However reinvasion of the boronia bush appeared essential for maturation to adult stage as no adults were observed on the weed species. The numbers of immature stages of black scale which settled on four major weeds at different distance from the host plants were assessed and this is summarised in Table 7. The most commonly occurring weed species were are sorrel, hawkbit, white clover at Cygnet and trigger plant at Kingston.

Table 7. The average number of immature stages of black scale on weed species at Kingston in March 1994

Distance of weeds from boronia plant (Cm)	*Rumex acetosella*. Fourr (sorrel)	*Leontondon tarazacoides*. (Vill) Merat. (hawkbit)	*Trifolium repens*. L. (white clover)	*Stulidium graminifolium*. Swartz. (trigger plant)
10	29.75	53.00	27.58	10.71
20	24.46	34.63	20.88	7.42
30	12.92	27.96	15.67	5.45
40	8.92	13.04	9.83	5.20
60	5.96	9.21	6.96	1.17

The relationship between the numbers of black scale per leaf of weed and distance of weeds from boronia plants is shown in Figures 32 a, b, c and d. Results show that numbers of immature black scale that settled on the nearest and most commonly occurring weed species were very high and the relationship with distance was curvilinear with negative slope. The value of r^2 is very high ca. 0.9 for all relationships.

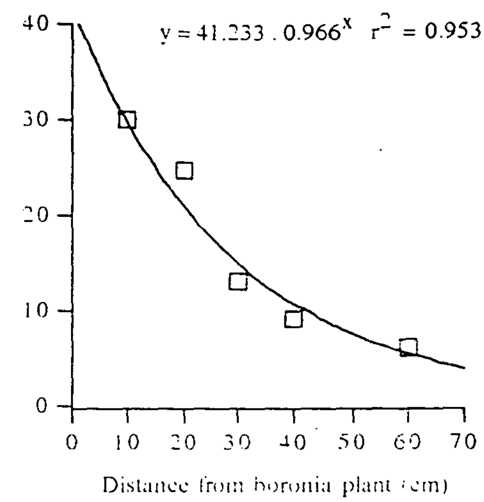


Fig. 32 a). Relationship between the numbers of black scale on sorrel, *R. acetosella*, at different distances from boronia plants in Cygnet, March, 1994.

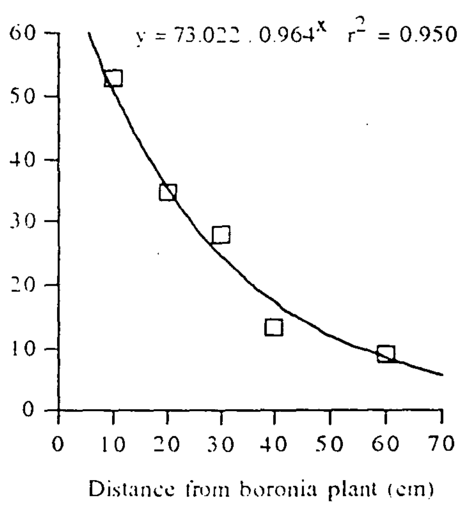


Fig. 32 b). Relationship between the number of black scale on hawkbit, *L. taraxacoides*, at different distances from boronia plants in Cygnet, March, 1994.

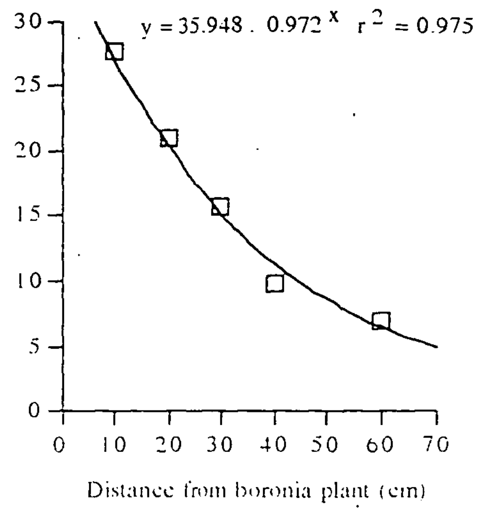


Fig. 32 c). Relationship between the numbers of black scale on white clover, *T. repens*, at different distances from boronia plants in Cygnet, March, 1994.

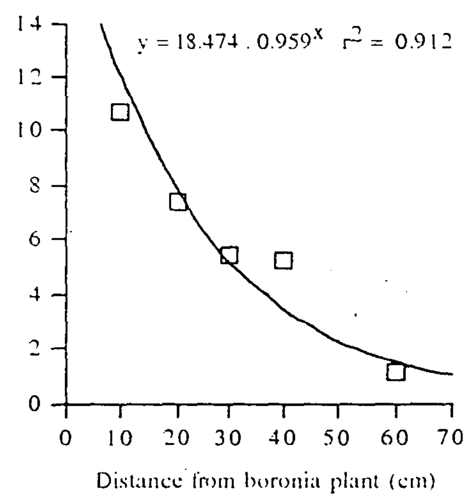


Fig. 32 d). Relationship between the number of black scale on trigger plant, *S. graminifolium*, at different distances from boronia plants in Kingston, March, 1994.

3. 4. Discussion

S. oleae has one generation per year on boronia plants in Tasmania. Based on field observations new generations on sprayed plants (at Cygnet) occurred later compared to unsprayed plants (at Kingston). Distribution of immature stages of black scale, *S. oleae*, was on both stems and leaves; however, adult stages prefer to settle on stems rather than leaves. The findings indicate that migration from leaves to stems took place at both study areas in the late autumn and winter. This observation agrees with Ebeling (1959) who claimed that scale migration on citrus trees is apparently to secure a permanent food supply. In winter the development of black scale on citrus trees was reported as very low (Bartlett, 1978) and migration and slow growth of black scale at Cygnet and Kingston may explain the low occurrence of the third stage nymphs in winter relative to second stage nymphs. Daane and Catagirone (1990) noted that distribution of black scale was affected by the type of canopy with scale generally preferring to settle in the lower and inner parts of the canopy.

According to the data obtained from the study it was possible to recognise the k factors responsible for change in the populations of *S. oleae*, although Morris (1959) stressed that to determine the operation of k factors required life-tables for several successive generations. The data (Table 4) indicates that mortalities within immature stages contributed most to total mortality. Maximum mortality occurred in first stage nymphs and this mortality could be separated into high mortality of crawlers followed by deaths of newly settled nymphs. Mortalities of adult stages, which are expressed by k4, were very low compared to total mortality.

Several mortality factors appear to operate during the period of nymphal development. Climatic factors, such as high (>30 ^{o}C) temperatures, which do occur in summer in Tasmania, can be effective in causing nymphal mortalities. Kapatos and Statopoulou (1990) in Greece found that the mortality of immature stages was mainly caused by high temperatures in summer. Ebeling (1959) and Simmonds (1951a) stated that a combination of high temperatures and low humidity was an important factor in causing mortalities during nymphal stages in California and Australia. During summer high temperatures and low humidity were responsible for increased mortality of scale life stages. Maximum mortalities occurred as temperatures exceeding 40° C were experienced.

In these studies natural enemies contributed insignificantly to the mortality of black scale. Parasitoids resulted in low percentage of parasitism of on average less than 5 per cent. The level of parasitism was low comparing to the black scale population. The result indicated that parasitoids alone could not keep scale population at low levels. There could be several reasons for interference with the effectiveness of parasitoids: a) lack of host-specificity, b) a relatively open environment i.e. habitat, c) ant interventions and d) parasitoids which preferred to act on the upper more illuminated and warmer parts of boronia. In general black scale tend to settle on the shaded regions of boronia bushes. Adult black scale tend to settle on the shoots of boronia bush, mainly on shoots, and immature scale occur either on shoots and leaves while the soft brown scale mainly occured on the upper younger and more leafy regions. Scale mortality due to predators was difficult to assess; however, their role can be appreciated through understanding their occurrence in the field. Peak occurrences of all predators, coccinellids, brown and green lacewing (*Micromus* sp. and *Chrysopa* sp.) and mite (*Anystis* sp.) were not compatible with black scale population numbers. Most predators collected when most black scale had entered the adult stage. It was concluded that the population of *S. oleae* was not much affected by predators which agrees with Richard (1981) who considered that biological control of *S. oleae* by predators was inadequate because of lack of synchronisation between predator and prey, immature stage, caused by their having different phenologies and temperature thresholds for feeding and reproduction.

Monitoring populations of black scale at Cygnet aimed to assess the effect of insecticides on *S. oleae* populations. Incomplete coverage in spraying and poor timing resulted in less effective control. Therefore control efforts must ensure thorough coverage and penetration of insecticides through the entire plant at the time of highest numbers of vulnerable stages for optimal results.

C. hesperidum is considered to have three generations per year and its populations occurred at low levels although all stages were found throughout most of the year. No third stage nymphs were found during the study. A similar result was reported in South Africa by Annecke (1966) who noted that the female moults only twice before reaching maturity. The result strongly suggest that *C. hesperidum* in Tasmania has only two nymphal stages. Distributions of soft brown scale were confined to the upper parts of plants on both stems and leaves. However, during spring and summer scale populations were greater on leaves than on stems.

Wilson (1960) reported that natural enemies were an important factor in keeping soft brown scale at low levels. Parasitoids contributed up to 19 per cent to the mortality of soft brown scale during this study. This value was high compared to parasitism of black scale (< 4 per cent) indicating that parasitoids were more effective on soft brown scale populations. Several factors could explain their effectiveness: a) the distribution of soft brown scale on the upper parts of the host plant and the greater number on boronia leaves in spring through summer in that region, b) parasitoids which may prefer to act in exposed and warmer upper parts of boronia and c) the colour of soft brown scale, i.e. yellowish, which may be better detected by parasitoids. Parasitism was mainly found in the second and pre-reproductive stages. In contrast the preference of black scale for lower, cooler, shaded and callous tissue at the base of more woody bushes may effectively isolate this species from active, density related parasitism. Predators may also contribute more to mortality of this scale because all stages of soft brown scale, which are softer than black scale, occurred throughout the year so that suitable prey for predators were relatively abundant.

Climatic factors, such as high temperatures in summer and low temperatures in winter (Appendix 6) were also important factors contributing to in the mortality of immature soft brown scale.

Pruning reduced the population of black scale by 34.5 per cent at Kingston and 15 per cent at Cygnet and reduction of soft brown scale population was about 55 per cent at Kingston and 1 per cent at Cygnet. Because of the ability of both scale species to disperse during their life-cycle, pruned shoots should be removed and disposed of avoiding the return of these scale insects to boronia plants. Differences in the results of pruning in reducing both scale species populations at Kingston and Cygnet were because of different cultural practices employed on the two boronia farms. Pesticide applications were regularly employed at Cygnet; therefore the populations of both scale species on the top parts of plants remained at low levels particularly for soft brown scale. On the other hand no pesticide applications were applied to boronia plants at Kingston and this led to the development of high densities of both scale species on the upper portions of boronia plants.

As mentioned above, mortality in the crawler stage was the most significant of the stage mortalities. Loss of crawlers from boronia could be affected by wind, rain and/or high temperatures plus failure to locate suitable and sustainable feeding sites. Immature black scale that settle on common weeds occurring at the study areas were found in high numbers. Numbers of immature black scale settling on weeds declined with greater distance of weeds from boronia plants. In contrast black scale did not develop through the adult stage on weed species. This result indicates that thorough weeding or mowing within and between rows of boronia is essential to minimise the numbers of alternative refugia for the carry over and survival of scale.

Chapter 4

The evaluation of insecticides for control of *Saissetia oleae* Oliver and *Coccus hesperidum* L. on *Boronia megastigma* Nees

4. 1. Introduction

Demand for insecticides to protect crop losses caused by insect pests is unavoidable in modern agriculture. However, excessive use of them and inappropriate applications can lead to new problems such as secondary pest outbreaks and pest resistance.

Commercial plantations of boronia have been developed to fulfil the increased demand for boronia oil. However, insect problems, i.e. scale insects, affect vegetative growth and flower production and despite control measures scale insects have remained a problem to growers.

This chapter describes the assessment of a range of insecticides for possible incorporation in an integrated pest program for boronia pests.

4. 2. Study areas

The studies were conducted at the same boronia farms as in previous experiments, i.e. Kingston and Cygnet, 1992 - 1994. Boronia plants used in the study were similar in height and planted with 0.5 m spacing within rows and 1.5 m between rows. Treated plants were separated from each other by 1 - 4 untreated plants in order to minimise insecticide drift.

Nuvacron (0.02 %) was applied to bushes at Cygnet in April, 1994 for control of psyllid infestations.

4. 3. Materials and methods

4. 3. 1. Application of individual and mixture of insecticides

Five insecticides and four mixtures of two insecticides were applied separately against both scale species on October 30, 1991. The five insecticides evaluated were summer oil (2.5% petroleum oil), winter oil (3.0% petroleum oil), metasystox (0.1%), pyrethrum (2.5%), and rogor (3.0% dimethoate). The three mixed insecticides tested were a mixture of summer oil (1.25% petroleum oil) plus pyrethrum (1.25 %), summer oil (1.25% petroleum oil) plus metasystox (0.05%) and pyrethrum (1.25%) plus metasystox (0.05%). Each treatment was applied with a 15 L capacity Tris Knapsack sprayer supplying ca. 0.12 L/plant.

A latin square design was used in this initial experiment to evaluate the effect of the insecticides, both individually and when mixed for control of both scale species. Two plants between each treated plant were left unsprayed as a buffer to minimise any insecticidal effect of one treatment on another. The number of scale insects were counted on three randomly selected terminal shoots for each replication. The sample shoots were 15 cm long measured from last season's growing point. Each sample was placed in a separate plastic bag to be brought to the laboratory where it was counted under a stereo microscope. Pre-treatment counts were taken one day before spraying and subsequent counts made 7, 14, 28 and 56 days post insecticide application.

The next two experiments were conducted separately as trials 1 and 2 in the same area as the previous experiment and were concerned with summer oil (2.0% petroelum oil), the mixture of summer oil (1.25 % petroleum oil) plus pyrethrum(1.25 %) and pyrethrum (2.5%). The concentration of summer oil was reduced to 2.0 % petroleum oil as was used by some boronia growers and applied to immature stages of scale. These insecticides were applied with 28 days' interval between applications. To evaluate the effect of these insecticides on scale species a completely randomised block design was used with five replications. Sample shoots were taken as described previously. Pre-treatment counts were made at one day before spraying and post-treatment counts taken at 7, 14, 28, and 56 days.

4. 3. 2. Effectiveness of complete and incomplete coverage of boronia plants with summer oil on scale infestations.

This experiment was commenced one week after pruning at Kingston, on November 17, 1992 and ran to February, 1993. Summer oil was used in this study at 2.0% concentration and applied to three different sites of boronia plant: sides, top, and a combination of sides and top using the same volume of oil emulsion ca. 0.12 L/plant. Boronia plants used as controls were left unsprayed. Each treatment within a block was separated from another by four plants to minimise insecticide drift. Treatments were arranged in a completely randomised block design with three replications to assess treatment effects.

Counts of black scale, *S. oleae* and soft brown scale, *C. hesperidum* were made on 5 randomly selected terminal shoots (15 cm long) for each treated and control plant. Parasitised scale insects of both species were counted during this study. Predator abundance was also assessed on 6 sweeps for each treated and control plant. Pre-treatment counts were made one day before spraying and post-treatment counts taken at 7, 14, 28 and 56 days. Because of difficulties of identifying species and species stages and the time involved to undertake such detailed work during initial 18 months of the study comparasions of total number of live stages of each species were employed in comparing population trends of different generations.

4. 3. 3. Effectiveness of summer oil applications at different times after pruning

This study was conducted at Kingston from November 1992 to February, 1993. The insecticide used was summer oil (2.0%). Oil sprays were applied to boronia plants at one, two, four and eight weeks after pruning. Control plants were left unsprayed. This study was arranged in a completely randomised block design with five replications. Each treatment within a block was separated from others by two plants to minimise insecticide drift effects.

Counts of both scale species were made on 8 randomly selected terminal shoots (15 cm long) for each treated and control plant. In addition, parasitised black scale, *S. oleae* and soft brown scale, *C. hesperidum* were counted during the study. In addition, predators were assessed on 10 sweeps of each treated and control plant. Pre-treatment counts were made one day before treatment and post-treatment counts taken at 7, 14, 28 and 56 days.

4. 3. 4. Effectiveness of the insect growth regulator (buprofezin) and the oil MP.9 for control of *Saissetia oleae* Oliver and *Coccus hesperidum* L.

The effectiveness of the insect growth regulator, buprofezin (Applaud 40 SC), was assessed on immature and mature stages of scale insects. The experiment to evaluate the effect of this insecticide on mature stages was conducted at Kingston from December, 1992 - February, 1993 and on immature stages at Cygnet from February - September, 1993.

Buprofezin (Applaud 40 SC supplied by DowElanco, New South Wales) and the oil MP.9 (kindly provided by Dr. G. A. C. Beattie, Biological and Chemical Research Institute, New South Wales) were applied to the mature stages of black and brown scale to assess their effect. Buprofezin was applied at concentrations of 0.1 g, 0.2 g, and 0.4 g ai. L^{-1} and the oil MP.9 at a concentration of 0.1 g ai. L^{-1}. Treated boronia plants were sprayed until run-off (ca. 0.12 L/plant) using a 15 L capacity Tris Knapsack sprayer. Control plants were left unsprayed. Treatment applications were arranged in a completely randomised block design with four replications. Counts of black scale and soft brown scale were made on 5 randomly selected terminal shoots (15 cm long) from each treated and control plant. Parasitised black scale and soft brown scale were recorded during the study. Predator abundance was assessed by 6 sweeps per treated and control plant. Pre-treatment counts were made one day before spraying and subsequent post treatment counts taken at 7, 14, 28, and 56 days post insecticide application.

Two applications of buprofezin at concentrations of 0.05 g, 0.10 g and 0.20 g ai. L^{-1} with an interval of 28 days between applications and a single application of buprofezin at a concentration of 0.05 g ai. L^{-1} to the immature stages of black scale were evaluated. There were no control, unsprayed bushes in the extended duration (>200 days) experiment as the grower considered that unsprayed infested plants would put the plantation at risk to higher infestation levels. Treatment applications were arranged in a completely randomised block design with three replications. Counts of black scale were made on 5 randomly selected terminal shoots (15 cm long) from each treated and control plant. Pre-treatment counts were made one day before spraying and subsequent counts taken at 7, 14, 56, 84, 140 and 210 days.

4. 3. 5. Application of insect growth regulators (IGRs), systemic insecticides, and petroleum oil to mature stage of scale

This experiment was commenced after pruning at Cygnet from November 15, 1993 - October, 1994. Boronia plants which were similar in size and height were used in the study.

Eight insecticides were evaluated mainly against black scale in this study because the population of soft brown scale was very low. The treatments were as follows: three insect growth regulators, kinoprene (Enstar® 5E) at 0.50 % ai. L^{-1}, methoprene (Diacon® 50) at 0.15 g ai. L^{-1}, buprofezin (Applaud® 40 SC) at 0.10 g ai. L^{-1}; four systemic insecticides, kilval at 0.125 % ai. L^{-1}, Temik® (aldicarb) at 0.75 mg ai. per plant, Confidor® (imidacloprid) at 0.75 mg ai. plant, Nuvacron® (monocrotophos) at 0.02 % ai. L^{-1} and petroleum oil (D-C-Tron NR NR) at 2.00 %. There were 8 unsprayed control bushes. The experiment was arranged in a completely randomised block design with the nine treatments (8 insecticides + unsprayed control) and eight replications (9 x 8 = 72 plants).

The three insect growth regulators were applied three times with 14 days' interval between applications. Kilval and Nuvacron were applied twice with an interval of 28 days and the others, Temik, Confidor and petroleum oil, were applied one time only. Treated boronia plants were sprayed until run-off (ca. 0.12 L/plant) using a 15 L capacity Tris Knapsack sprayer. Plants next to treated plants were covered with cartons to protect them from insecticide drift while insecticides were sprayed. Because of their granular formulation Temik and Confidor were incorporated into soil around boronia plants to a depth of 1 - 2 cm. Boronia plants used as controls were left unsprayed.

The effect of these insecticides on black scale, vegetative growth (numbers of new nodes and length of shoot extension), and reproductive growth (numbers of flowers and their weights) was assessed on 36 randomly selected terminal shoots for each treatment. Pre-treatment counts of black scale were taken one day before spraying and subsequent counts made at 56, 196, and 252 days. Counts of new nodes were taken at 28, 42, 56, 84, 196, and 252 days post treatment applications and the length of shoot extension was measured at 252 days post-treatment. In addition, flower yield was assessed at 252 days post-treatment on October 5, 1994.

4. 3. 6. Application of petroleum oil, insect growth regulators (IGRs), and a mixture of IGRs plus petroleum oil on immature stages

The study was conducted at Cygnet from February 21 - October, 1994. Boronia plants were similar in size and height.

Seven insecticides were tested against the black scale. Three were the IGRs: kinoprene (Enstar® 5E) at 0.50 % L^{-1}, methoprene (Diacon® 50) at 0.15 g ai. L^{-1}, and buprofezin (Applaud® 40 SC) at 0.05 g ai. L^{-1}. Three other insecticides were a mixture of kinoprene (0.40 % ai. L^{-1}) plus petroleum oil (D-C-Tron NR NR) at 1.00 % L^{-1}, methoprene (0.15 g ai. L^{-1}) plus petroleum oil (D-C-Tron NR NR) at 1.00 % L^{-1}, and Buprofezin (0.05 g ai. L^{-1}) plus petroleum oil (D-C-Tron NR NR) at 1.00 % L^{-1}. The other treatment was petroleum oil (D-C-Tron NR NR) at 2.00 % L^{-1}. These insecticides were applied with a 15 L capacity Tris Knapsack sprayer delivering about 0.16 L/plant of liquid. Control plants were left unsprayed.

Treatments were arranged in a completely randomised block design with six replications. Each treatment block consisted of seven scale infested boronia plants the central three plants providing subsequent sample. The remaining plants were used as a buffer to minimise insecticide drift and movement of black scale among plants. The effect of these insecticides on black scale, vegetative growth (new nodes and length of shoot extension), and reproductive growth (numbers of flowers and their weight) was evaluated on 36 random terminal shoots selected from each treated and control plant.

Pre-treatment counts of black scale were taken one day before spraying and subsequent counts made at 7, 14, 28, 56, 84 and 154 days. Counts of additional new nodes were made at 14, 28, 56, 154, and 224 days post treatment application. Yield was assessed at 224 days post treatment in October, 1994.

4. 3. 7. Effectiveness of petroleum oil applications at different concentrations

The study was conducted at Cygnet from February 21 - October, 1994. Boronia plants were similar in size and height.

Five different concentrations of petroleum oil (D-C-Tron NR NR), at 1.0, 1.2 , 1.4, 1.8 and 2.2%, were assessed on immature stages of black scale and applied separately using a 15 L capacity Tris Knapsack sprayer delivering about 158 ml/plant of liquid. Control plants were left unsprayed.

The experimental design of this study was similar to that described in 4. 3. 6. ie. a completely randomised block design with eight replications with treatments established in the same way. In addition, pre-treatment and treatment counts of black scale and were taken at the same frequency as in 4. 3. 6. The yield was assessed at 224 days post-treatment in October, 1994.

4. 4. Results

4. 4. 1. Effectiveness of individual and mixtures of insecticides

Results of the efficacy of individual insecticides in the initial experiment are presented in terms of number of scale insect following application and mortality at 28 days post treatment (Table 8). Analysis of variance of the survival of scale species at 28 days post-treatment revealed in significant differences (p = 0.05) between all treatment ie. winter and summer oil and the insecticides: Rogor, pyrethrum, Metasystox and controls (unsprayed bushes). Winter oil (3%)caused ca. 88 % mortality of scale insects and summer oil (2.5%) ca. 85 % mortality. There was no significant difference between remaining insecticides: Metasystox (0.1%), Rogor (3.0%), pyrethrum (2.5%), and control resulting in ca. 30, 25, 17 and 0.60 % scale mortality respectively (Table 8).

The average numbers of scale per sample shoot were plotted against time before and after treatment application (Fig. 33). In general, the results showed that numbers of scale declined to about 28 days post-treatment and then increased.

Table 8. Scale survival and mortality following a single application of summer oil (2.5 %), winter oil (3.0 %), Rogor (3.0 %), pyrethrum (2.5 %), and Metasystox (0.1 %) at Kingston on October 30, 1991.

Treatments	Mean number of scale insects per sample shoot					Mortality at 28 days post-treatment (%)
	pre-treatment	post-treatment (day(s))				
	-1	7	14	28	56	
Summer oil (2.5%)	8.94	3.89	3.11	1.33	7.04	85.03
Winter oil (3.0 %)	6.55	0.89	0.67	0.78	4.60	88.02
Rogor (3.0 %)	6.61	3.67	4.56	8.16	11.46	24.81
Pyrethrum (2.5%)	6.33	4.61	3.77	5.72	12.22	17.04
Metasystox (0.1%)	9.77	6.50	6.88	6.78	12.59	30.19
Control	6.60	6.22	8.49	6.56	14.71	0.60

Lsd (0.05) at 28 days = 3.27

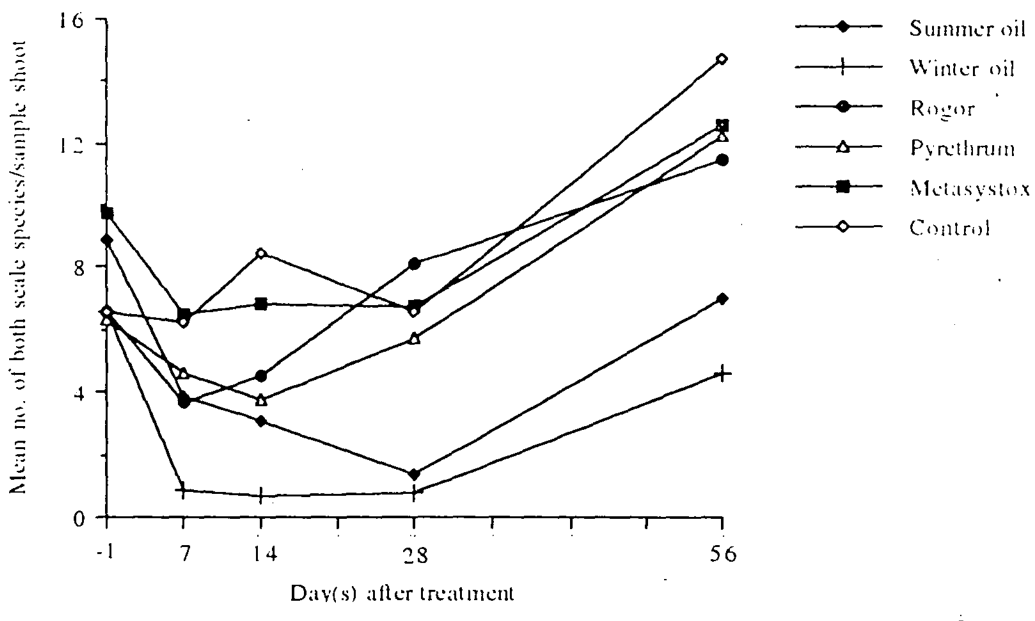


Fig. 33. The average number of scale following the single application of summer oil (2.5%), winter oil (3.0%), rogor (3.0%), pyrethrum (2.5%), and metasystox (0.1%) at Kingston on October 30, 1991.

The results for the efficacy of mixed materials are summarised and presented in Table 9 and Figure 34. in terms of the numbers of scale insects and mortality 28 days post-treatment. The mixtures of pyrethrum (1.25%) plus summer oil (1.25%) and metasystox (0.05%) plus summer oil (1.25%) resulted in a mortality of scale insect of ca. 90% and ca. 76% respectively. The mixtures of pyrethrum (1.25%) plus rogor (1.50 %) and pyrethrum (1.25%) plus metasystox (0.05%) were less effective for control of scale and resulted in only ca. 50 % and 46 % mortality respectively. According to the analysis of variance for the survival of scale insects at 28 days post treatments, there were significant differences not only between treatments and control but also among treatments. The efficacy of the mixture of pyrethrum plus summer oil was significantly greater than that of pyrethrum mixed with metasystox but not significantly different to both the mixtures of metasystox plus summer oil and pyrethrum plus rogor. Mixtures of pyrethrum plus metasystox, metasystox plus summer oil and pyrethrum plus rogor were not significantly different in reducing the number of scale.

Table 9. Scale survival and mortality following the single application of a mixture of pyrethrum (1.25 %) plus metasystox (0.05 %), pyrethrum (1.25 %) plus summer oil (1.25 %), metasystox (0.05 %) plus summer oil (1.25 %) and pyrethrum (1.25 %) plus rogor (1.50 %) at Kingston on October 30, 1991.

Treatments	Mean number of scale insects per sample shoot					Mortality at 28 days post-treatment (%)
	pre-treatment	post-treatment (day(s))				
	-1	7	14	28	56	
Pyrethrum (1.25%) + metasystox (0.50%)	8.87	4.20	4.93	5.19	7.40	46.67
Pyrethrum (1.25%) + summer oil(1.25%)	6.26	2.06	1.87	0.60	3.40	90.42
Metasystox (0.50%) + summer oil (1.25 %)	5.96	2.67	2.40	1.20	5.20	79.87
Pyrethrum (1.25%) + rogor (1.50%)	7.80	6.33	4.60	3.87	5.47	50.38
Control	8.93	10.53	8.27	10.50	8.93	-13.44

Lsd $_{(0.05)}$ at 28 days = 4.55

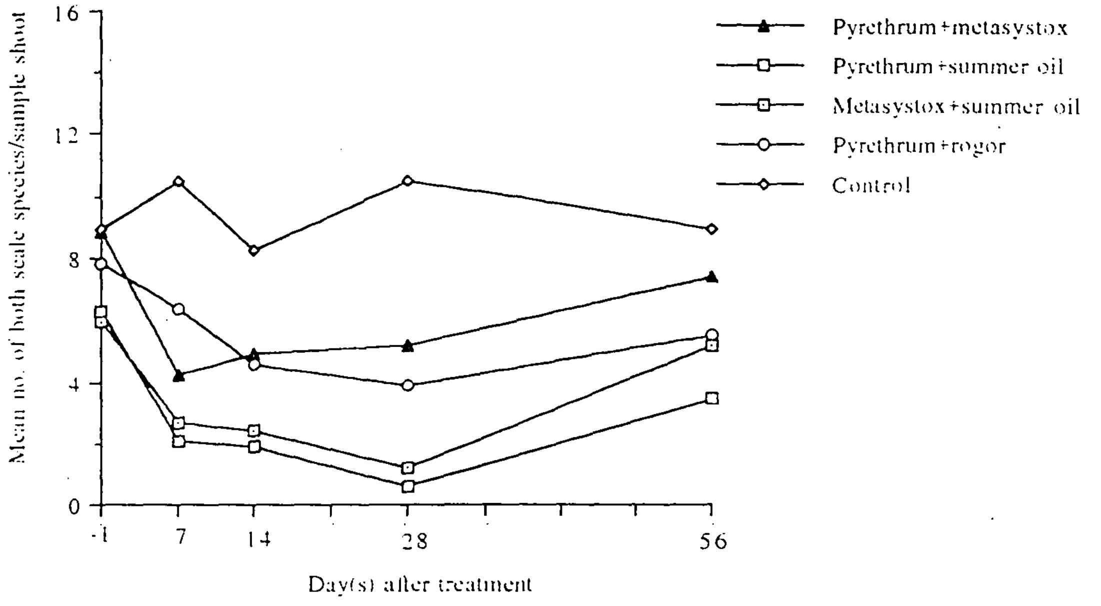


Fig. 34. The average numbers of scale following the single application of the mixtures of pyrethrum (1.25 %) plus metasystox (0.50 %), pyrethrum (1.25 %) plus summer oil (1.25 %), metasystox (0.50 %) plus summer oil (1.25 %), and pyrethrum (1.25 %) plus rogor (1.50 %) at Kingston on October 30, 1991.

The effect of double (two separate) applications of summer oil, a mixture of summer oil plus pyrethrum and pyrethrum was assessed and scale survival and mortality are given in Table 10 and Table 11.

Table 10. Scale survival and mortality following double applications of summer oil (2.00 %), a mixture of pyrethrum (1.25 %) plus summer oil (1.25 %) and pyrethrum (2.50 %) at Kingston in trial site I on March 15 and April 13, 1992.

Treatments	Mean number of scale insects per sample shoot					Mortality (%) at post-treatment (day(s))	
	pre-treatment	post-treatment (day(s))					
	-1	7	14	28	56	7	56
Summer oil (2.00%)	156.40	18.40	3.50	11.10	2.90	88.24	97.46
Pyrethrum (1.25%) + Summer oil (1.25%)	226.10	15.70	10.30	36.80	1.70	93.01	97.75
Pyrethrum (2.50%)	176.70	130.10	81.00	98.60	45.30	26.37	64.86
Control	198.20	226.40	261.40	212.10	144.60	-14.28	27.04

Lsd (0.01) at 28 days = 45.60

Table 11. Scale survival and mortality following double applications of summer oil (2.00 %), a mixture of pyrethrum (1.25 %) plus summer oil (1.25 %) and pyrethrum (2.50 %) at Kingston in trial site I on March 15 and April 13, 1992.

Treatments	Mean number of scale insects per sample shoot					Mortality (%) at post-treatment (day(s))	
	pre-treatment	post-treatment (day(s))					
	-1	7	14	28	56	7	56
Summer oil (2.00%)	217.66	17.50	12.88	17.03	2.63	91.95	98.09
Pyrethrum (1.25%) + summer oil (1.25%)	263.29	7.75	8.38	11.39	2.10	97.05	98.74
Pyrethrum (2.50%)	260.42	170.00	190.00	161.36	69.04	34.72	58.16
Control	256.91	257.88	298.25	195.34	162.81	-13.44	36.63

Lsd (0.01) at 28 days = 95.70

At both trial sites summer oil (2 %) and the mixture of pyrethrum (1.25 %) and summer oil (2 %) resulted in a similar effect in reducing the numbers of scale insect. Summer oil affected a mortality of scale insects of ca. 88 and 91 per cent at trial sites I and II respectively at 7 days post treatment. Pyrethrum plus summer oil caused mortality of ca. 93 and 97 per cent in trial sites I and II. Both summer oil and a mixture of pyrethrum plus summer oil resulted in similar scale mortality (ca. 97 - 98 %) at 56 days post-treatment. According to the analysis of variance, these materials were not significantly different in reducing the number of scale, but they significantly differed between pyrethrum and control at 28 days post treatment (p = 0.05). Pyrethrum was not effective for control of scale causing less than 35 percent mortality. Pre- and post-treatment counts of scale for all treatments and control are given in Figure 35 and 36. Percentage mortality at 7 and 56 days post treatments were determined using Abbotts formula.

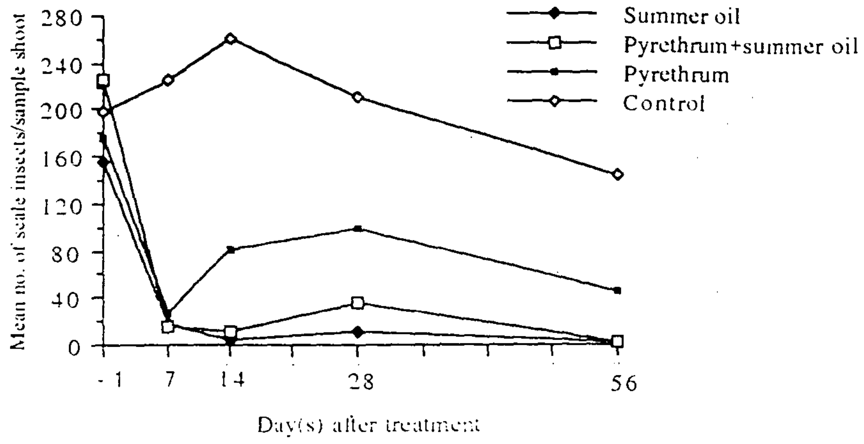


Fig. 35. The average number of scale insects following two applications of summer oil (2.00 %), pyrethrum (1.25 %) plus summer oil (1.25 %), and pyrethrum (2.50 %) at Kingston (Trial I).

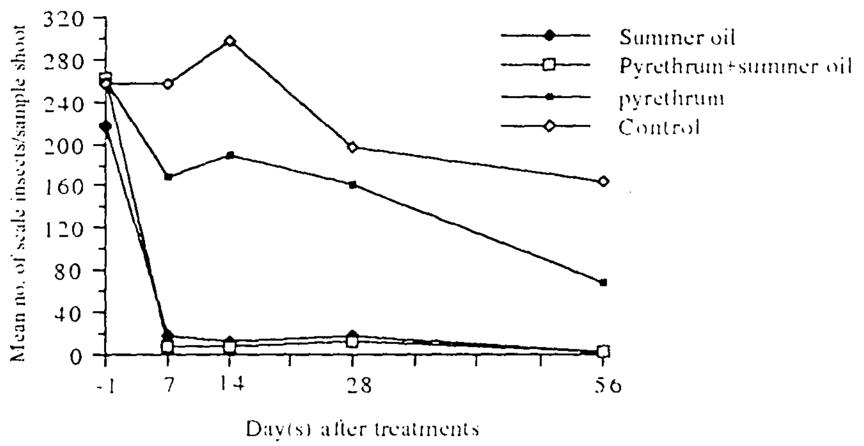


Fig. 36. The average number of scale insects following two applications of summer oil (2.00 %), pyrethrum (1.25 %) plus summer oil (1.25 %), and pyrethrum (2.50 %) at Kingston (Trial II).

4. 4. 2. Effectiveness on scale infestations of complete and incomplete coverage of boronia plants with summer oil

Application of summer oil to both sides and tops and to sides alone of boronia plants gave similar levels of control of black scale with mortality ca. 76 and 71 % respectively (Tables 12). In contrast, summer oil applied only to tops of boronia plants gave less effective control of black scale.

Complete(sides and top) and incomplete (sides or top) applications of summer oil to boronia plants for control of *C. hesperidum* are summarised in Table 13. It can be seen that all treatments resulted in low mortality of soft brown scale. The survival in numbers of *C. hesperidum* did not differ significantly among treatments. However, application of summer oil to both sides and tops of boronia gave the highest mortality ca. 61 per cent and this was followed by applications of summer oil to sides (ca. 50 %) and to tops (ca. 42 %) alone. Percentage mortalities at 14 days post treatment were determined using Abbotts formula.

Table 12. Scale survival and mortality of black scale following the single application of summer oil (2 %) to different sites of boronia plants on November 17, 1992 at Kingston.

Treatments	Mean number of black scale per sample shoot					Mortality (%) at 14 days post-treatment
	Pre-treatment	Post-treatment (day(s))				
	-1	7	14	28	56	
Top	3.07 a	2.53 a	2.00 c	1.40 a	1.40 a b c	24.30
Sides	3.73 a	3.00 a	0.93 a b	0.93 a	0.53 a b	71.03
Sides and top	3.27 a	2.53 a	0.67 a	0.63 a	0.40 a	76.19
Control	2.87 a	2.73 a	2.47 c	2.40 b	2.33 c	13.94
Lsd(0.05)			0.359	0.930	0.850	
(0.01)			0.543	1.409	1.288	

Table 13. Scale survival and mortality of soft brown scale following single application of summer oil (2%) on different sites of boronia plants on November 17, 1992 at Kingston.

Treatments	Mean number of soft brown scale per sample shoot					Mortality (%) at 14 days post-treatment
	pre-treatment	Post-treatment (day(s))				
	-1	7	14	28	56	
Top	1.67 a	1.53 a	0.80 a	1.87 a	7.40 a	42.86
Sides	1.93 a	1.60 a	0.80 a	3.00 a	4.93 a	50.55
Sides and top	1.93 a	1.20 a	0.63 a	2.87 a	5.13 a	61.10
Control	1.67 a	1.60 a	1.40 a	3.00 a	7.13 a	16.17

Parasitised black scale and soft brown scale and predator, *Anystis* sp, were recorded and presented in the Tables 14, 15 and 16 respectively. Level of parasitism and predation of black and soft brown scale were very low with differences between treatment and control mean values. At the same time the use of 2.0 percent petroleum oil did not affect numbers of natural enemies.

Table 14. Parasitised black scale following single application of summer oil (2%) to different sites of boronia plants on Nov. 17, 1992 at Kingston.

Treatment	Mean number of parasitised black scale per sample shoot				
	pre-treatment	post-treatment (day(s))			
	-1	7	14	28	56
Top	0.00	0.00	0.00	0.00	0.00 a
Sides	0.00	0.00	0.00	0.00	0.07 a
Sides and top	0.00	0.00	0.00	0.00	0.07 a
Control	0.00	0.00	0.00	0.00	0.13 a

Table 15. Parasitised soft brown scale following a single application of summer oil (2%) to different sites of boronia plants on Nov. 17, 1992 at Kingston.

Treatment	Mean number of parasitised soft brown scale per sample shoot				
	pre-treatment	post-treatment (day(s))			
	-1	7	14	28	56
Top	0.00	0.00 a	0.07 a b	0.07 a	0.07 a
Sides	0.00	0.27 a	0.13 a b	0.07 a	0.00 a
Sides and top	0.00	0.07 a	0.00 a	0.00 a	0.07 a
Control	0.00	0.07 a	0.47 a b	0.13 a	0.07 a
Lsd (0.05)			0.394		
(0.01)			0.597		

Table 16. Numbers of predator (*Anystis.* sp) following single application of summer oil (2%) to different sides of boronia plants on Nov. 17, 1992 at Kingston.

Treatment	Mean number of *Anystis* sp per sweep				
	pre-treatment	post-treatment (day(s))			
	-1	7	14	28	56
Top	3.28 a	2.50 a	2.88 a	1.33 a	0.72 a
Sides	3.17 a	2.11 a	2.17 a	1.17 a	0.67 a
Sides and top	2.33 a	2.22 a	2.06 a	1.72 a	0.50 a
Control	2.89 a	2.28 a	2.28 a	1.33 a	0.50 a

4. 4. 3. Effectiveness of single summer oil applications at different times after pruning

Results of the effect of single application of summer oil (2 %) at one, two, four, and eight weeks after pruning in November, 1992 for control of black scale are presented in Table 17 and for soft brown scale in Table 18 in terms of post-treatment survival. Percentage mortalities at 7 days post treatment were determined using abbots formula.

Table 17. Scale survival and mortality of black scale following summer oil applications (2 %) at different times after pruning on Nov. 17, 1992 at Kingston.

Treatment (after pruning)	Mean number of black scale per sample shoot					Mortality(%) at 7 days Post treatment
	pre-treatment	Post-treatment (day(s))				
	-1	7	14	28	56	
One week	3.18 a	0.89 a	0.33 a	0.42 a	0.37 a	70.10
Control	2.82 a	2.64 b	2.40 b	1.87 b	1.71 b	6.38
Two weeks	3.04 a	1.17 a	0.55 a	0.58 a	0.46 a	57.66
Control	2.64 a	2.40 b	2.23 a	1.78 b	9.64 b	9.09
Four weeks	2.11 a	1.38 a	1.58 a	0.87 a	6.52 a	22.02
Control	2.23 a	1.87 b	1.78 a	2.09 b	19.71 b	16.14
Eight weeks	1.47 a	0.82 a	4.29 a	4.8 a	6.24 a	31.83
Control	2.09 a	1.71 b	9.64 b	19.71 b	30.56 b	18.18.

Table 18. Scale survival and mortality of soft brown scale following summer oil applications (2 %) at different times after pruning on Nov. 17, 1992 at Kingston.

Treatment (after pruning)	Mean number of soft brown scale per sample shoot					Mortality(%) at 7 days Post treatment
	pre-treatment	Post-treatment (day(s))				
	-1	7	14	28	56	
One week	1.29 a	0.73 a	0.49 a	2.98 a	1.66 a	34.70
Control	1.20 a	1.04 a	1.05 a	4.87 a	6.51 a	13.33
Two weeks	1.47 a	0.60 a	0.69 a	4.49 a	1.89 a	59.18
Control	1.04 a	2.40 b	1.95 a	5.85 a	3.07 a	-130.76
Four weeks	2.69 a	2.22 a	2.24 a	1.24 a	0.93 a	17.47
Control	1.95 a	4.87 a	5.85 a	7.18 b	3.25 a	-149.74
Eight weeks	5.80 a	0.38 a	0.07 a	0.40 a	0.14 a	92.78
Control	7.18 a	6.51 b	3.07 b	3.25 b	2.72 b	9.33

The results indicate that all treatments significantly affected the numbers of black scale after application. On the other hand, as can be seen in Table 18, summer oil application only at eight weeks after pruning resulted in significantly reducing the numbers of soft brown scale.

These results are shown graphically for black and soft brown scale in Figure 37 and 38 respectively.

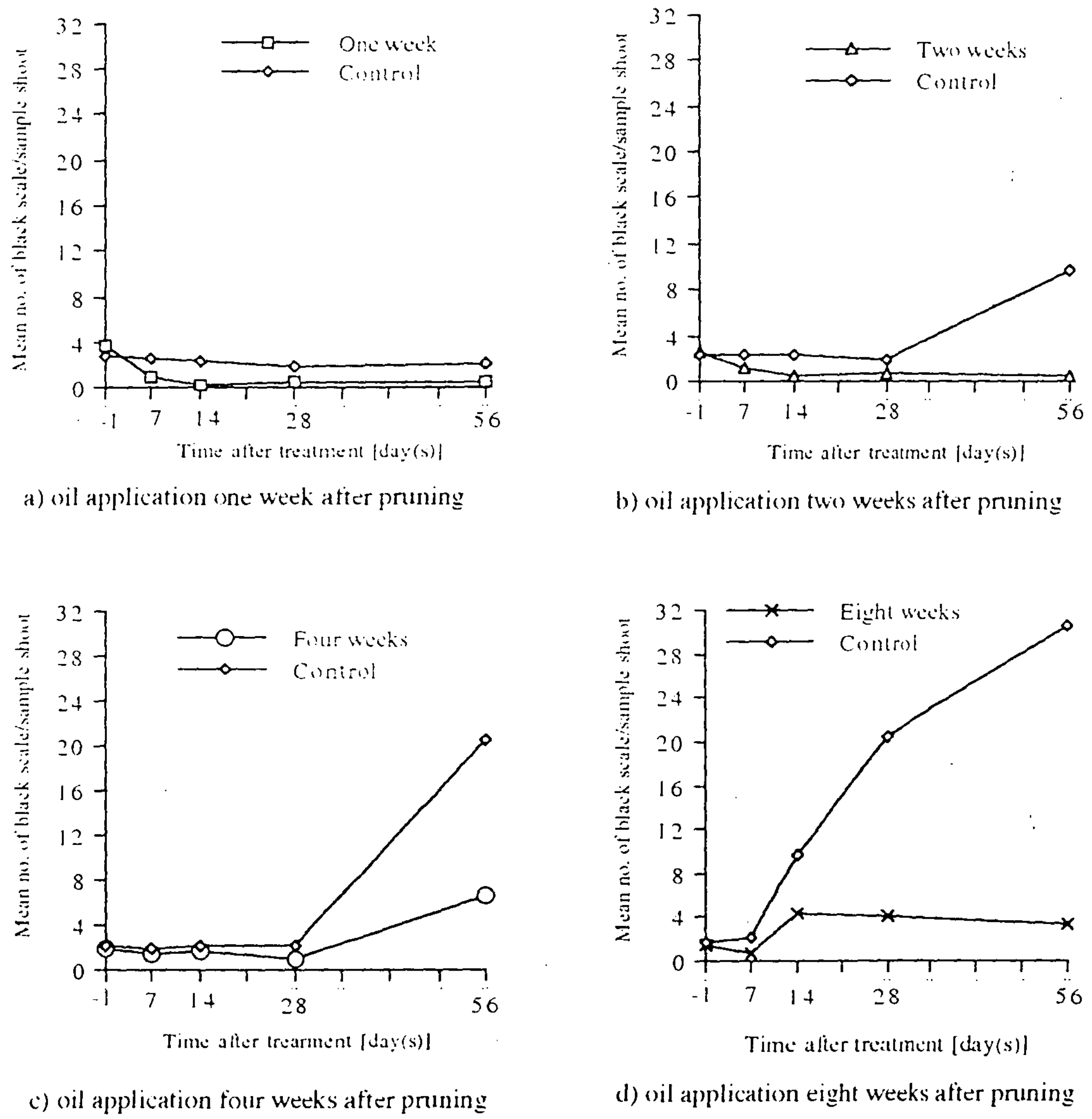
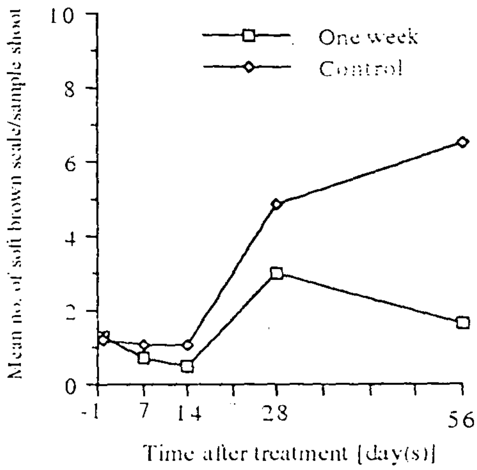
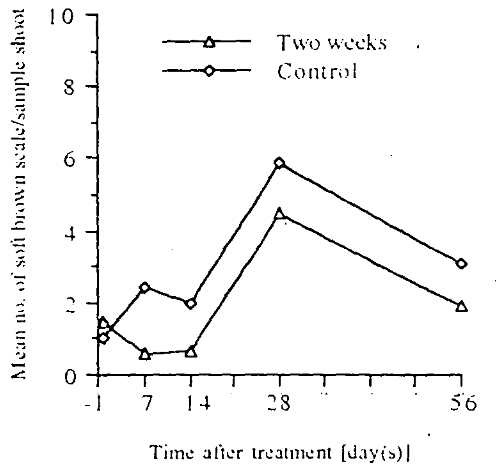


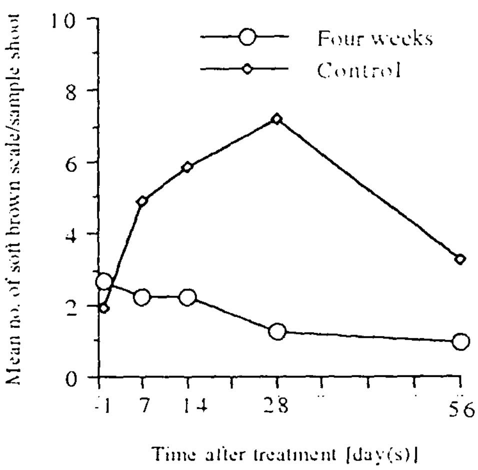
Fig. 37. Effect of a single application of summer oil (2 %) after pruning on Nov. 17, 1992 on control of black scale at Kingston.



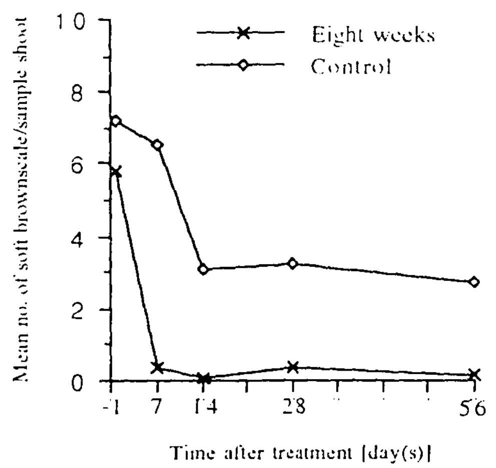
a) oil application one week after pruning



b) oil application two weeks after pruning



c) oil application four weeks after pruning



d) oil application eight weeks after pruning

Fig. 38. Effect of single application of summer oil (2 %) after pruning on Nov. 17, 1992 on control of soft brown scale at Kingston.

Numbers of parasitised black scale and soft brown scale are presented in Tables 19 and 20 and numbers of the predatory mite, *Anystis.* sp, in Table 21. Parasitism levels of black and soft brown scale were not significantly different between treatments and control. In addition, the predator mite was not affected by summer oil application at different times after pruning.

Table 19. Parasitised black scale following a single application of summer oil (2 %) one, two, four, and eight weeks after pruning on Nov. 17, 1992 at Kingston.

Treatments (after pruning)	Mean number of parasitised black scale per sample shoot				
	Pre-treatment	Post treatment (day(s))			
	-1	7	14	28	56
One week	0.00 a	0.00 a	0.00 a	0.02 a	0.00 a
Control	0.00 a	0.00 a	0.00 a	0.00 a	0.02 a
Two weeks	0.02 a	0.02 a	0.00 a	0.00 a	0.00 a
Control	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Four weeks	0.00 a	0.04 a	0.00 a	0.02 a	0.00 a
Control	0.00 a	0.00 a	0.00 a	0.04 a	0.00 a
Eight weeks	0.02 a	0.00 a	0.00 a	0.00 a	0.00 a
Control	0.04 a	0.02 a	0.00 a	0.00 a	0.00 a

Table 20. Parasitised soft brown scale following a single application of summer oil (2 %) one, two, four, and eight weeks after pruning on Nov. 17, 1992 at Kingston.

Treatments (after pruning)	Mean number of parasitised soft brown scale per sample shoot				
	Pre-treatment	Post-treatment (day(s))			
	-1	7	14	28	56
One week	0.20 a	0.07 a	0.07 a	0.02 a	0.00a
Control	0.22 a	0.09 a	0.11 a	0.07 a	0.07 a
Two weeks	0.11 a	0.09 a	0.07 a	0.02 a	0.04 a
Control	0.09 a	0.11 a	0.04 a	0.02 a	0.22 a
Four weeks	0.13 a	0.02 a	0.02 a	0.02 a	0.09 a
Control	0.04 b	0.07 a	0.02 a	0.11 a	0.26 a
Eight weeks	0.09 a	0.02 a	0.02 a	0.00 a	0.02 a
Control	0.11 a	0.07 a	0.22 a	0.26 a	0.29 a

Table 21. Number of predator mite (*Anystis* sp) following a single application of summer oil (2 %) one, two, four, and eight weeks after pruning on Nov. 17, 1992 at Kingston.

Treatments (after pruning)	Mean number of the predator mite (*Anystis*. sp) per sweep				
	Pre-treatment	Post-treatment (day(s))			
	-1	7	14	28	56
One week	3.09 a	2.69 a	2.69 a	0.35 a	0.42 a
Control	2.80 a	2.60 a	2.58 a	0.33 a	0.62 a
Two weeks	2.42 a	3.84 a	1.60 a	0.18 a	1.65 a
Control	2.60 a	2.58 a	1.78 a	0.20 a	1.73 a
Four weeks	0.14 a	0.20 a	0.11 a	0.44 a	2.29 a
Control	1.78 a	0.33 a	0.20 a	0.71 a	3.04 a
Eight weeks	0.69 a	0.69 a	1.78 a	3.20 a	0.35 a
Control	0.71 a	0.62 a	1.73 a	3.04 a	0.40 a

4. 4. 4. Effectiveness of an insect growth regulator (buprofezin) and oil (MP. 9) on scale insect

Application of buprofezin to mature stage could reduce numbers of both black and soft brown scale (Tables 22 and 23). Increasing the concentration of buprofezin from 0.1 g up to 0.4 g ai. L^{-1} did not significantly increase the level of suppression of the next generation of both scale species. The oil MP. 9 did not significantly reduce numbers of scale. It was not until this investigation was complete that it was learnt that the latter product was actually a mixture of two polysaccharides.

Table 22. Numbers of black scale, *S. oleae*, per sample shoot following application of buprofezin and oil MP.9 to boronia plants on December 10, 1992 in Kingston.

Treatment	Mean number of black scale per sample shoot					Mortality at 56 days post-treatment (%)
	pre-treatment	post-treatment (day(s))				
	-1	7	14	28	56	
Buprofezin (0.4 g ai./L)	4.30 a	3.25 a	2.95 a	2.45 a	3.80 a	11.63
Buprofezin (0.2 g ai./L)	3.45 a	2.75 a	2.25 a	3.00 a	1.85 a	46.38
Buprofezin (0.1 g ai./L)	3.80 a	2.90 a	2.35 a	2.85 a	3.25 a	14.47
Oil MP. 9 (0.1 g ai./L)	4.95 a	3.70 a	3.50 a	3.00 a	19.65 b	-296.97
Control	4.40 a	4.30 a	3.70 a	3.60 a	27.70 b	-529.55
Lsd (0.05)					15.268	
(0.01)					21.405	
P-Value					0.0089	

Table 23. Numbers of soft brown scale, *C. hesperidum*, per sample shoot following application of buprofezin at different concentrations and oil MP. 9 to boronia plants on December 10, 1992 at Kingston.

Treatments	Mean number of soft brown scale per sample shoot					Mortality at 56 days post-treatment
	pre-treatment	post-treatment (day(s))				
	-1	7	14	28	56	
Buprofezin (0.4 g ai./L)	1.95 a	2.05 a	1.75 a	1.45 a	0.50 a	74.36
Buprofezin (0.2 g ai./L)	1.60 a	1.35 a	1.55 a	1.10 a	0.45 a	71.88
Buprofezin (0.1 g ai./L)	2.00 a	2.15 a	1.85 a	1.70 a	0.85 a	57.50
Oil MP. 9 (0.1 g ai./L)	2.25 a	3.00 a	4.60 a	8.90 b	5.80 b	-157.78
Control	2.50 a	2.25 a	3.60 a	6.38 b	4.65 b	-86.00
Lsd(0.05)				2.362	1.462	
(0.01)				3.312	2.050	
P-Value				0.0001	0.0001	

The numbers of parasitised black and soft brown scale are presented in Tables 24 and 25 and the numbers of *Anystis* sp. in Table 26.

Table 24. Numbers of parasitised black scale following applications of buprofezin and oil MP. 9 to boronia plants on December 10, 1992 at Kingston.

Treatments	Mean number of parasitised black scale per sample shoot				
	pre-treatment	post-treatment (day(s))			
	-1	7	14	28	56
Buprofezin (0.4 g ai./L)	0.00 a	0.00 a	0.00 a	0.00 a	0.05 a
Buprofezin (0.2 g ai./L)	0.05 a	0.00 a	0.00 a	0.05 a	0.00 a
Buprofezin (0.1 g ai./L)	0.00 a	0.00 a	0.00 a	0.00 a	0.05 a
Oil MP. 9 (0.1 g ai./L)	0.00 a	0.00 a	0.00 a	0.00 a	0.05 a
Control	0.00 a	0.00 a	0.00 a	0.05 a	0.05 a

Table 25. Numbers of parasitised soft brown scale following applications of Buprofezin and oil MP. 9 to boronia plants on December 10, 1992 at Kingston.

Treatments	Mean number of parasitised browm soft scale per sample shoot				
	pre-treatment	post-treatment			
	-1	7	14	28	56
Buprofezin (0.4 g ai./L)	0.10 a	0.05 a	0.10 a	0.05 a	0.05 a
Buprofezin (0.2 g ai./L)	0.05 a	0.05 a	0.00 a	0.10 a	0.10 a
Buprofezin (0.1 g ai./L)	0.15 a	0.05 a	0.00 a	0.20 a	0.15 a
Oil MP. 9 (0.1 g ai./L)	0.10 a	0.15 a	0.00 a	0.25 a	0.05 a
Control	0.15 a	0.15 a	0.10 a	0.20 a	0.10 a

Table 26. Numbers of the predator mite, *Anystis* sp. following applications of buprofezin and oil MP. 9 to boronia plants on December 10, 1992 at Kingston.

Treatments	Mean number of the predator mite (*Anystis* sp) per sweep				
	pre-treatment	post-treatment			
	-1	7	14	28	56
Buprofezin (0.4 g ai./L)	4.17 a	2.38 a	0.79 a	0.09 a	0.42 a
Buprofezin (0.2 g ai./L)	3.54 a	2.67 a	1.21 a	0.25 a	0.95 a
Buprofezin (0.1 g ai./L)	3.54 a	2.71 a	1.21 a	0.34 a	0.63 a
Oil MP. 9 (0.1 g ai./L)	4.25 a	2.52 a	1.33 a	0.13 a	1.37 a
Control	3.79 a	2.71 a	1.25 a	0.09 a	0.84 a

The effectiveness of two applications of Buprofezin at 28 days' interval for control of black scale is presented in Table 27. The results suggest that Buprofezin resulted in a gradual effect rather than directly killing this scale. Furthermore, Buprofezin inhibited the development of scale to mature stages. Increasing the concentration of Buprofezin did not significantly affect numbers of surviving black scale.

Table 27. Numbers of black scale, *S. oleae*, per sample shoot following two applications of Buprofezin (0.20, 0.10 and 0.05 g ai. L^{-1}) at 28 days' interval (Feb. 25 and March 25, 1993) and single application of buprofezin (0.05 g ai. L^{-1}) to boronia plants on February 25, 1993 at Cygnet.

Treatments	Stages	Mean number of black scale per sample shoot							mortality at 210 days post-treatment (%)
		pre-treatment	post-treatment (day/s)						
		-1	7	14	56	84	140	210	
Buprofezin	1st stage nymphs	92.06	38.46	37.00	24.13	16.40	7.67	0.00	
(0.20 g ai.)	2nd stage nymphs	48.67	41.20	33.00	27.73	26.93	16.87	0.20	
two appli-	3rd stage nymphs	0.00	0.00	0.00	0.00	0.00	0.00	0.33	
cations	adult	1.40	0.87	0.53	0.00	0.13	0.00	0.00	
	Total	142.13 a	80.53 a	70.53 a	51.87 a	43.47 a	24.53 a	0.53 a	99.63
Buprofezin	1st stage nymphs	79.07	47.27	43.48	30.68	18.20	7.27	0.00	
(0.10 g. ai.)	2nd stage nymphs	34.67	34.67	35.80	33.80	30.47	17.14	0.26	
two appli-	3rd stage nymphs	0.06	0.06	0.00	0.00	0.00	0.06	0.67	
cations	adult	0.53	0.53	0.59	0.79	0.00	0.06	0.00	
	Total	114.33 a	82.53 a	79.87 ab	65.27 a	48.67 a	24.52 a	0.93 a	99.17
Buprofezin	1st stage nymphs	77.67	51.83	51.27	31.82	22.00	4.40	0.00	
(0.05 g. ai.)	2nd stage nymphs	44.40	48.60	46.74	40.86	31.73	17.80	0.13	
two appli-	3rd stage nymphs	0.13	0.06	0.06	0.06	0.00	0.00	0.80	
cations	adult	2.20	0.78	0.53	0.06	0.00	0.00	0.13	
	Total	124.40 a	101.27 a	98.59 bc	72.80 a	53.73 a	22.20 a	1.06 a	99.15
Buprofezin	1st stage nymphs	108.2	80.6	50.53	33.13	33.13	10.27	0.00	
(0.05 g. ai.)	2nd stage nymphs	59.60	49.16	57.64	52.87	36.00	32.80	0.73	
single ap-	3rd stage nymphs	0.27	0.00	0.13	0.67	0.13	3.13	2.87	
plication	adult	0.66	1.79	0.37	0.53	0.00	0.00	0.87	
	Total	168.73 a	131.53 a	108.67 c	87.20 a	64.20 a	46.20 a	4.47 a	97.35

Lsd(0.05)	23.132
(0.01)	35.048
P-Value	0.0239

4. 4. 5. Effectiveness of insect growth regulators (IGRs), systemic insecticides, and petroleum oil on the survival of mature stages of *Saisssetia oleae* Oliver

The effect of Kinoprene, Methoprene, and Buprofezin as IGRs, and petroleum oil. Aldicarb, Confidor, Kilval, and Nuvacron applications on boronia for control of *S. oleae* is presented in Table 28 and Figure 39. Numbers of new nodes are presented in Table 28 and Figure 40 and the length of shoot extension , numbers of flowers and the flower yield (g/plant) after treatment application are shown in Table 28.

Table 28. Numbers of black scale (immature and mature black scale), numbers of new nodes and flowers, extension shoot length and the flower yield per sample shoot at 252 days following three applications (15th, 22nd Nov., and 6th Dec.) of Kinoprene, Methoprene, and Buprofezin; two application (15th and 29th Nov.) of Kilval and Nuvacron; and a single application (15th Nov.) of Aldicarb, Confidor and petroleum oil at Cygnet, 1994.

Treatments	Mean no of black scale /sample shoot	Mean no. of new nodes	Mean length shoot extension	Mean no of flowers	Flower yield/plant (g)
Kinoprene (0.50% ai./L)	15.88	18.13	17.85	30.31	1.45
Methoprene (0.15 g. ai./L)	10.96	16.83	16.59	32.81	1.53
Buprofezin (0.10 g. ai./L)	12.13	16.80	16.25	29.06	1.33
Petroleum oil (2.00%ai.)	7.71	17.05	18.13	44.44	1.89
Aldicarb (0.75 mg. ai./plant)	17.92	18.70	19.56	34.31	1.57
Confidor (0.75 mg. ai./plant)	18.30	16.38	15.77	31.88	1.41
Kilval (0.125 %)	18.17	15.98	15.99	25.69	1.15
Nuvacron (0.02 %)	24.54	15.28	14.83	27.25	1.16
Control	31.03	12.65	10.44	23.31	0.97
Lsd (0.005)	8.830	2.694	4.005	5.589	0.267
(0.01)	11.754	3.585	5.331	7.440	0.356
P-Value	0.0001	0.0030	0.0035	0.0001	0.0001

The effect of petroleum oil on the number of black scale (immature and mature scale) did not significantly differ from that of Buprofezin, Binoprene and Methoprene but was significantly different from the insecticide treatments and control. Even though the effect of petroleum oil on both numbers of new nodes and shoot extension length was not significantly different to other treatments, numbers of flowers and flower yield increased significantly. Kilval and nuvacron were not effective in reducing black scale populations and increasing flower yield.

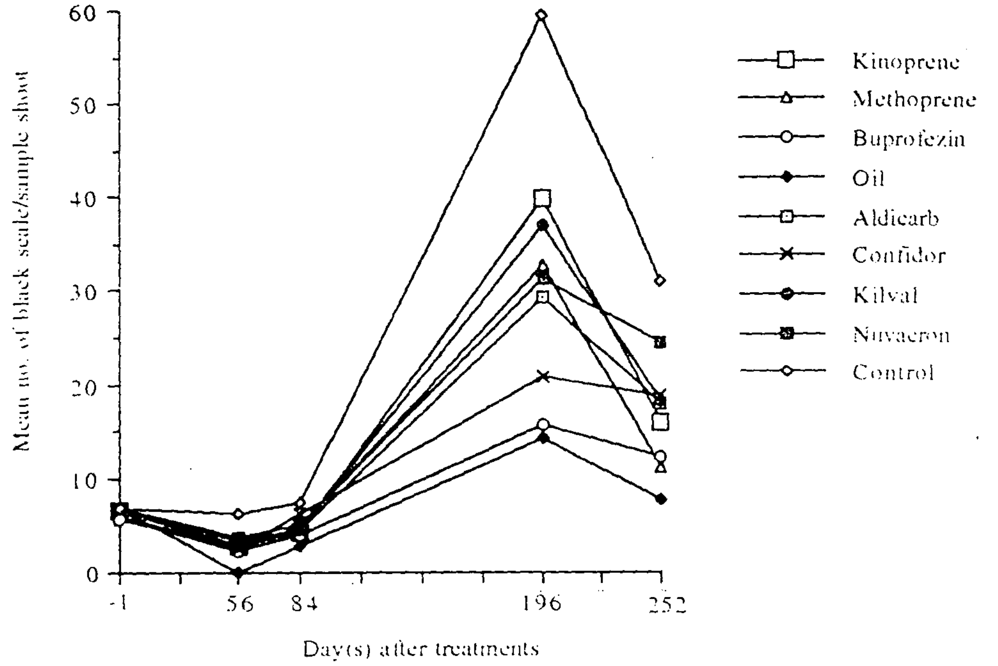


Fig. 39. Effect of three applications (15th, 22nd Nov. and 6th Dec.) of Kinoprene, Methoprene, and Buprofezin; two application (15th and 29th Nov.) of Kilval and Nuvacron; and a single application (15th Nov.) of Aldicarb, Confidor and petroleum oil for control of *S. oleae* at Cygnet, 1993.

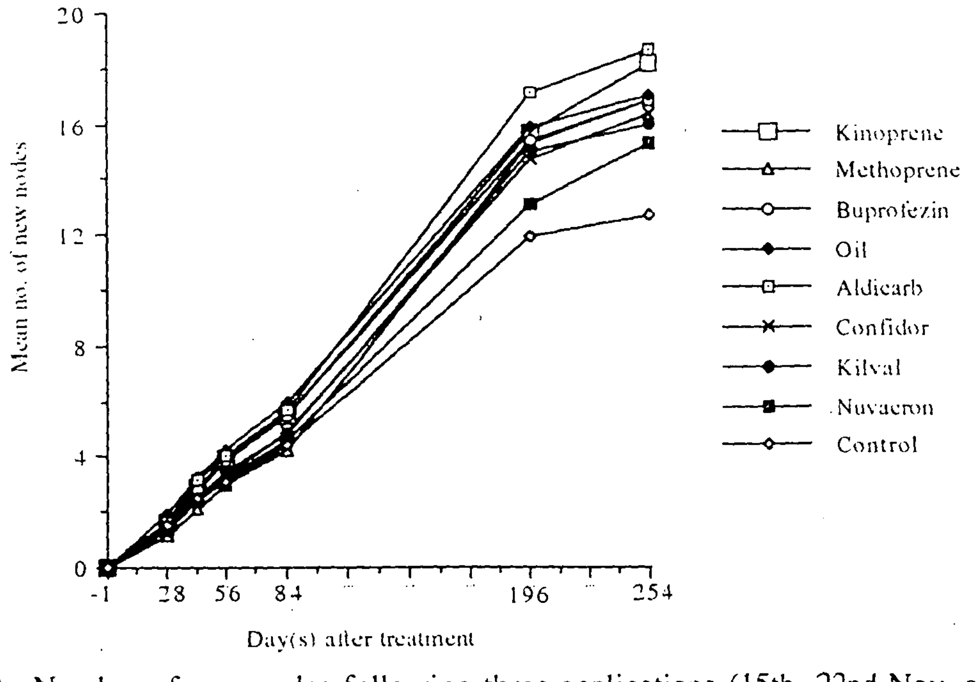


Fig. 40. Number of new nodes following three applications (15th, 22nd Nov. and 6st Dec.) of Kinoprene, Methoprene, and Buprofezin; two applications (15th and 29th Nov.) of Kilval and Nuvacron; and a single application (15th Nov.) of Aldicarb, Confidor and petroleum oil at Cygnet, 1993.

4. 4. 6. Effectiveness of IGRs, a combination of IGRs plus petroleum oil and petroleum oil alone on immature stages of black scale

The effect of kinoprene, methoprene, buprofezin, a mixture of these IGRs and petroleum oil, and petroleum oil alone for control of black scale attacking boronia is presented in Table 29 in terms of survival number and per cent mortality at 7 and 154 days post treatment that were determined using Abbotts formula.

Table 29. Survival and mortality of *S. oleae* following two applications of three IGRs (Kinoprene, Methoprene and Buprofezin) (21st Feb. and 21st March) and a single application of mixtures of petroleum oil plus these IGRs (21st Feb.) at Cygnet, 1994.

Treatments	Mean number of black scale per sample shoot							Mortality (%) at 7 and 154 days	
	pre-treatment	at post-treatment							
	-1	7	14	28	56	84	154	7	154
Kinoprene	87.28	50.50	46.83	49.94	32.78	14.89	11.25	42.14	79.50
Methoprene	76.55	37.22	40.67	48.06	33.00	31.78	17.70	51.38	63.24
Buprofezin	74.45	72.11	62.72	69.50	46.72	28.61	10.39	3.14	77.80
Kinoprene + petroleum oil	102.28	7.06	10.52	10.23	4.11	4.33	1.86	93.10	97.11
Methoprene + petroleum oil	91.56	13.17	15.17	17.06	13.22	17.33	9.92	85.62	82.78
Buprofezin + petroleum oil	87.83	4.89	8.44	7.22	3.11	1.83	1.36	94.43	97.54
Petroleum oil	84.44	1.89	3.67	2.28	1.56	1.67	0.08	97.76	99.86
Control	71.50	71.74	80.00	74.34	66.11	75.34	44.97	- 0.34	37.11
Lsd (0.05)		12.11	16.44	12.34	18.01	14.25	9.08		
(0.01)		16.24	22.06	16.56	24.16	19.12	12.18		
P-Value		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		

The results indicate that all IGRs, kinoprene, methoprene, and buprofezin did not directly kill scale but resulted in a gradual reduction of scale numbers. However, application of a mixture of these IGRs plus petroleum oil and petroleum oil alone gave a significant reduction in the numbers of black scale and resulted in directly killing this scale.

The effects of IGRs, the mixture of IGRs plus petroleum oil and petroleum oil on vegetative (new nodes and extension shoot length) and reproductive growth (numbers of flowers and their weights) are presented in Table 30 and Figure 41.

Table 30. Numbers of new nodes and flowers, shoot extension length and flower yield (g) at the end of the experiment of Kinoprene, Methoprene and Buprofezin, the mixtures of these IGRs plus petroleum and petroleum oil alone at 224 days after application on October 5, 1994 at cygnet .

Treatments	Number of new nodes per sample shoot	Length of shoot extension per sample shoot	Number of flowers per sample shoot	Weight of flowers (gram) per sample shoot
Kinoprene	10.36	9.78	35.39	1.59
Methoprene	9.81	9.88	38.78	1.69
Buprofezin	10.14	9.92	35.78	1.57
Kinoprene + petroleum oil	10.38	10.15	40.11	1.80
Methoprene + petroleum oil	11.31	11.87	41.92	1.83
Buprofezin + petroleum oil	9.75	10.24	40.80	1.78
Petroleum oil	10.95	11.33	45.64	1.90
Control	8.22	7.84	26.00	1.16
Lsd(0.05)	1.380	1.879	5.527	0.226
(0.01)	1.851	2.520	7.416	0.303
P-Value	0.0040	0.0004	0.0001	0.0001

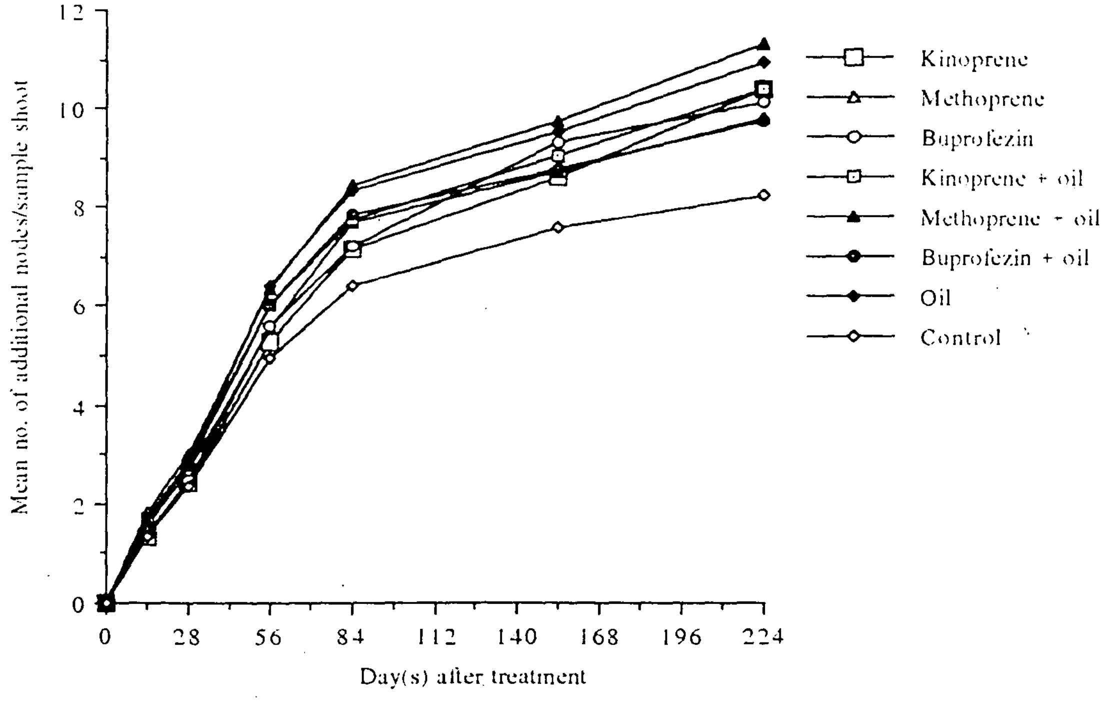


Fig. 41. Numbers of new nodes of boronia following two applications of three IGRs, Kinoprene, Methoprene and Buprofezin (21st Feb. and 21st March), a single application of the mixtures of these IGRs plus petroleum oil and petroleum oil alone (21 st Feb.) at Cygnet, 1994.

The result shows that both numbers of new nodes and the extension shoot length were significantly different between treated and control plants (p = 0.05). The effect of a mixture of methoprene plus oil on new nodes was not significantly different to that of the mixture of Kinoprene plus petroleum oil, petroleum oil, Kinoprene, Buprofezin, and Methoprene, but the effect was significantly different to Methoprene and a mixture of Buprofezin plus oil. On the other hand, a mixture of methoprene plus petroleum oil did not significantly affect shoot extension compared to the mixture of buprofezin plus petroleum oil, kinoprene plus petroleum oil, and petroleum oil alone but its effect was significantly different to all IGRs, buprofezin, methoprene, and kinoprene.

4. 4. 7. Effect of petroleum oil at different concentrations on immature stages of *Saissetia oleae* Oliver

Five different concentrations of petroleum oil were applied to boronia for control of black scale. Their efficacy was recorded at seven days post treatment and is presented in Table 31. The results indicate that the petroleum oil application at different concentrations did not significantly differ in their effect on black scale post-treatment.

The number of new nodes and the length of extension shoot are summarised in Table 32 and Figure 42. In addition, number of flowers and flower yield are also presented in Table 32. Numbers of new nodes and shoot extension lengths were significantly different not only between all treated plants and control but also among treated plants. The effect of petroleum oil application (1.0 %) on number of new nodes did not significantly differ to that of petroleum oil at concentration of 1.2 % but was significantly different from the remaining treatments. However, the length of shoot extension did not differ significantly among treated plants with petroleum at concentrations of 1.0, 1.2 and 1.4 %.

Applications of petroleum oil to boronia bushes at five different concentrations significantly increased both numbers of flowers and flower yield over control bushes. There were no significant differences between the different treatments.

Table 31. Effectiveness of single application of oil (D-C-Tron NR) at different concentrations to boronia plants on February 21st, 1994 on the survival of black scale, *S. oleae* in Cygnet.

Treatments	Mean number of black scale per sample shoot						Mortality at 7 days post-treatment (%)
	pre-treatment	post treatment					
	-1	7	14	28	56	84	
Petroleum oil (1.0 %)	90.94	6.79	8.29	6.12	7.38	5.79	92.53
Petroleum oil (1.2 %)	89.67	6.58	7.71	6.08	4.29	4.50	92.66
Petroleum oil (1.4 %)	80.54	5.13	7.58	5.50	4.17	4.79	93.63
Petroleum oil (1.8 %)	80.62	1.92	4.71	4.13	1.96	2.96	97.62
Petroleum oil (2.2 %)	95.42	1.96	3.00	2.50	1.58	2.21	97.95
Control	84.08	96.96	84.83	98.25	87.08	85.42	-15.32
Lsd 0.05		16.239					
0.01		21.787					
P-Value		0.001					

Table 32. Number of new nodes and flower, extension shoot length and flower yield at 224 days after a single application of petroleum oil (Dc-Tron NR) on 21st Feb. 1994 at different concentrations to boronia plants for control of black scale, *S. oleae* at Cygnet.

Treatments	Number of new nodes per sample shoot	Length of extension shoot (cm) per sample shoot	Number of flowers per sample shoot	Weight of flowers (g) per sample shoot
Petroleum oil (1.0 %)	12.25	12.34	35.50	1.80
Petroleum oil (1.2 %)	11.29	10.94	34.54	1.80
Petroleum oil (1.4 %)	10.75	10.87	34.27	1.70
Petroleum oil (1.8 %)	10.71	10.32	34.27	1.72
Petroleum oil (2.2 %)	10.04	9.51	31.15	1.63
Control	8.79	7.44	15.94	0.94
Lsd(0.05)	1.389	1.922	4.514	0.296
(0.01)	1.863	2.579	6.056	0.397
P-Value	0.005	0.004	0.001	0.001

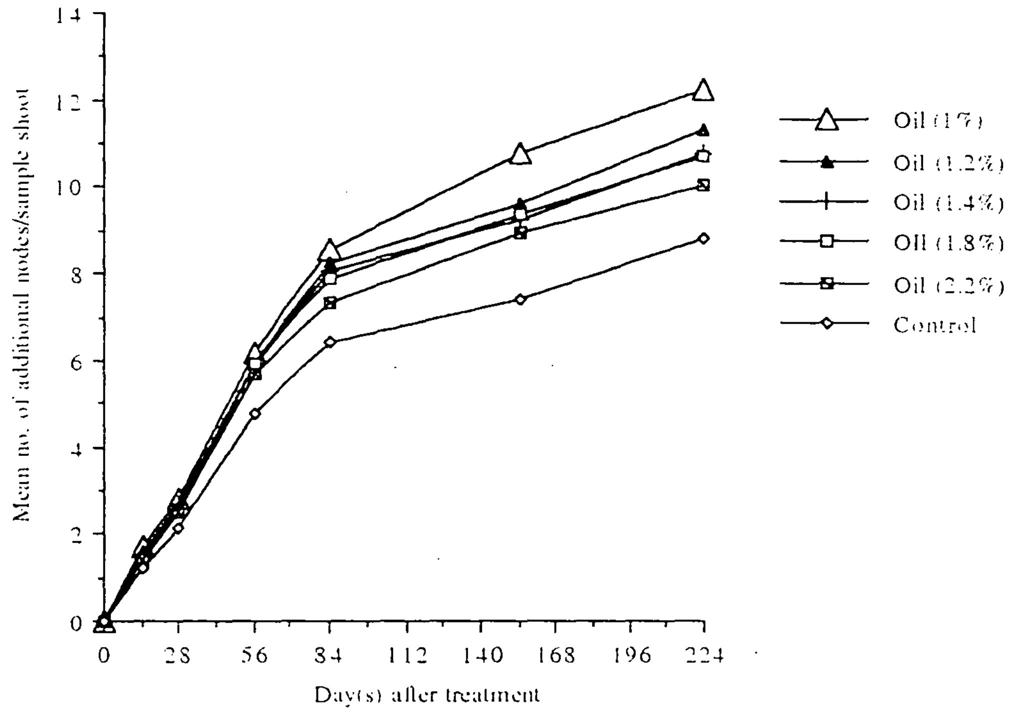


Fig. 42. Number of new nodes following a single application of petroleum oil at different concentrations to boronia plants for control of black scale on Feb. 21, 1994 at Cygnet.

4. 4. Discussion

Applications of a range of insecticides for control of scale insect on boronia were evaluated at Kingston and Cygnet. Results of initial experiments showed that winter (3.0 %) and summer oil (2.5 %) resulted in significantly lower levels of scale compared with rogor (3.0 %), pyrethrum (2.5 %), metasystox (0.1 %) and control, with scale mortality being ca. 88 and 85 percent respectively. Others, eg., metasystox, pyrethrum and rogor, were less effective agents for control of scale with an average scale mortality of less than 30 percent and there was no significant difference among them in reducing numbers of scale. However, metasystox (0.05 %) plus summer oil (1.25 %) and pyrethrum (1.25 %) plus summer oil (1.25 %) also resulted in a high mortality of scale insect at ca. 80 and 90 per cent respectively. While a mixture of pyrethrum (1.25 %) plus metasystox (0.05 %) and pyrethrum (1.25 %) plus rogor (1.50 %) gave better results compared to these insecticides when applied alone (Table 8 and 9), scale mortality was less than 50 per cent.

Two applications of summer oil (2.00 %) and a mixture of summer oil (1.25%) plus pyrethrum (1.25 %) on vulnerable stages at 28 days' interval effectively controlled scale and resulted in mortality of ca. 97 per cent at 56 days post-treatment. Pyrethrum (2.50 %) alone reduced the number of scale with a mortality of ca. 64 per cent.

Methods of insecticide application are an important factor in supporting successful control of insect pests. Different applications, incomplete and complete, of summer oil (2 %) were assessed for control of scale insects. Incomplete applications of summer oil to boronia were less effective as scale were distributed over the bushes while complete coverage applications of summer oil from both sides and tops of plants resulted in a significant reduction of both black and soft brown scale populations. Distributing summer oil to cover the entire boronia plant is necessary to have the best control of scale insects. This result agrees with Beattie (1991 and 1992) who suggested that petroleum oils have to be applied to plants thoroughly to run off to achieve an excellent result because petroleum oil, through leaving a thin coverage of oil, effectively suffocates insect pests. In addition Ishaaya and Swirski (1970) found that mineral oil affected the invertase activity of scale insects.

Summer oil (2 %) application to predominantly second and third stage nymphs one week after pruning was most effective in reducing numbers of black scale with a mortality of ca. 70 per cent. This shows that second and third stage nymphs were still relatively vulnerable. Application of this material two, four and eight weeks after pruning, as most of this scale develops to the third and adult stages, was less effective with an average black scale mortality of less than 58 per cent. The pre-reproductive female may be less affected due to the formation of wax on the scale. In contrast, the application of summer oil, eight weeks after pruning, in January, resulted in a good control for soft brown scale because most of this scale occurred as early immature stages which are most vulnerable. Summer oil applications one, two and four weeks after pruning was less effective for control of soft brown scale, *C. hesperidum*, due to most of this scale occurring as the adult stage which was less affected by summer oil.

The efficacy of buprofezin to control scale insect was evaluated on both mature and immature stages. A single application of buprofezin to mature stages of *S. oleae* and *C. hesperidum* did not significantly affect adult *S. oleae* and *C. hesperidum* but suppressed numbers in the next generation of these scale. Increasing concentration up to 0.4 g. ai. L^{-1} did not significantly further suppress numbers of the next generation of both scale species. This result agrees with Yarom et al (1988) who reported that buprofezin did not affect adult scales but suppressed embryogenesis of *S. oleae* by inhibiting egg hatch and affected California red scale, *Aonidiella aurantii* Maskell, by reducing production of crawlers. A similar result was obtained with *Bemisia tabaci* Gennadius in which egg hatch and progeny formation were suppressed by buprofezin (Ishaaya et al, 1988). On the other hand, application of buprofezin to immature stages of black scale significantly reduced numbers and the scale development following treatments but the effect of this insect growth regulator was only gradual. Two applications of buprofezin (0.10 and 0.20 g. ai. L^{-1}) at 28 days' interval completely inhibited *S. oleae* entering the adult stage for 210 days. Two applications and a single application of buprofezin at a concentration of 0.05 g. ai. L^{-1} resulted in less than 1 percent of *S. oleae* entering the adult stage. This shows that the most immature stages, first and second stage nymphs, of *S. oleae* were more affected than the adult stage because the LC_{50} for first and second stage nymphs were very low at 0.008 and 0.031 mg. ai. L^{-1} respectively (Yarom et al. 1988). Similar results were obtained with white louse scale, *Unaspis citri* Comstock. in which three and two applications of buprofezin resulted in less than one per cent adult female scale after four months (Smith and Papacek, 1990).

Three insect growth regulators (IGRs); buprofezin (0.05 g. ai. L^{-1}), kinoprene (5.00 % ai. L^{-1}) and methoprene (0.15 g. ai. L^{-1}), a mixture of buprofrezin (0.05 g. ai. L^{-1}), kinoprene (4.00 % ai. L^{-1}), methoprene (0.15 g. ai. L^{-1}) plus petroleum oil (1.00 % ai. L^{-1}) and petroleum oil (D-C-Tron NR) (2.00 % ai. L^{-1}) were evaluated for control of black scale, their effects on vegetative growths (number of new nodes and shoot extension length) and flower yields. Buprofezin, kinoprene and methoprene resulted in a gradual kill of *S. oleae* with the scale mortality ca. 63, 79 and 77 per cent respectively after 154 days. Peleg and Gothilf (1981) also reported that the development of *S. oleae* was greatly affected by methoprene and application at above 3 % ai. L^{-1} inhibited scale entering the adult stage. These materials increased significantly the number of new nodes and shoot extension length compared to control plants. Flower yield of all IGR-treated plants increased by approximately 27 percent from untreated plants. As buprofezin, kinoprene and methoprene were mixed with petroleum oil they directly killed *S. oleae* to result in an average mortality of ca. 94, 93 and 85 per cent respectively at 7 days post-treatment. Therefore, the number of new nodes and shoot extension length of boronia plants treated with these mixtures was significantly greatest and flower yields were slightly higher than those of plants treated with IGRs alone in which yield increased by 35 per cent compared to untreated plants. A single application of petroleum oil (2.00 % ai. L^{-1}) gave effective control of *S. oleae* with a mortality of ca. 99 per cent at 7 days post treatment. The number of new nodes and shoot extension length also increased following application of petroleum oil and flower yield was increased by 40 per cent in comparison with unsprayed infested plants.

Three applications of Buprofezin (0.10 g. ai. L^{-1}), Kinoprene (0.50 ai. L^{-1}) and Methoprene (0.15 g. ai. L^{-1}) at 14 days' interval between applications, two applications of Kilval (0.125 % ai. L^{-1}) and Nuvacron (0.02 % ai. L^{-1}) at 28 days' interval and single applications of Confidor (0.75 mg. ai. per plant), Aldicarb (0.75 mg. ai. per plant) and petroleum oil (D-C-Tron NR) (2.00 % L^{-1}) were also assessed for control of adult black scale. Petroleum oil (2.00 %) was still the most effective for control of black scale when applied soon after pruning. Observations at the end of the study, indicated that confidor and aldicarb remained in the soil near treated plants. This indicated slow release of these materials into soil; therefore, in the absence of regular rain or irrigation, these systemics were only moderately effective. Similarly, Kilval and Nuvacron were less effective in controlling of *S. oleae*.

Due to the risk of phytotoxicity to plants (Beattie, 1990) petroleum oil applied at different concentrations of 1.0, 1.2, 1.4, 1.8 and 2.2 % was assessed for control of *S. oleae* infestations on boronia. A single application of petroleum oil at these concentrations significantly reduced the number of *S. oleae* but did not significantly differ among treatments. Petroleum oil applied at a concentration of 1.0, 1.2 and 1.4 per cent resulted in scale mortality of ca. 92, 92 and 93 per cent respectively after 7 days. Petroleum oil applied at concentrations of 1.8 and 2.2 per cent resulted in scale mortality ca. 97 percent. All treatments increased significantly the number of new nodes, shoot extension length and flower yield compared with untreated plants. Although petroleum oil at 1.0 and 1.2 % concentration resulted in slightly lower mortality compared to that at concentration of 1.8 an 2.2 %, they had less affect on the numbers of new nodes and shoot extension lengths; therefore, flower yield was slightly higher than that of remaining treatments. This result supports Beattie' s recommendation (1992) that petroleum oil applied at a concentration of 1.0 to 1.2 per cent is sufficient for control of scales. Flower yield increased by 42 to 47 per cent following petroleum oil applications at different concentrations in response to the rapid action of petroleum oil in killing scale. According to this result, the use of insect growth regulators was not necessary as petroleum oil at concentration of 1.0 per cent reduced numbers of black scale to low levels and had a beneficial effect on flower yield. In commercial application it is difficult to apply petroleum oil in complete coverage to boronia plants because of the bush density so that two applications may be necessary for control of scale insects.

Levels of parasitism of *S. oleae* and *C. hesperidum* were low in these studies. In general, levels of parasitism of both scale species were not affected by insecticide applications. Nor did the number of predatory mites (*Anystis* sp.) significantly differ among treatments and control.

Chapter
5
General Discussion and Conclusion

The relevant results of investigations reported in previous chapters are gathered here to formulate the development of a control program. Recommendations which should ensure successful control are made in the conclusions as are areas that may require further investigation.

Commercial boronia plantations have been established in Tasmania to fulfil an increasing demand for boronia oil for the perfume and flavour industry. As a monocultural practice, the boronia plantation is relatively more vulnerable to insect pest attack partly due to the lack of plant diversity and inefficient biological control. Outbreaks of psyllids on boronia have been reported to be due to inappropriate insecticide applications (Mensah, 1990).

In the late 1980's scale insects were found infesting boronia after psyllids were controlled by appropriately timed sprays. Scale infestation was reported to significantly reduce the flower yield and to have the capacity to kill some boronia plants (Pullen personal communication). Due to the lack of biological information about these scale insects on Boronia, control measures were ill-timed and inefficient. To develop a suitable control program it was necessary to gain an understanding of the biology, population performance, insect-plant relationships and the role of natural enemies of damaging scale species.

Damage to the boronia bush caused by these scale species is by excessive removal of sap through feeding and contamination of the boronia bush with sooty-mould growing on excreted liquid which in turn reduces photosynthesis. In heavily infested bushes vegetative growth is significantly inhibited and flower yield decreased. In extreme cases parts of the boronia bush may be killed due to scale infestation. Boronia bushes which have been mechanically damaged during mechanical flower harvesting are most vulnerable to infestation as described ie. damage followed by formation of wound callus as described in the damage results section for the wound callus tissue provides ideal establishment sites for first stage nymphs. In addition, this callus growth provides protection from insecticide, i.e. petroleum oil. Boize et al (1976) pointed out that the spreading oil drop is a function of the physical properties of the liquid and the nature of the leaf surface. The efficiency of petroleum oil is greater on smooth surfaces rather than on rough surfaces (Beattie. 1991).

Scale species which occurred on boronia were identified as black scale, *Saissetia oleae* Oliver, and soft brown scale, *Coccus hesperidum* L. Both these scale species are exotic to Australia (Wilson, 1960), black scale is originally from South Africa (De Lotto, 1976) and soft brown scale is native to Europe (McLeod and Coppel, 1966). Black scale has become a serious pest to commercial boronia plantations and the role of this scale on boronia was studied intensively to develop a successful control program. These scale species are easily differentiated from each other at the adult stage but first stage nymphs must be differentiated under the microscope. Numbers of antennal segments, sub apical and apical setae, fringe setae and colour in dorsal view and body size (Argyriou, 1963; Annecke, 1966; Podoler et al, 1979) were employed to recognise each stage of both scale species. Numbers of marginal setae on the posterior parts near to the anal plate were another important characteristic for black scale.

Black scale, *S. oleae* , has one generation per year and passes through egg and three stages to enter the adult stage on boronia plants in Tasmania. The distribution of black scale was over both stems and leaves and before reaching the adult stage migration from leaves to woody stems took place from winter through spring so that adult scales were rarely found on leaves. This migration to stems was supported by stylet length which increases with increasing body size width, permitting access to cells within stems. Migration from leaves to twigs has been documented (Ebeling, 1959; Simmonds, 1951a). The development of scale was slow in winter and immature stages, mainly second and third stage nymphs, occurred during this season. New generations appeared in summer, in January. According to "Key Factor" analysis, the highest mortality occurred to first stage nymphs reaching up to ca 98 per cent and was followed by up to 73 per cent mortality of surviving second stage nymphs. High temperatures, which may reach 41°C on some summer days (Appendix 6) were the most important factors contributing to scale mortality, as the *S. oleae* population consisted of first stage nymphs, the most vulnerable stage. At this time suppressed plant growth also contributed to this mortality because translocation of nutrients was very low. Contribution of parasitoids to the scale mortality was very low although suitable hosts were available throughout the year.

Soft brown scale (*C. hesperidum*) was found to have 3 generations each year and no third stage nymphs were found. This result agrees with Annecke (1966) and Ebeling (1959) who reported that soft brown scale moults only twice before the adult stage. The distribution of immature and mature stages of this scale tends to be on the upper leaves and shoots of the boronia bush but preferring to settle on leaves rather than stems in spring through summer. Parasitism of up to 19 % of soft brown scale populations contributed to keeping soft brown scale populations at low levels. New generations of the soft brown scale appear in summer, autumn and spring season.

A number of insecticides were evaluated to assess their effectiveness to control scale insects. Results indicated that petroleum oil was the best insecticide to control both scale species. In addition, IGRs promised to be selective agents because they inhibited the development to the adult stage. Due to their gradual effect on scale insects IGRs have to be applied when scale populations are at low levels or mixed with petroleum oil to give direct kill.

This study has shown that choosing effective materials and applying them in the proper way and at the correct time were the most important factors in developing a pest control program. Petroleum oil (D-C-Tron NR) at a concentration of 1.0 to 1.2 per cent gave the best results. This material must be applied during the third through fourth weeks of February to achieved the best result. Although the efficiency of parasitoids on black scale population was low they did contribute significantly to control of soft brown scale. Parasitism of soft brown scale, which prefers to settle on the upper parts of boronia was as high as 19 % suggesting that parasitoids may prefer to act on the upper warmer, more exposed and illuminated parts of boronia plants. On the other hand, the parasitism level of black scale was very low. This was most likely due to the distribution of black scale remaining on the lower stems of the boronia bush which were permanently shaded, cooler and often with wound callus providing protected sites. Pruning resulted in a reduction of scale populations but prunings which were not removed from a farm can provide a source of reinfestation. Mensah (1990) suggested that prunings should be removed to avoid reinfestation by psyllids.

As discussed previously, inappropriate application of insecticides can result in poor control so that multiple applications have to be applied to reduce scale populations. Results of this study indicated that the best control of scale insects was achieved by the application of petroleum oil (1.0 - 1.2 %) in such a way which provided complete coverage of bushes at less than recommended dosages and at a time when most of both scale species consisted of the most vulnerable first and second stage nymphs. Petroleum oil applied in this way was beneficial to both vegetative growth and flower yield. The flower yield was increased by up to 42 per cent following the thorough application of petroleum oil. In addition, application of petroleum spray oil (D-C-Tron NR) following pruning resulted in the control of black scale with no observable disruption to existing natural enemy population.

The important factors in the control program were (a) the use of petroleum oil at an effective dosage of 1 - 1.2 % to reduce immature stage nymphs by ca. 92 per cent, (b) the application of petroleum oil to the entire bush to run-off to ensure good contact with the target pest, (c) applying petroleum oil in February when most of both scale species were first and second stage nymphs, (d) removal of prunings (e) removal of weeds within and between rows to reduce refuges, and (f) minimising mechanical damage through maintaining boronia below a height of about 110 cm which minimises bending tension on stem-root during cultural practices and the mechanical harvesting of flowers.

Reducing the dosage of petroleum oil to 1 to 1.2 % and applying to the most vulnerable stages of citrus scale has been recommended by Beattie (1992). He also stressed that petroleum oil must be applied until run-off occurs to achieve an excellent result.

The concept of IPM was achieved in this study which evaluated all control practices, reduced dosages of insecticides and application of these materials at the correct time and in the appropriate way. Results show that oils were still the most powerful treatment to reduce pest populations to low levels and increase flower and oil yields. Natural enemies, especially parasitoids, were not capable of regulating black scale population during the period of study.

Knowledge of pest biology, behaviour and ecology, the host plant and the relationship between pest and the host plant plus proper timing and thorough wetting of the entire boronia bush when spraying with petroleum oil were found to be the essential components for successful control of *S. oleae* and *C. hesperidum*. infesting *Boronia megastigma*.

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Appendices

Appendix 1.

Numbers of black scale per sample shoot were counted in February, 1994 and numbers of new nodes, lengths of shoot extension and flower yield were counted in October, 1994

No	Number of black scale	Flower yield (g)	Number of new nodes	Length of shoot extension (cm)
1	0	311	15.90	16.20
2	0	280	11.00	11.75
3	0	298	16.50	14.50
4	0	378	15.50	11.15
5	1	231	10.00	10.00
6	1	265	15.00	15.20
7	2	206	14.00	12.10
8	2	212	13.50	12.95
9	3	250	12.00	13.60
10	3	262	11.50	11.10
11	6	208	10.00	10.00
12	6	184	10.00	10.10
13	6	172	9.50	9.35
14	7	151	11.00	10.35
15	8	206	11.00	10.10
16	9	175	10.00	9.10
17	9	216	9.50	9.30
18	16	212	14.00	14.40
19	17	175	11.00	11.70
20	18	274	8.50	7.95
21	19	272	8.00	8.70
22	19	220	12.00	12.10
23	19	175	10.00	9.00
24	21	172	11.00	10.80
25	23	150	8.00	7.80
26	24	181	8.50	7.75
27	29	128	11.00	10.20
28	33	165	10.00	10.55
29	38	145	9.00	8.25
30	38	152	8.50	8.10
31	39	122	11.00	11.15
32	46	129	9.00	7.70
33	57	135	10.50	9.10
34	58	154	9.50	10.45
35	62	110	8.00	6.90
36	88	133	8.00	6.45
37	89	94	8.00	6.20
38	101	45	7.50	6.20
39	154	73	7.00	6.20
40	178	25	8.00	6.55
41	179	43	7.50	5.20
42	213	15	7.00	5.35

Appendix 2.

Populations of black scale on boronia bushes which were estimated from 88 sample shoots collected every month from 1991 to 1994 at Kingston

Months	1992	1993	1994
N	1255	0	
D	1194	0	
J	1050	458	
F	639	6753	
M	221	8306	
A	79	8213	
M	58	5456	
J	53	3538	
J	21	2956	
A		2351	
S		1578	
O		1347	
N		1003	
D		830	
J		721	243
F		398	5964
M		216	6605
A		68	5374
M		26	3704
J		8	2320
J			1877
A			1756
S			1170
O			1044
N			792
D			693
J			556
F			321
M			164
A			67
M			25
J			12

Appendix 3.

Numbers of black scale settling on both stems and leaves of boronia bushes were counted on 88 sample shoots from 1992 to 1994 at Kingston.

Years	Months	1st stage nymphs		2nd stage nymphs		3rd stage nymphs		Pre-reproductive female		Reproductive female	
		stems	Leaves	stems	Leaves	stems	Leaves	stems	Leaves	stems	Leaves
1991	N	0	0	35	11	380	339	389	38	63	0
	D	0	0	0		168	52	572	21	373	0
1992	J	86	372	0	0	6	3	539	4	507	6
	F	3557	3116	74	16	0	0	227	0	406	6
	M	5457	2599	366	84	0	0	37	0	184	0
	A	4549	1530	1396	740	0	0	0	0	79	0
	M	1905	2017	960	435	137	2	0	0	58	0
	J	866	1342	682	421	202	25	0	0	53	0
	J	444	1389	509	574	273	46	0	0	21	0
	A	166	800	325	424	574	61	1	0	0	0
	S	13	354	94	380	494	136	99	8	0	0
	O	0	0	40	234	382	407	264	24	0	0
	N	0	0	0	0	342	216	408	20	17	0
	D	0	0	0	0	21	9	460	16	324	0
1993	J	97	146	0	0	7	9	297	13	391	4
	F	3100	2864	0	0	4	6	160	2	221	5
	M	3615	2841	120	29	0	0	18	0	198	0
	A	2883	1357	765	369	0	0	7	0	61	0
	M	1228	1424	673	379	0	0	0	0	26	0
	J	560	741	573	399	39	8	0	0	8	0
	J	245	556	422	538	99	17	0	0	0	0
	A	159	493	332	389	325	58	0	0	0	0
	S	8	94	146	416	383	220	3	0	0	0
	O	0	0	62	250	312	285	168	17	0	0
	N	0	0	8	14	236	301	208	11	14	0
	D	0	0	0	0	45	57	341	10	238	2
1994	J	46	80	0	0	16	6	202	3	317	5
	F	2662	2205	0	0	0	0	94	8	215	4
	M	3496	2602	105	96	0	0	54	2	106	2
	A	1820	1800	660	408	0	0	20	0	46	0
	M	936	1169	594	576	18	8	0	0	24	1
	J	705	328	525	450	81	86	0	0	12	0

Appendix 4.

Populations of soft brown scale on boronia bushes which were estimated from 88 sample shoots collected every month from 1992 to 1994 at Kingston.

Years	Months	1st stage nymphs	2nd stage nymphs	Pre-reproductive female	Reproductive female	Total
1991	N	112	57	76	32	277
	D	513	30	29	40	612
1992	J	319	12	10	30	371
	F	265	59	7	12	343
	M	154	128	18	4	304
	A	220	146	17	1	384
	M	128	124	18	13	283
	J	126	106	5	2	239
	J	91	105	19	0	215
	A	24	189	15	0	228
	S	115	126	64	12	317
	O	18	202	110	8	338
	N	3	65	106	6	180
	D	0	29	115	25	169
1993	J	332	33	11	25	401
	F	248	111	4	17	380
	M	124	128	17	3	272
	A	174	108	24	11	317
	M	131	76	27	10	244
	J	70	51	4	7	132
	J	20	59	29	2	110
	A	44	62	11	3	120
	S	85	45	27	14	171
	O	32	73	36	6	147
	N	9	37	52	7	105
	D	4	23	33	29	89
1994	J	192	9	16	27	244
	F	201	20	6	11	238
	M	86	88	5	2	181
	A	132	46	13	5	196
	M	77	54	11	7	149
	J	26	37	4	3	70

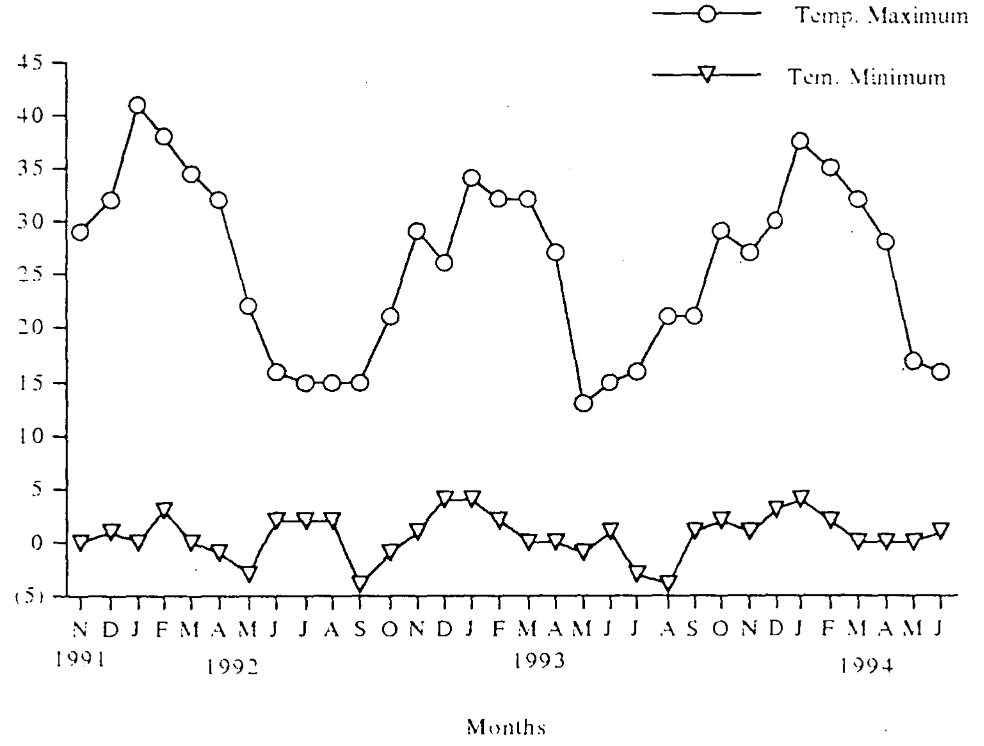
Appendix 5.

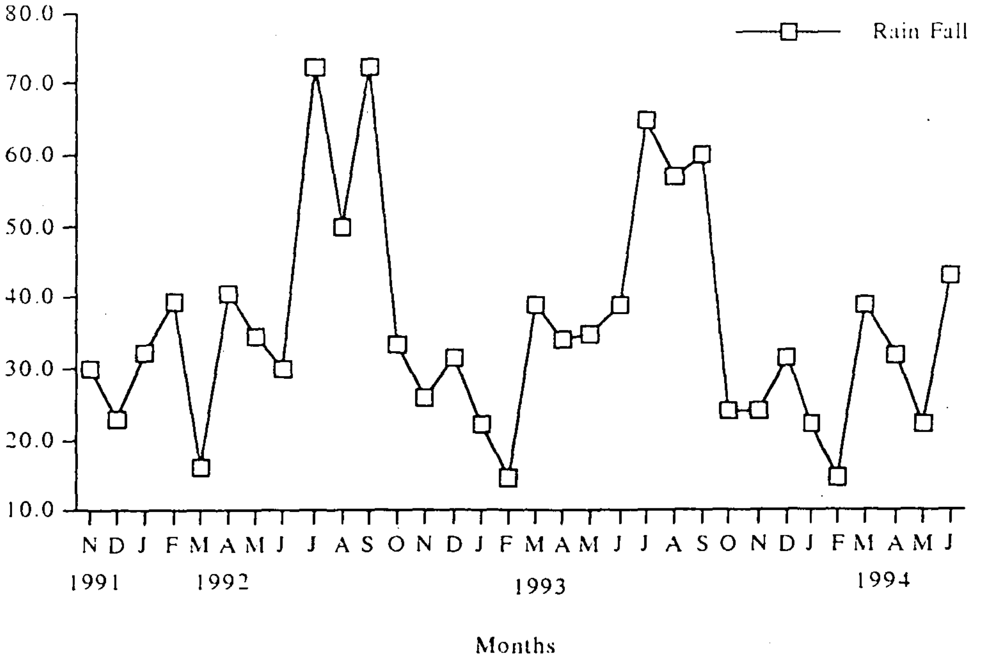
Numbers of soft brown scale settling on both stems and leaves were counted every month on 88 sample shoots from 1992 to 1994 at Kingston.

Years	Months	1st stage nymphs		2nd stage nymphs		Pre-reproductive female		Reproductive female	
		Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
1991	N	45	67	3	54	20	56	6	26
	D	187	326	5	25	11	19	8	32
1992	J	70	249	4	8	0	10	2	28
	F	92	173	19	40	1	6	5	7
	M	91	63	92	36	11	7	0	4
	A	133	87	106	40	12	5	1	0
	M	68	60	58	66	8	10	10	3
	J	58	68	44	62	3	2	2	0
	J	33	58	74	31	8	11	0	0
	A	9	15	33	156	7	8	0	0
	S	2	113	11	115	19	45	3	9
	O	0	18	12	190	18	92	2	6
	N	0	3	2	63	7	99	2	4
	D	0	0	3	26	15	100	7	18
1993	J	122	210	12	21	0	11	2	23
	F	91	157	39	72	0	4	3	14
	M	63	61	82	46	10	7	0	3
	A	114	60	76	32	11	13	2	9
	M	72	59	32	44	8	19	6	4
	J	26	44	27	24	3	1	6	1
	J	7	13	31	28	19	10	2	
	A	27	17	26	36	7	4	2	1
	S	5	80	10	35	7	20	4	10
	O	6	26	13	60	9	27	1	5
	N	0	9	7	30	4	48	2	5
	D	0	4	4	19	14	19	13	16
1994	J	68	124	2	7	2	14	2	25
	F	66	135	6	14	0	6	4	7
	M	49	37	40	48	3	2	0	2
	A	75	57	31	15	10	3	3	2
	M	44	33	29	25	7	4	4	3
	J	16	10	16	21	2	2	3	0

Appendix 6.

Maximum and minimum temperatures (above) and rain-fall (bellow) were recorded every month from 1991 to 1994 at Kingston.





Appendix 7.

Numbers of new nodes per sample shoot following three applications of Kinoprene, Methoprene and Buprofezin (Nov. 15, 22 and Dec. 6), two applications of Kilval and Nuvacron (Nov. 15 and 22) and single application of Petroleum oil, Confidor and Temik (Nov. 15) at Cygnet, 1994.

Treatments	Average number of new nodes per sample shoot						
	0	28	42	56	84	196	252
Kinoprene	0.00	1.67	2.90	3.95	5.48	15.70	18.13
Methoprene	0.00	1.20	2.15	3.00	4.20	15.33	16.83
Buprofezin	0.00	1.45	2.78	3.84	5.50	15.40	16.80
Petroleum oil	0.00	1.92	3.28	4.25	6.00	15.90	17.05
Temik	0.00	1.65	3.15	4.03	5.63	17.10	18.70
Confidor	0.00	1.35	2.50	3.28	4.93	14.68	16.38
Kilval	0.00	1.30	2.53	3.42	4.80	15.03	15.98
Nuvacron	0.00	1.38	2.45	3.20	4.63	13.05	15.28
Control	0.00	1.55	2.50	3.10	4.43	11.95	12.65
Lsd(0.05)						3.047	2.694
(0.01)						4.056	3.585

Appendix 8.

Numbers of new nodes per sample shoot following two applications of Kinoprene. Methoprene and Buprofezin (Feb. 21 and March 21), single application of a mixture of Kinoprene plus Petroleum oil, Methoprene plus Petroleum oil. Buprofezin plus Petroleum oil and Petroleum oil (Feb. 21) on immature stage of black scale at Cygnet 1994.

Treatments	Number of new nodes per sample shoot						
	-1	14	28	56	84	154	224
Kinoprene	0.00	1.36	2.42	5.25	7.17	8.61	10.36
Methoprene	0.00	1.58	2.69	5.56	7.72	8.70	9.81
Buprofezin	0.00	1.39	2.45	5.58	7.22	9.33	10.14
Kinopren+petroleum oil	0.00	1.72	2.78	6.03	7.75	9.05	10.38
Methoprene+petroleum oil	0.00	1.83	3.00	6.33	8.47	9.72	11.31
Buprofezin+petroleum oil	0.00	1.59	2.83	6.03	7.83	8.78	9.75
Petroleum oil	0.00	1.67	2.86	6.39	8.33	9.53	10.95
Control	0.00	1.34	2.36	4.97	6.43	7.58	8.22
Lsd(0.05)		0.269	0.278	0.742	1.106	1.368	1.380
(0.01)		0.362	0.373	0.995	1.483	1.835	1.851

Appendix 9.

Numbers of new nodes per sample shoot following single applications of petroleum oil (Feb. 21, 1994) at different concentrations on immature stage of black scale at Cygnet 1994.

Treatment	Number of new nodes per sample shoot						
	0	14	28	56	84	154	224
Petroleum oil (1.0 %)	0.00	1.69	2.83	6.15	8.58	10.79	12.25
Petroleum oil (1.2 %)	0.00	1.56	2.65	5.90	8.23	9.60	11.29
Petroleum oil (1.4 %)	0.00	1.54	2.67	5.88	8.04	9.21	10.75
Petroleum oil (1.8 %)	0.00	1.40	2.52	5.90	7.90	9.35	10.71
Petroleum oil (2.2 %)	0.00	1.42	2.50	5.69	7.31	8.90	10.04
Control	0.00	1.25	2.12	4.77	6.40	7.40	8.79
Lsd(0.05)		0.238	0.307	0.577	0.813	1.030	1.389
(0.01)		0.319	0.411	0.774	1.091	1.382	1.863

Appendix 10.

Analysis of variance table for numbers of black scale following complete and incomplete applications of summer oil on boronia one week after pruning (Nov. 17, 1992).

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	1.240	.413	.259	.8527
Block	2	4.607	2.303	1.443	.3079
Residual	6	9.580	1.597		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.440	.147	.201	.8921
Block	2	2.580	1.290	1.767	.2492
Residual	6	4.380	.730		

Dependent: Numbers of black scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	6.597	2.199	68.241	.0001
Block	2	.607	.303	9.414	.0141
Residual	6	.193	.032		

Dependent: Numbers of black scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	5.520	1.840	8.492	.0140
Block	2	1.127	.563	2.600	.1537
Residual	6	1.300	.217		

Dependent: Numbers of black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	7.213	2.404	13.276	.0047
Block	2	.647	.323	1.785	.2464
Residual	6	1.087	.181		

Dependent: Numbers of black scale

Appendix 11.

Analysis of variance table for numbers of soft brown scale following complete and incomplete application of summer oil on boronia at one week after pruning (Nov, 17, 1992).

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.213	.071	1.730	.2599
Block	2	.740	.370	9.000	.0156
Residual	6	.247	.041		

Dependent: Numbers of soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.330	.110	3.000	.1170
Block	2	.927	.463	12.636	.0071
Residual	6	.220	.037		

Dependent: Numbers of soft brown scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.880	.293	.710	.5807
Block	2	.107	.053	.129	.8813
Residual	6	2.480	.413		

Dependent: Numbers of soft brown scale

Twenty-eight day post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	2.703	.901	.243	.8638
Block	2	15.287	7.643	2.058	.2087
Residual	6	22.287	3.714		

Dependent: Numbers of soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	15.130	5.043	.870	.5069
Block	2	14.640	7.320	1.262	.3487
Residual	6	34.800	5.800		

Dependent: Numbers of soft brown scale

Appendix 12.

Analysis of variance table for numbers of parasitised black scale following complete and incomplete application of summer oil on boronia at one week after pruning (Nov. 17, 1992).

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.027	.009	.727	.5720
Block	2	.007	.003	.273	.7703
Residual	6	.073	.012		

Dependent: Parasitised black scale

Appendix 13.
Analysis of variance table for numbers of parasitised soft brown scale following complete and incomplete application of summer oil on boronia at one week after pruning (Nov. 17, 1992).

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.120	.040	.706	.5826
Block	2	.140	.070	1.235	.3554
Residual	6	.340	.057		

Dependent: Parasitised soft brown scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	2	.167	.083	2.143	.1985
Treatments	3	.387	.129	3.314	.0987
Residual	6	.233	.039		

Dependent: Parasitised soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.027	.009	.400	.7583
Block	2	.027	.013	.600	.5787
Residual	6	.133	.022		

Dependent: Parasitised soft brown scale

Appendix 14.
Analysis of variance table for numbers of predatory mites following complete and incomplete application of summer oil on boronia at one week after pruning (Nov. 17, 1992).

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	1.618	.539	.523	.6821
Block	2	13.814	6.907	6.700	.0296
Residual	6	6.185	1.031		

Dependent: Numbers of mite

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.241	.080	.149	.9268
Block	2	2.304	1.152	2.127	.2003
Residual	6	3.249	.541		

Dependent: Numbers of mite

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	1.207	.402	1.640	.2772
Block	2	6.992	3.496	14.252	.0053
Residual	6	1.472	.245		

Dependent: Numbers of mite

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.502	.167	.280	.8386
Block	2	.019	.010	.016	.9841
Residual	6	3.593	.599		

Dependent: Numbers of mite

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	.118	.039	.225	.8760
Block	2	.128	.064	.363	.7097
Residual	6	1.054	.176		

Dependent: Numbers of mite

Appendix 15.
Analysis of variance table for numbers of black scale per sample shoot following summer oil application on boronia at one week after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.317	.317	.105	.7621
Block	4	18.885	4.721	1.566	.3373
Residual	4	12.061	3.015		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	7.674	7.674	10.489	.0317
Block	4	6.332	1.583	2.164	.2365
Residual	4	2.926	.732		

Dependent: Numbers of black scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	10.692	10.692	17.906	.0134
Block	4	4.208	1.052	1.762	.2984
Residual	4	2.388	.597		

Dependent: Numbers of black scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	5.227	5.227	13.566	.0211
Block	4	1.216	.304	.789	.5880
Residual	4	1.541	.385		

Dependent: Numbers of black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	4.462	4.462	47.999	.0023
Block	4	.434	.108	1.166	.4426
Residual	4	.372	.093		

Dependent: Numbers of black scale

Appendix 16.
Analysis of variance table for numbers of black scale per sample shoot following summer oil application on boronia at two weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.400	.400	.886	.3998
Block	4	26.770	6.692	14.825	.0115
Residual	4	1.806	.451		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	3.758	3.758	33.001	.0046
Block	4	11.777	2.944	25.856	.0041
Residual	4	.455	.114		

Dependent: Numbers of black scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	7.039	7.039	3.585	.1312
BBlock	4	8.403	2.101	1.070	.4747
Residual	4	7.854	1.964		

Dependent: Numbers of black scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	3.612	3.612	11.542	.0273
Block	4	.843	.211	.674	.6445
Residual	4	1.252	.313		

Dependent: Numbers of black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	214.740	214.740	7.969	.0477
Block	4	119.351	29.838	1.107	.4618
Residual	4	107.782	26.945		

Dependent: Numbers of black scale

Appendix 17.
Analysis of variance table for numbers of black scale per sample shoot following summer oil application on boronia at four weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.036	.036	.172	.7000
Block	4	27.620	6.905	32.909	.0026
Residual	4	.839	.210		

Dependent: Numbers of black scale

Seven days post-treatment

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.086	.086	.339	.5919
Block	4	4.999	1.250	4.893	.0766
Residual	4	1.022	.255		

Dependent: Numbers of black scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	3.745	3.745	15.910	.0163
Block	4	.772	.193	.820	.5741
Residual	4	.942	.235		

Dependent: Numbers of black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	434.808	434.808	9.276	.0382
Block	4	310.720	77.680	1.657	.3183
Residual	4	187.491	46.873		

Dependent: Numbers of black scale

Appendix 18.
Analysis of variance table for numbers of black scale per sample shoot following summer oil application on boronia at eight weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.967	.967	1.898	.2403
Block	4	2.121	.530	1.041	.4851
Residual	4	2.038	.510		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	1.962	1.962	36.965	.0037
Block	4	.743	.186	3.498	.1263
Residual	4	.212	.053		

Dependent: Numbers of black scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	71.663	71.663	1.681	.2646
Block	4	97.528	24.382	.572	.6992
Residual	4	170.555	42.639		

Dependent: Numbers of black scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	617.167	617.167	11.723	.0267
Block	4	409.921	102.480	1.947	.2674
Residual	4	210.588	52.647		

Dependent: Numbers of black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	1838.736	1838.736	27.894	.0062
Block	4	752.070	188.018	2.852	.1672
Residual	4	263.674	65.918		

Dependent: Numbers of black scale

Appendix 19.
Analysis of variance table for numbers of soft brown scale per sample shoot following summer oil application on boronia at one week after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.019	.019	.172	.7000
Block	4	3.034	.759	6.720	.0460
Residual	4	.452	.113		

Dependent: Numbers of soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.240	.240	.900	.3965
Block	4	.694	.174	.650	.6566
Residual	4	1.068	.267		

Dependent: Numbers of soft brown scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.778	.778	2.633	.1800
Block	4	.837	.209	.708	.6270
Residual	4	1.183	.296		

Dependent: Numbers of soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	8.968	8.968	6.429	.0643
Block	4	102.728	25.682	18.411	.0077
Residual	4	5.580	1.395		

Dependent: Numbers of soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	56.074	56.074	7.004	.0572
Block	4	46.925	11.731	1.465	.3601
Residual	4	32.024	8.006		

Dependent: Numbers of soft brown scale

Appendix 20.
Analysis of variance table for numbers of soft brown scale per sample shoot following summer oil application on boronia at two weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.445	.445	.974	.3797
Block	4	1.499	.375	.819	.5742
Residual	4	1.829	.457		

Dependent: Numbers of soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	8.100	8.100	9.924	.0345
Block	4	2.825	.706	.865	.5540
Residual	4	3.265	.816		

Dependent: Numbers of soft brown scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	2.841	2.841	5.171	.0854
Block	4	1.607	.402	.731	.6155
Residual	4	2.198	.549		

Dependent: Numbers of soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	8.968	8.968	6.429	.0643
Block	4	102.728	25.682	18.411	.0077
Residual	4	5.580	1.395		

Dependent: Numbers of soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	3.481	3.481	2.176	.2142
Block	4	8.485	2.121	1.326	.3955
Residual	4	6.398	1.599		

Dependent: Numbers of soft brown scale

Appendix 21.

Analysis of variance table for numbers of soft brown scale per sample shoot following summer oil application on boronia at four weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	1.347	1.347	.375	.5736
Block	4	15.351	3.838	1.067	.4755
Residual	4	14.381	3.595		

Dependent: Numbers of soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	8.100	8.100	9.924	.0345
Block	4	2.825	.706	.865	.5540
Residual	4	3.265	.816		

Dependent: Numbers of soft brown scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	32.436	32.436	3.417	.1382
Block	4	34.924	8.731	.920	.5313
Residual	4	37.967	9.492		

Dependent: Numbers of soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	88.031	88.031	10.517	.0316
Block	4	11.711	2.928	.350	.8333
Residual	4	33.480	8.370		

Dependent: Numbers of soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	13.386	13.386	7.253	.0545
Block	4	8.212	2.053	1.112	.4601
Residual	4	7.383	1.846		

Dependent: Numbers of soft brown scale

Appendix 22.

Analysis of variance table for numbers of soft brown scale per sample shoot following summer oil application on boronia at eight weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	4.733	4.733	.885	.4001
Block	4	20.748	5.187	.970	.5116
Residual	4	21.399	5.350		

Dependent: Numbers of soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	94.065	94.065	11.016	.0294
Block	4	39.464	9.866	1.155	.4460
Residual	4	34.156	8.539		

Dependent: Numbers of soft brown scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	22.530	22.530	20.118	.0109
Block	4	5.291	1.323	1.181	.4379
Residual	4	4.480	1.120		

Dependent: Numbers of soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	20.249	20.249	13.409	.0215
Block	4	9.056	2.264	1.499	.3522
Residual	4	6.040	1.510		

Dependent: Numbers of soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	16.641	16.641	24.893	.0075
Block	4	3.566	.891	1.334	.3935
Residual	4	2.674	.668		

Dependent: Numbers of soft brown scale

Appendix 23.
Analysis of variance table for numbers of parasitised black scale following summer oil application at one week after pruning on November 17, 1992 at Kingston.

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	0.000	0.000	•	•
Block	4	.019	.005	•	•
Residual	4	-2.541E-21	-6.353E-22		

Dependent: Numbers of parasitised black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	1.000	.3739
Block	4	.005	.001	1.000	.5000
Residual	4	.005	.001		

Dependent: Numbers of parasitised black scale

Appendix 24.
Analysis of variance table for numbers of parasitised black scale following summer oil application at two weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	1.000	.3739
Block	4	.005	.001	1.000	.5000
Residual	4	.005	.001		

Dependent: Numbers of parasitised lack scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	1.000	.3739
Block	4	.005	.001	1.000	.5000
Residual	4	.005	.001		

Dependent: Numbers of parasitised black scale

Appendix 25.
Analysis of variance table for numbers of parasitised black scale following summer oil application at four weeks after pruning on November 17, 1992 at Kingston.

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.005	.005	2.667	.1778
Block	4	.007	.002	1.000	.5000
Residual	4	.007	.002		

Dependent: Numbers of parasitised black scale

Twenty-eight days post-treatmnent

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	1.000	.3739
Block	4	.044	.011	9.000	.0280
Residual	4	.005	.001		

Dependent: Numbers of parasitsed black scale

Appendix 26.
Analysis of variance table for numbers of parasitised black scale following summer oil application at eight weeks after pruning on November, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.167	.7040
Block	4	.019	.005	.667	.6480
Residual	4	.029	.007		

Dependent: Number of parasitized black scale

Seven day post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.005	.005	1.000	.3739
Block	4	.019	.005	1.000	.5000
Residual	4	.019	.005		

Dependent: Numbers of parasitised black scale

Appendix 27.
Analysis of variance table for numbers of parasitised soft brown scale following summer oil application at one week after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.074	.7990
Block	4	.065	.016	1.000	.5000
Residual	4	.065	.016		

Dependent: Numbers of parasitised soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.286	.6213
Block	4	.104	.026	6.143	.0533
Residual	4	.017	.004		

Dependent: Numbers of parasitised soft brown scale

Fourteen day post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.005	.005	2.667	.1778
Block	4	.056	.014	7.667	.0369
Residual	4	.007	.002		

Dependent: Numbers of parasitised soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.005	.005	2.667	.1778
Block	4	.017	.004	2.333	.2160
Residual	4	.007	.002		

Dependent: Numbers of parasitised soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.011	.011	2.250	.2080
Block	4	.019	.005	1.000	.5000
Residual	4	.019	.005		

Dependent: Numbers of parasitised soft brown scale

Appendix 28.
Analysis of variance table for numbers of parasitised soft brown scale following summer oil application at two weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treaments	1	.001	.001	.118	.7489
Block	4	.065	.016	1.588	.3325
Residual	4	.041	.010		

Dependent: Numbers of parasitised soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.286	.6213
Block	4	.065	.016	3.857	.1097
Residual	4	.017	.004		

Dependent: Numbers of parasitised soft brown scale

Fouteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.118	.7489
Block	4	.012	.003	.294	.8685
Residual	4	.041	.010		

Dependent: Numbers of parasitised soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.019	.019	2.667	.1778
Bock	4	.029	.007	1.000	.5000
Residual	4	.029	.007		

Dependent: Numbers of parasitised soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.077	.077	1.882	.2420
Block	4	.455	.114	2.765	.1742
Residual	4	.165	.041		

Dependent: Numbers of parasitised soft brown scale

Appendix 29.
Analysis of variance table for numbers of parasitised soft brown scale following summer oil application at four weeks after pruning on November, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.019	.019	.865	.4050
BLock	4	.080	.020	.892	.5428
Residual	4	.090	.022		

Dependent: Numbers of parasitised soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.005	.005	2.667	.1778
Block	4	.017	.004	2.333	.2160
Residual	4	.007	.002		

Dependent: Numbers of parasitised soft brown scale

Fouteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	0.000	0.000	0.000	1.0000
Block	4	.007	.002	.600	.6836
Residual	4	.012	.003		

Dependent: Numbers of parasitised soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.019	.019	2.667	.1778
Block	4	.029	.007	1.000	.5000
Residual	4	.029	.007		

Dependent: Numbers of parasitised soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.077	.077	1.243	.3274
Block	4	.307	.077	1.233	.4220
Residual	4	.249	.062		

Dependent: Numbers of parasitised soft brown scale

Appendix 30.
Analysis of variance table for numbers of parasitised soft brown scale following summer oil application at eight weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.118	.7489
Block	4	.041	.010	1.000	.5000
Residual	4	.041	.010		

Dependent: Numbers of parasitised soft brown scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
TReatments	1	.005	.005	.615	.4766
Block	4	.017	.004	.538	.7182
Residual	4	.031	.008		

Dependent: Numbers of parasitised soft brown scale

Fouteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.098	.098	1.227	.3301
Block	4	.271	.068	.848	.5613
Residual	4	.319	.080		

Dependent: Numbers of parasitised soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.174	.174	2.667	.1778
Block	4	.261	.065	1.000	.5000
Residual	4	.261	.065		

Dependent: Numbers of parasitised soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.174	.174	4.235	.1087
Block	4	.271	.068	1.647	.3203
Residual	4	.165	.041		

Dependent: Numbers of parasitised soft brown scale

Appendix 31.

Analysis of variance table for numbers of predatory mites following summer oil application at one weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.210	.210	2.816	.1687
Block	4	9.999	2.500	33.475	.0025
Residual	4	.299	.075		

Dependent: Numbers of mite

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.018	.018	.007	.9355
Block	4	4.355	1.089	.437	.7790
Residual	4	9.973	2.493		

Dependent: Numbers of mite

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.030	.030	.131	.7358
Block	4	1.877	.469	2.031	.2547
Residual	4	.924	.231		

Dependent: Numbers of mite

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.043	.8459
Block	4	.042	.011	.452	.7698
Residual	4	.093	.023		

Dependent: Numbers of mite

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.102	.102	.992	.3756
Block	4	.727	.182	1.768	.2972
Residual	4	.411	.103		

Dependent: Numbers of mite

Appendix 32.
Analysis of variance table for numbers of predatory mites following summer oil application at two weeks after pruning on November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.083	.083	.849	.4091
Block	4	6.007	1.502	15.390	.0107
Residual	4	.390	.098		

Dependent: Numbers of mite

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	4.020	4.020	11.375	.0280
Block	4	2.506	.626	1.773	.2964
Residual	4	1.413	.353		

Dependent: Numbers of mite

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.081	.081	.374	.5739
Block	4	.769	.192	.888	.5443
Residual	4	.866	.217		

Dependent: Numbers of mite

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.118	.7489
Block	4	.056	.014	1.353	.3883
Residual	4	.041	.010		

Dependent: Numbers of mite

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.019	.019	.176	.6965
Block	4	.592	.148	1.345	.3904
Residual	4	.440	.110		

Dependent: Numbers of mite

Appendix 33.
Analysis of variance table for numbers of predatory mites following summer oil application at four weeks after pruningon November 17, 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	6.757	6.757	588.063	.0001
Block	4	.083	.021	1.814	.2891
Residual	4	.046	.011		

Dependent: Numbers of mite

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	.044	.044	1.831	.2474
Block	4	.192	.048	2.022	.2561
Residual	4	.095	.024		

Dependent: Numbers of mite

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.019	.019	.865	.4050
Block	4	.041	.010	.459	.7651
Residual	4	.090	.022		

Dependent: Numbers of mite

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.180	.180	1.728	.2590
Block	4	1.884	.471	4.532	.0862
Residual	4	.416	.104		

Dependent: Numbers of mite

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	1.421	1.421	7.974	.0476
Block	4	5.787	1.447	8.116	.0335
Residual	4	.713	.178		

Dependent: Numbers of mite

Appendix 34.
Analysis of variance table for numbers of predatory mites following summer oil application at eight weeks after pruning on November 1992 at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.001	.001	.006	.9427
Block	4	1.061	.265	1.282	.4077
Residual	4	.828	.207		

Dependent: Numbers of mite

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.011	.011	1.000	.3739
Block	4	1.267	.317	29.086	.0032
Residual	4	.044	.011		

Dependent: Numbers of mite

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.005	.005	.067	.8082
Block	4	.680	.170	2.160	.2371
Residual	4	.315	.079		

Dependent: Numbers of mite

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.061	.061	.098	.7693
Block	4	13.166	3.292	5.3287	.0670
Residual	4	2.471	.618		

Dependent: Numbers of mite

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	1	.005	.005	.375	.5732
Block	4	.196	.049	3.477	.1274
Residual	4	.056	.014		

Dependent: Numbers of mite

Appendix 35.
Analysis of variance table for numbers of black scale following single application of buprofezin and oil MP.9 on mature stage (December 10, 1992) at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	5.332	1.333	.820	.5730
Block	3	1.224	.408	.251	.8592
Residual	12	19.516	1.626		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	6.372	1.593	.689	.6133
Block	3	2.440	.813	.352	.7886
Residual	12	27.740	2.312		

Dependent: Numbers of black scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	6.860	1.715	1.497	.2642
Block	3	4.822	1.607	1.403	.2898
Residual	12	13.748	1.146		

Dependent: Numbers of black scale

Twenty-eight days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	6.860	1.715	1.497	.2642
Block	3	4.822	1.607	1.403	.2898
Residual	12	13.748	1.146		

Dependent: Numbers of black scale

Fifty-six days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	2196.100	549.025	5.590	.0089
Block	3	530.806	176.935	1.802	.2005
Residual	12	1178.524	98.210		

Dependent: Numbers of black scale

Appendix 36.

Analysis of variance table for numbers of soft brown scale following single application of buprofezin and oil MP.9 on mature stage (December 10. 1992) at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	1.828	.457	.593	.6742
Block	3	1.576	.525	.682	.5799
Residual	12	9.244	.770		

Dependent: Numbers of soft brown scale

Seven days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	5.528	1.382	.976	.4561
Block	3	4.176	1.392	.984	.4331
Residual	12	16.984	1.415		

Dependent: Numbers of soft brown scale

Fourteen days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	29.452	7.363	1.824	.1892
Block	3	6.598	2.199	.545	.6610
Residual	12	48.452	4.038		

Dependent: Numbers of soft brown scale

Twenty-eight days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	207.843	51.961	22.100	.0001
Block	3	19.285	6.428	2.734	.0900
Residual	12	28.213	2.351		

Dependent: Numbers of soft brown scale

Fifty-six days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	4	105.700	26.425	29.329	.0001
Block	3	3.718	1.239	1.376	.2974
Residual	12	10.812	.901		

Dependent: Numbers of soft brown scale

Appendix 37.

Analysis of variance table for numbers of parasitised black scale following single application of buprofezin and oil MP.9 on mature stage (December 10, 1992) at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	3	.006	.002	1.000	.4262
Treatments	4	.008	.002	1.000	.4449
Residual	12	.024	.002		

Dependent: Parasitised black scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	3	.008	.003	.615	.6181
Treatments	4	.012	.003	.692	.6114
Residual	12	.052	.004		

Dependent: Parasitised black scale

Fifty-six day post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	3	.048	.016	2.667	.0951
Treatments	4	.008	.002	.333	.8503
Residual	12	.072	.006		

Dependent: Parasitised black scale

Appendix 38.
Analysis of variance table for numbers of parasitised soft brown scale following single application of Buprofezin and oil MP.9 on mature stage (December 10, 1992) at Kingston.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	3	.022	.007	.386	.7651
Treatments	4	.028	.007	.368	.8266
Residual	12	.228	.019		

Dependent: Parasitised soft brown scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	3	.086	.029	1.536	.2559
Treatments	4	.048	.012	.643	.6422
Residual	12	.224	.019		

Dependent: Parasitised soft brown scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	3	.208	.069	2.237	.1365
Treatments	4	.108	.027	.871	.5092
Residual	12	.372	.031		

Dependent: Parasitised soft brown scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	3	.070	.023	2.800	.0853
Treatments	4	.028	.007	.840	.5258
Residual	12	.100	.008		

Dependent: Parasitised soft brown scale

Appendix 39.
Analysis of variance table for numbers of black scale following single application of buprofezin at different concentrations on immature black scale in Cygnet, 1993.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	5115.760	1705.253	.757	.5576
Block	2	14813.540	7406.770	3.288	.1086
Residual	6	13517.180	2252.863		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	5027.160	1675.720	1.780	.2508
Block	2	8243.287	4121.643	4.378	.0672
Residual	6	5648.660	941.443		

Dependent: Numbers of black scale

Fourteen days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	2708.037	902.679	6.734	.0239
Block	2	5091.947	2545.973	18.993	.0025
Residual	6	804.293	134.049		

Dependent: Numbers of black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	1956.947	652.316	1.795	.2481
Block	2	2329.460	1164.730	3.205	.1130
Residual	6	2180.193	363.366		

Dependent: Numbers of black scale

Eighty-four days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	704.117	234.706	.229	.8730
Block	2	1897.212	948.606	.926	.4462
Residual	6	6147.528	1024.588		

Dependent: Numbers of black scale

One-hundred and forty days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	3	1144.333	381.444	.763	.5548
Block	2	2239.927	1119.963	2.240	.1876
Residual	6	2999.727	499.954		

Dependent: Numbers of black scale

Two-hundred and ten days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	2	.462	.231	.794	.5124
Block	2	2.676	1.338	4.595	.0920
Residual	4	1.164	.291		

Dependent: Numbers of black scale

Appendix 40.

Analysis of variance table for numbers of black scale per sample shoot following three applications of buprofezin, kinoprene and methoprene (Nov. 15, 22 and Dec. 6), two applications of kilval and nuvacron (Nov. 15 and 22), and single application of petroleum oil, confidor and temix (Nov. 15) at Cygnet, 1994.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	21.162	2.645	.526	.8320
Block	7	204.967	29.281	5.822	.0001
Residual	56	281.668	5.030		

Dependent: Numbers of black scale

Fifty-six days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	165.687	20.711	5.726	.0001
Block	7	91.844	13.121	3.627	.0027
Residual	56	202.562	3.617		

Dependent: Numbers of black scale

Eighty-four days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	107.222	13.403	2.361	.0289
Block	7	85.504	12.215	2.152	.0527
Residual	56	317.877	5.676		

Dependent: Numbers of black scale

One-hundred and ninety-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	12296.382	1537.048	2.500	.0214
Block	7	4394.677	627.811	1.021	.4268
Residual	56	34432.141	614.860		

Dependent: Numbers of black scale

Two-hundred and fifty-two days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	3243.964	405.496	5.217	.0001
Block	7	688.905	98.415	1.266	.2837
Residual	56	4352.377	77.721		

Dependent: Numbers of black scale

Appendix 41.
Analysis of variance table for the numbers of new nodes per sample shoot following three applications of buprofezin, kinoprene and methoprene (Nov. 15, 22 and Dec. 6), two applications of kilval and nuvacron (Nov. 15 and 22), and single application of petroleum oil, confidor and temix (Nov. 15) at Cygnet, 1994.

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	3.254	.407	.911	.5139
Block	7	7.751	1.107	2.481	.0272
Residual	56	24.994	.446		

Dependent: Numbers of new nodes

Fifty-six days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	13.329	1.666	1.020	.4316
Block	7	20.276	2.897	1.774	.1108
Residual	56	91.427	1.633		

Dependent: Numbers of new nodes

Eighty-four days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	25.584	3.198	1.098	.3783
Block	7	33.791	4.827	1.658	.1385
Residual	56	163.064	2.912		

Dependent: Numbers of new nodes

One-hundred and ninety-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	172.211	21.526	2.326	.0312
Block	7	96.584	13.798	1.491	.1894
Residual	56	518.296	9.255		

Dependent: Numbers of new nodes

Two-hundred and fifty-two days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	196.278	24.535	3.393	.0030
Block	7	128.448	18.350	2.537	.0243
Residual	56	404.967	7.232		

Dependent: Numbers of new nodes

Appendix 42.
Analysis of variance table for the length of shoot extension (at 252 days post-treatment) per sample shoot following three applications of buprofezin, kinoprene and methoprene (Nov. 15, 22 and Dec. 6), two applications of kilval and nuvacron (Nov. 15 and 22), and single application of petroleum oil, confidor and temix (Nov. 15) at Cygnet, 1994.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	424.889	53.111	3.322	.0035
Block	7	261.443	37.349	2.336	.0364
Residual	56	895.323	15.988		

Dependent: Length of shoot extension

Appendix 43.
Analysis of variance table for numbers of boronia flowers and flower yield (g) per sample shoot following three applications of buprofezin, kinoprene and methoprene (Nov. 15, 22 and Dec. 6), two applications of kilval and nuvacron (Nov. 15 and 22), and single application of petroleum oil, confidor and temix (Nov. 15) at Cygnet, 1994.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	2409.590	301.199	9.673	.0001
Block	7	1371.413	195.916	6.292	.0001
Residual	56	1743.743	31.138		

Dependent: Numbers of boronia flowers

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	8	4.827	.603	8.475	.0001
Block	7	2.200	.314	4.414	.0006
Residual	56	3.987	.071		

Dependent: Flower yield

Appendix 44.
Analysis of variance table for numbers of black scale following single application of petroleum oil and a mixtures of petroleum oil plus IGRs on February 21, 1994 and two applications of IGRs on February 21 and March 21, 1994 at Cygnet.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Black	5	4975.470	995.094	1.990	.1045
Treatments	7	2714.812	387.830	.776	.6118
Residual	35	17503.133	500.090		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	1598.688	319.738	2.998	.0235
Treatments	7	37045.700	5292.243	49.619	.0001
Residual	35	3733.035	106.658		

Dependent: Numbers of black scale

Fourteen day post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	1598.688	319.738	2.998	.0235
Treatments	7	37045.700	5292.243	49.619	.0001
Residual	35	3733.035	106.658		

Dependent: Numbers of black scale

Twenty-eight days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	2758.861	551.772	4.978	.0015
Treatments	7	35454.023	5064.860	45.693	.0001
Residual	35	3879.602	110.846		

Dependent: Numbers of black scale

Fifty-six days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	240.311	48.062	.204	.9588
Treatments	7	23341.524	3334.503	14.129	.0001
Residual	35	8259.945	235.998		

Dependent: Numbers of black scale

Eighty-four days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	240.311	48.062	.204	.9588
Treatments	7	23341.524	3334.503	14.129	.0001
Residual	35	8259.945	235.998		

Dependent: Numbers of black scale

One-hundred and fifty-four days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	329.456	65.891	1.098	.3790
Treatment	7	8908.715	1272.674	21.206	.0001
Residual	35	2100.519	60.015		

Dependent: Numbers of black scale

Appendix 45.

Analysis of variance table for number of new nodes following a single application of petroleum oil and a mixtures of petroleum oil plus IGRs on February 21, 1994 and two applications of IGRs on February 21 and March 21, 1994, at Cygnet.

Fourteen days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	.381	.076	1.442	.2339
Treatments	7	1.400	.200	3.784	.0037
Residual	35	1.850	.053		

Dependent: Numbers of new nodes

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	.281	.056	1.001	.4317
Treatments	7	2.355	.336	5.989	.0001
Residual	35	1.966	.056		

Dependent: Numbers of new nodes

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	1.942	.388	.969	.4498
Treatments	7	10.922	1.560	3.894	.0031
Residual	35	14.024	.401		

Dependent: Numbers of new nodes

Eighty-four days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	6.285	1.257	1.413	.2438
Treatments	7	18.316	2.617	2.940	.0157
Residual	35	31.146	.890		

Dependent: Numbers of new nodes

One-hundred and fifty-four days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	17.221	3.444	2.528	.0469
Treatments	7	18.904	2.701	1.983	.0857
Residual	35	47.677	1.362		

Dependent: Numbers of new nodes

Two-hundred and twenty-four days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	5	17.773	3.555	2.565	.0444
Treatments	7	36.315	5.188	3.744	.0040
Residual	35	48.495	1.386		

Dependent: Numbers of new nodes

Appendix 46.

Analysis of variance table for the length of shoot extension at harvesting time (224 days post-treatment) following single application of petroleum oil and a mixture of petroleum oil plus IGRs on February 21, 1994 and two applications of IGRs to boronia on February 21 and March 21, 1994 at Cygnet.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	7	22.452	3.207	.895	.5214
Treatments	5	109.697	21.939	6.119	.0004
Residual	35	125.487	3.585		

Dependent: Length of shoot extension

Appendix 46.
Analysis of variance table for numbers of boronia flowers and flower yield (grm) per sample shoot (224 days post-treatment) following a single application of petroleum oil and a mixtures of IGRs plus petroleum oil on February 21, 1994 and double application of IGRs on February 21 and March 21, 1994 at Cygnet.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	7	1422.982	203.283	9.142	.0001
Block	5	1188.746	237.749	10.692	.0001
Residual	35	778.251	22.236		

Dependent: Numbers of boronia flowers

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	7	2.351	.336	9.047	.0001
Block	5	3.016	.603	16.251	.0001
Residual	35	1.299	.037		

Dependent: Flower yield

Appendix 47.
Analysis of variance table for numbers of black scale following single application of petroleum oil at different concentrations on February 21, 1994 at Cygnet.

Pre-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	1473.996	294.799	.404	.8424
Block	7	9972.267	1424.610	1.955	.0901
Residual	35	25510.361	728.867		

Dependent: Numbers of black scale

Seven days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	57256.584	11451.317	57.047	.0001
Block	7	924.027	132.004	.658	.7057
Residual	35	7025.715	200.735		

Dependent: Numbers of black scale

Fourteen days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	41329.023	8265.805	32.297	.0001
Block	7	703.679	100.526	.393	.9002
Residual	35	8957.500	255.929		

Dependent: Numbers of black scale

Twenty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	58211.875	11642.375	55.970	.0001
Block	7	1194.615	170.659	.820	.5770
Residual	35	7280.440	208.013		

Dependent: Numbers of black scale

Fifty-six days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	46327.755	9265.551	135.858	.0001
Block	7	1058.289	151.184	2.217	.0565
Residual	35	2387.011	68.200		

Dependent: Numbers of black scale

Forty-eight days post-treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	44204.720	8840.944	56.039	.0001
Block	7	1040.856	148.694	.943	.4871
Residual	35	5521.764	157.765		

Dependent: Numbers of black scale

Appendix 48.
Analysis of variance table for numbers of new nodes following a single petroleum oil application at different concentrations to boronia plants on February 21, 1994, at Cygnet.

Fourteen days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	.932	.186	3.389	.0133
Block	7	.247	.035	.643	.7176
Residual	35	1.925	.055		

Dependent: Numbers of new nodes

Twenty-eight days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	2.307	.461	5.056	.0014
Block	7	.465	.066	.727	.6499
Residual	35	3.194	.091		

Dependent: Numbers of new nodes

Fifty-six days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	5	9.357	1.871	5.788	.0005
Block	7	3.688	.527	1.629	.1597
Residual	35	11.317	.323		

Dependent: Numbers of new nodes

Eighty-four days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	24.455	4.891	7.626	.0001
Block	7	4.726	.675	1.053	.4137
Residual	35	22.448	.641		

Dependent: Numbers of new nodes

One-hundred and fifty-four days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	42.598	8.520	8.268	.0001
Block	7	8.816	1.259	1.222	.3169
Residual	35	36.063	1.030		

Dependent: Numbers of new nodes

Two-hundred and twenty-four days post treatment

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	54.440	10.888	5.819	.0005
Block	7	26.012	3.716	1.986	.0852
Residual	35	65.492	1.871		

Dependent: Numbers of new nodes

Appendix 49.
Analysis of variance table for the length of shoot extension of boronia at harvesting time (224 days post-treatment) following single application of petroleum oil at different concentrations in February 21st, 1994 at Cygnet

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatments	5	109.697	21.939	6.119	.0004
Block	7	22.452	3.207	.895	.5214
Residual	35	125.487	3.585		

Dependent: Length of shoot extension

Appendix 50.
Analysis of variance table for numbers of boronia flowers and flower yield per sample shoot at harvesting time following (224 days post-treatment) single application of petroleum oil at different concentrations in February 21, 1994 at Cygnet

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	7	594.101	84.872	4.292	.0016
Treatments	5	2248.534	449.707	22.744	.0001
Residual	35	692.035	19.772		

Dependent:Number of boronia flowers

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Block	7	.977	.140	1.645	.1552
Treatments	5	4.339	.868	10.226	.0001
Residual	35	2.970	.085		

Dependent: Flowers yield