SURVEY OF THE ARTHROPOD COMPLEX AND MONITORING AND MANAGEMENT OF HOMOPTERAN PESTS OF CITRUS (*CITRUS SPP*) AND THEIR NATURAL ENEMIES

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DECLARATION

DECLARATION BY THE CANDIDATE

This thesis is my original work and has not been presented for a degree in this or any other University

..........................11\8\04

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DECLARATION BY SUPERVISORS

This thesis has been submitted for examination with our approval as supervisors

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Signed.. Date...Aug 12, 2004...

Dr. S. D. Obukosia

DEDICATION

To my husband Joseph Ngeranwa and my children Faith, Grace, Patience and Wisdom for their understanding and prayers made for me

I will go before you
and will level the mountains;
I will break down gates of bronze
and cut through bars of iron.
I will give you the treasures of darkness,
riches stored in secret places,
so that you may know that I am the Lord,
the God Almighty, who summons you by name. **Isaiah 45:2-3**

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May God bless you!

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ABSTRACT

Citrus production in Kenya is hindered by several constraints. These include pests and diseases, inadequate disease-free planting materials, drought, low soil fertility and poor orchard management in order of decreasing importance. This study was undertaken to determine important pests of citrus and their natural enemies, to monitor the seasonal fluctuations of major homopteran pests and to evaluate the efficacy of various pesticides on homopteran pests in the farmers' fields.

To determine important pests of citrus, a survey was conducted using a structured questionnaire administered to 63 citrus farmers drawn from three major agro-ecological zones present within Bungoma and Machakos districts. This was followed by an on-spot assessment of insect species on randomly selected citrus trees in each farm. To monitor the seasonal population fluctuations, four randomly selected farms in two locations, Upper midlands (UM) and Lower midlands (LM) zones were used. In each farm, four citrus trees were marked for monitoring homopteran pests and the natural enemies fortnightly for two seasons. In the same zones, three orchards were used to evaluate the efficacy of selected pesticides on the homopteran pests. Pesticides used included Metasystox (Oxydementon methyl), Confidor (Imidacloprid), DC Tron (petroleum spray oil) and a mixture of Metasystox and DC Tron. These were applied as foliar or soil drench and in two regimes fortnightly or monthly applications. Homopteran pests were counted fortnightly in the experiment.

A hundred and seventeen insects species were found associated with the citrus plants. Eighty-seven of them were pests while 30 were their natural enemies. The most important pest species were citrus whiteflies, citrus psyllids, aphids, blackflies, scale insects, leafhoppers, and leaf miner. All were widely distributed in the three agro-ecological zones. The natural enemy complex comprised of the spiders, coccinellids, chrysopids, mantids, tachnids, syrphids and reduviid bugs. However, important and conspicuous natural enemies were the spiders and the coccinellids. Farmers relied on their own knowledge to make pest management decisions; hence the pest control strategies applied were inadequate. Monitoring showed that homopteran pest populations varied with seasons and location. Whitefly, aphid and citrus psyllid populations significantly fluctuated with seasons ($P<0.05$) whereas aphid, blackfly and citrus psyllid populations significantly varied with location ($P<0.05$). The insect pest load was heaviest during the vigorous flush growth periods, which were preceded by rainfall and the loads were light during the hot and dry months. Treatment schedules significantly reduced the pest populations and the natural enemies ($P<0.001$). Metasystox schedules had the least populations, particularly in the UM zone. Their effect was, however, not different from Confidor and DC Tron schedules, which effectively lowered homopteran pest populations. Soil drench and foliar methods of applications did not differ nor did the fortnightly and monthly regimes of applications in their effect on homopteran pests.

The findings have shown that citrus are associated with many insect species. Some of the pests observed are known vectors of diseases pointing to the need for effective pest management to prevent the spread of diseases. The rich diversity of natural enemies dominated by the spiders and coccinellids indicates that the pests are under some form of natural control. Natural enemies require conservation to play a significant role in suppressing pest populations. Flush growth identified as the critical period for protection of citrus should be the target of any pest control strategy to prevent increases of pest populations. Pesticides demonstrated to effectively reduce pest populations in the farmer's fields could be used as a component of an Integrated Pest Management (IPM) strategy of citrus pests. Monthly schedules of Confidor or DC Tron as soil drench and foliar applications, respectively, would help optimise the use of synthetic pesticides while conserving natural enemies. An IPM strategy utilizing scouting and judicious use of insecticides among other components would help citrus farmers to deal effectively with insect pest problems in their orchards. Farmers need training on insect pest and natural enemy identification as well as effective use of pesticides to help bridge the knowledge gap identified in crop protection practices among them.

CHAPTER ONE

1.0 INTRODUCTION, LITERATURE REVIEW AND GENERAL MATERIALS AND METHODS

1.1 GENERAL INTRODUCTION

1.1.1 The Citrus plant

1.1.1.1 Taxonomy and morphology

Citrus is one of the major fruit crops of the world. Citrus fruits are second only to the apple in world trade and have been cultivated and enjoyed for over 4000 years (Chapot, 1975; Samson, 1986). Citrus species belong to the order Geraniales and family Rutaceae (Davies and Albrigo, 1994). The species are members of the tribe citreae, which contains the 'true' citrus group of six genera that include *Citrus, Poncirus, Eremocitrus, Microcitrus, Fortunella and Clymenia* (Davies and Albrigo, 1994). Although there is controversy between Swingle (1948) and Tanaka's (1977) taxonomic system, it is generally agreed that eight species/cultivars of citrus are cultivated. These include sweet orange (*Citrus sinensis* (L.) Osbeck), sour orange (*C. aurantium* Osbeck), mandarin (*C. reticulata* Blanco), grape fruit (*C. paradisi* Macf.), lemon (*C. limon* (L.) Osbeck), lime (*C. aurantifolia* Swingle), shaddock (*C. grandis* Osbeck) and citron (*C. medica* Swingle) (Chapot, 1975; Samson, 1986; Davies and Albrigo, 1994; Smith *et al.*, 1997).

Citrus is primarily an evergreen plant that grows up to 4-8m tall (Barden *et al.*, 1987). Its size control is achieved through two major types of pruning cuts: that is heading back and thinning (Boegler, 1967; Samson, 1986). Tree shapes vary from upright to spreading. Leaves are unifoliate with lamina ranging from very large to small. Petiole size varies with species in the same manner to leaf size. Flowers are borne singly or in groups in leaf axils and may either be perfect or stamminate. Flowers have 4-5 sepals, 4-8 petals, 20-40 fused stamens, and 8-15 carpels with 4-8 ovules in seedy cultivars. The fruit, a hesperidia berry, consists of a single ovary of fused carpels surrounded by a leathery peel. Fruit shape varies from spheroid to oblate to prolate. Peels contain numerous oil glands and vary in colour from green-yellow to red-orange and deep orange. Seeds are obovoid to round in shape and contain one to many embryos and cotyledon colours vary from white to green (Davies and Albrigo, 1994).

1.1.1.2 Origin and Distribution

The natural environment of the true citrus group is a large Asiatic region stretching from India to China in the northwest to Australia and New Caledonia in the southeast. Its worldwide dissemination has been associated with many of the great explorations and conflicts in history such as that of Alexander the great, spread of Mohammedanism and he explorations of Columbus to the then new world. Travellers and missionaries also layed a role in the spread of citrus from its origin (Davies and Albrigo, 1994; Hill and aller, 1996). Currently, it is cultivated throughout the subtropics and tropics between e latitudes 40°N and 40°S where temperatures seldom go below 5°C. The northern and thern Mediterranean regions, northern and southern regions and associated Islands of American continent, China, Japan, South Africa and Australia are the major mercial production regions of citrus. Brazil is the largest citrus producer worldwide. ever, all tropical countries and marginally tropical countries produce citrus from backyard plantings or small farms, which is sold locally (Davies and Albrigo, 1994). Since the orchards are perennial (permanent) they provide a good environment for many arthropods.

1.1.2 The Citrus Industry in Kenya

Citrus production in Kenya is ranked third after bananas and mangoes (MOARD, 2001; Waithaka and Obukosia, 1988). It is grown in a range of regions from the coastal belt (sea level) through to the Kenyan highlands (>2000m a.s.l). These areas include Kilifi, Kwale, Makueni, Machakos, Thika, Nakuru (Naivasha), Kericho, Siaya, Busia, Trans Nzoia and Bungoma districts (MOA, 1992). These areas offer a wide environmental variation due to changes in altitude, rainfall, natural vegetation and soil types (Gonzalez, 1980; Jaetzold and Schimdt, 1983). With the exception of a few large plantations, small-scale farmers mainly grow citrus on a citrus area ranging in size from 0.5-3 hectare (Seif, 1996). Although there are many species of citrus cultivated, the sweet orange (*C. sinensis* (L.) Osbeck) accounts for 70% of the total citrus grown in Kenya. The popular cultivars are Valencia 'late' and Washington 'navel'. Other species grown are lemons, limes, mandarins and grape fruits in order of decreasing popularity (MOA, 1992). Since citrus production is mainly under small scale holdings, the orchards are largely intercropped with other crops such as maize, pigeon peas, irish potatoes, beans, vegetables (pepper, kales and onions). They are established adjacent to cropped land and also intermingled with natural vegetation. These conditions allow for continued sheltering and provision of food for both pests and natural enemies. Furthermore, the agro-ecosystem boundaries extend beyond the particular acreage devoted to citrus. The agro-ecosystem includes adjacent crops, hedges, weed patches and intermingling natural vegetation. This pattern directly or indirectly influences the composition and balance of the pest and natural enemy complex (Gonzalez, 1980).

The area under citrus cultivation is about 16,500 hectares with an annual production of 170,000 tons of fruit valued at 1.1 million US dollars (MOA, 1999; Waithaka and Obukosia, 1988). Production at the farm level ranges from 4-10 tons per hectare, far much below the 50 tons per hectare yields potential reported in countries where Integrated Pest Management (IPM) is practiced (FAO, 1996a). Production in quantity and quality has never been sufficient to meet the demand of citrus in the country. This has necessitated the importation of large quantities of citrus and its products into the country.

1.1.3 Citrus production constraints in Kenya

Various constraints hinder citrus production. These include pests and diseases, inadequate capital, inadequate disease-free planting materials, drought/water stress, low soil fertility and poor orchard management in order of decreasing importance (Obukosia *et al.*, 1999). Major insect pests reported to cause damage on citrus in Kenya are false codling moth, aphids, fruit flies, blackflies, whiteflies, orange dog and mites (Le Pelley, 1959; Gonzalez, 1980; Farell *et al.*, 1995; Mailu, 1996). Diseases of importance are Huanglongbing disease (citrus greening) (HLB), *Phytophthora* related gummosis, cercospora fruit and leaf spot (*Phaeomullaria spp*), scab and psorosis (Seif and Whittle, 1984; Seif and Hillocks, 1993). Incidence of various insect pests and diseases and bad orchard management, have resulted into a downward trend of citrus production. By 1991, HLB was reported to be wide spread throughout all highland citrus growing areas above 800m rendering approximately 25% of the total citrus trees unproductive (KARI, 1991).

There is however, scope for improving production and quality of local citrus. The citrus sector still presents good employment opportunities, a good source of income, capacity to develop agro-industries as well as contributing to the nutritional well being of the Kenyan people. It can play a role in poverty alleviation among the rural poor, a priority policy being fostered by the Kenya government.

1.1.4 Problem statement and Justification

Citrus is the third most important fruit crop in Kenya. Its production is a source of income to the small-scale farmers, a source of employment to the rural population and is also used as food. It has a potential of alleviating poverty in the rural areas. However, on-farm citrus yields are low. A Participatory Rural Appraisal (PRA) conducted in 1998 revealed various constraints that hinder citrus production. These included pests and diseases, inadequate capital, inadequate planting materials, poor orchard management in order of decreasing importance (Obukosia *et al.*, 1999). Through assistance from the Netherlands government (Biotechnology Trust Africa), the faculty of Agriculture of the University of Nairobi has undertaken mass production of disease free planting materials through tissue culture technology. However, there is scanty information concerning the pests of citrus hindering on-farm production and their management. Therefore, these studies were undertaken to contribute information that would help re-habilitate the citrus industry and improve production in Kenya.

1.1.5 OBJECTIVES

1.1.5.1 Overall objective

The overall objective of the study was to develop pest management strategies to control citrus insect pests for increased citrus production and integrate the resource poor farmers into the cash economy. The results would contribute to the national goal of alleviating poverty among the rural population.

1.1.5.2 Specific objectives

The specific objectives were

a) To collect, identify and estimate the relative abundance of pests and the beneficial insects associated with citrus insect pests under different agro ecological zones.

b) To monitor the seasonal population trends of the homopteran pests that includes the citrus psyllid (*Trioza erytreae*), the vector of HLB, and their natural enemies.

c) To determine the effect of insecticides on the homopteran pests and their natural enemies.

1.1.6 Hypotheses

1) Current pest management practices do not control citrus insect pests within citrus orchards.

2) Seasonal variations do not affect homopteran pest populations infesting citrus orchards.

3) Routine insecticide application does not effectively control homopteran pests of citrus.

1.2 LITERATURE REVIEW

1.2.1 Effects of pests on crop production

Crop pests interacting with other environmental conditions, play a major role in limiting crop production. These contribute to crop losses that are estimated to be 30% by the Food and Agricultural Organization of the United Nations (FAO, 1996b). Africa is deprived of its food security by pathogens, arthropods and weeds. Around 50% of the crop yield is lost in the field and a further 10-20 % is lost post-harvest. Resource poor farmers suffer more seriously because often they cannot afford to control the pests and are vulnerable to the loss of food and income (CAB, 2002). This percentage crop loss needs to be minimised, although the challenges are increasing as new pests are recognised and older technologies for their control are no longer acceptable.

1.2.2 Pests and diseases of citrus

The chief enemies to plant health are pests and diseases (Boegler, 1967). Weeds, arthropods, nematodes, insect pests and pathogens are major biotic constraints to citrus worldwide. They are reported to be the cause of many problems that result in almost complete economic loss or alteration of the citrus industry (Davies and Albrigo, 1994).

1.2.2.1 Weeds

Weeds mainly compete for nutrients and water. Severe weed pressure may reduce yields (Jordan, 1981) while competition of weeds with young trees can cause significant reduction in growth and development (FAO, 1996a).

1.2.2.2 Parasitic nematodes

Parasitic nematodes belonging to six genera have been reported to attack citrus (Duncan and Cohn, 1990). However, the citrus nematode (*Tylenchulus semipenetrans* Cob.) is the most widespread. The citrus nematode is reported to be widespread and common in citrus in Florida (US), South and Central America and the Mediterranean Basin (Lo Guidice 1981). Four biotypes of this nematode exist worldwide. There are no records of work done on the nematode here in Kenya.

1.2.2.3 Diseases

Diseases are a serious limitation to profitable production of citrus in otherwise suitable environments (Davies and Albrigo, 1994). Important diseases of citrus include tristeza, Huanglongbing (HLB) disease, citrus canker, brown rot/foot rot (gummosis), stubborn disease, fruit and leaf spots, Armillaria root rot, exocortis and psorosis (Whittle, 1992). They are caused by pathogens that include bacteria, fungi, mycoplasmas and viruses. In Kenya important diseases are HLB, phytophthora associated gummosis and cercospora fruit and leaf spot diseases (Seif and Whittle, 1984; Seif and Hillocks, 1993).

1.2.2.4 Insect pests of citrus

Insect pests are one of the most important constraints of citrus production in the world. Many workers have shown that citrus supports a number of insects (Hill, 1975; Gemini, 1977; Albrigo, 1978; Singh, 1983; Vyas, 1994; Kfoury and El-Amil, 1997; Smith *et al.*, 1997; Kalita, 1998). Eberling (1959) compiled a list of over 875 species of insects and mites reported to feed on citrus in different parts of the world. In Australia, a hundred different pest species have been reported (Smith *et al.*, 1997). These insects are classified as 'major', 'occasional' or 'minor'. Seventy-two of these insect species associated with citrus have been reported to be major in different areas of the world where they occur (Talhouk, 1975). However, major pests vary in importance in space and time. This range of insects is largely determined by the climatic conditions in the area where the citrus is grown (Davidson, 1979; Ram and Pathak, 1987). Hence occurrence and level of the insect pest populations varies from area to area and season to season (Smith *et al.*, 1997). Similarly, attacks, which are damaging in some areas, may hardly be known in others (Samson, 1977). Knowledge about the insect complex of citrus and their relative importance in Kenya is scanty.

Several insect species are associated with each of the above ground parts of the citrus tree namely: the flowers, fruits, foliage, twigs and branches. Majority are sucking insects. These cause extensive damage to the growing crops lowering both yield and quality. Flowers provide a short-term substratum of colonisation by insects whose feeding on petals and developing fruit-lets lead to fruit scarring and drop. Fruit development and growth provides another stage where insects feed on and within the fruits. Such insects lower the cosmetic appearance of the fruits rendering mature fruits unmarketable so long as they are infested. Leaves are another suitable substrate for many insect species, which utilise the leaves throughout the growth and protracted life span on the trees. Twigs, branches and trunk also host several groups of insects that feed on wood and those that feed on the outer bark cells (Browning, 1999). Pests also attack citrus roots. The root weevil larvae that cause extensive damage to citrus attacks the roots particularly the young trees because of girdling of the trunk or the primary shoots (Futch and McCoy, 1992). Termites also have been reported to cause young tree losses on recently cleared land (Stanlsy *et al.*, 1991).

Some insect species such as aphids, sharp shooters (leafhoppers) and psyllids not only inflict direct damage by feeding on citrus leaves but also transmit pathogens (Browning, 1999). Most of these species have been reported to infest newly emerging foliage as primary feeding sites, although, populations can be sustained on mature leaves and twigs. Vector populations; vary over time (fluctuate) with citrus tree phenology and variable flushing patterns. However, disease transmission often occurs during colonisation and during periods when vectors move among trees or from orchard to orchard (Browning, 1999).

1.2.2.4.1 Homopteran insects damage on citrus

Deluchi (1975) reported fruit flies, scale insects, whiteflies and mites as important groups of citrus pests worldwide. All are sucking insects except the fruit flies. The plant-sucking insects of the suborder homoptera are a diverse assemblage. They include leafhoppers (Cicadellidae), plant hoppers (Delphacidae), psyllids (Psyllidae), whiteflies and black flies (Aleyrodidae), aphids (Aphididae), scale insects (Coccidae and Diaspididae) and mealy bugs (Pseudococcidae). These are devastating insect pests of perennial crops, particularly citrus (Samways, 1981).

1.2.2.4.2 Scale insects (Coccidae and Diaspididae)

These are oligophagous to polyphagous insects, which congregate in groups. Through sucking, the scales extract plant sap and inject toxic saliva into plants. They also excrete a lot of honeydew on which the sooty mould fungus develops. A severe attack cause discolouration of the leaves, kills branches, deforms fruits and may result in fruit shedding. Trees become black and their assimilation surface is reduced. Plant vigour is also reduced (Deluchi, 1975; Lamb, 1974).

1.2.2.4.3 Whiteflies and blackflies (Aleyrodidae)

These are polyphagous insects. They suck plant sap from tender leaves especially those of vigorous sprouts. Their nymphs excrete honeydew, which favours the development of sooty mould fungus. Their damage is confined to the leaves. Infested trees are weakened. Severe infestation may lead to defoliation, loss of fruits or dwarfing of the tree. The insects are occasionally serious pests (Lamb, 1974; Knapp and Browning, 1989; Berg, 1999).

1.2.2.4.4 Citrus psyllids (Psyllidae)

These insects are sap feeders infesting the young succulent leaves that are utilized throughout the growth and their life span on the tree. During infestation, they form conspicuous bumps on the upper leaf surface. Heavy infestation may lead to leaf deformation and leaf fall. The long-term effect is reduced foliage production and structural damage to the twigs. The pests are not important on mature trees. However, the main importance of the citrus psyllid is as a vector of the serious HLB disease (greening) of citrus caused by *Liberobacter species* (Aubert, 1987; EPPO/CAB, 1997).

1.2.2.4.5 Aphids (Aphididae)

Aphids are phloem feeders, which often colonize the first flush growth in any growing cycle, with high intensity that gives no chance to prevent damage to foliage, twigs, and bloom due to their feeding action. They suck the nutrients, deforming the twigs and leaves. Severe infestations may lead to death of the growing points. A number of aphid species are known vectors of disease pathogens. Species such as *Toxoptera aurantii* (Fonscolombe), *Toxoptera citricidus* (Kirkaldy), *Aphis gossypii* (Glover) and *Aphis spireacola* (Quaint) are reported to be vectors of tristeza virus (Yokami and Garnsey, 1987; Rocha-Pena *et al.*, 1995). The most efficient species among these is the brown citrus aphid, *T. citricidus*. The aphids, *T. citricidus, T. aurantii* and *A. spireacola* are also vectors of psorosis (Portillo and Bena-tena, 1989). *Toxoptera citricidus* is capable of developing high populations that cover feathery young flush or young trees and reduce tree growth and development (Lee *et al.*, 1992). The populations increase very fast with a reproduction time as short as four days in warm weather and up to ten days in cool periods. Temperature and the incidence of natural enemies are key factors that affect aphid population densities (Portillo, 1989).

1.2.3 Beneficial insects associated with citrus insect pests

In addition to destructive insect species, there are numerous beneficial insects associated with insect pests of citrus (Smith *et al.*, 1997). The efficiency and potential importance of these in checking destructive pest species has not been demonstrated in Kenya.

1.2.3.1 Predators

Clausen (1940) reported that in a crop that has not been sprayed with pesticides various predatory members are expected. These include mites (Acarina: Phytoseiidae), spiders (Araneida), lacewings (Neuroptera: Chrysopidae), ground beetles (Coleoptera: Carabidae) staphylanid beetles (Coleoptera: Staphylanidae), ladybird beetles (Coleoptera: Coccinellidae), hover fly larvae (Diptera: Syrphidae) and some bugs (Heteroptera) of the families Nabidae, Anthocoridae, Reduviidae and Pentatomidae. Though all orders containing predatory insects are important, the Coleoptera, Neuroptera, Diptera and Heteroptera contain families that have so far been of major importance in biological insect pest suppression (Coppel and Mertins, 1977; Hill, 1997). In his book Moreton (1968) reported that capsid and related bugs, dragonflies and coccinellid beetles constitute an important group of common predators in Europe. Hemipteran bugs (Pentatomidae, Reduviidae, Nabidae and Anthocoridae) feed on immature stages of phytophagous insects especially small caterpillars and insect eggs (Horn, 1988). In central Tanzania, Bohlen (1973) recorded Assassin bugs, *Phonoctonous spp* (Reduviidae) as predators of plant pests such as (*Dysdercus spp*). The predatory bugs are distinguished from the plant-sucking bugs by their curved proboscis and slender head with a conspicuous 'neck'.

Ladybird beetles (Coccinellidae) that are recognized by their bright colours are predators, adults as well as larvae (DeBach, 1974; Samways, 1981; Smith *et al.*, 1997; Amitava, 1998). They have been reported as invaluable for controlling many citrus insects such as scale insects, mealy bugs, aphids, whiteflies, blackflies and mites (Hodek, 1986; Samways, 1981; Samways and Grech, 1984; FAO, 1996a; Hill, 1997; Amitava, 1998). Alongside hymenopterans, they have proved invaluable for controlling many scales and mealy bugs particularly at high-density pest populations (Samway, 1981). However, Bohlen (1973) claimed that the efficiency of these beetles might be reduced if ants attend the pests. Some coccinellids recorded as predators are *Cheilomenes sulpurea* F., *C. lunata* F., *C. sexmaculata* F., *C.vicina* Muls., *Chilocorus nigritus* Muls., *C. septempunctata* Muls. *C.distigima* F., *C.wahlbergi* F., *Platynapsis vittigera* Muls., and *Schymus morelleti* Thunberg (Bohlen, 1973; FAO,1996a; Samways, 1981; Smith *et al.*,1997; Amitava,1998). Ground beetles (Carabidae) are reported to feed on caterpillars. The *Calosoma* species (Carabidae) have an impact against the defoliators of forest tree (Thiele, 1977).

The praying mantids (Mantidae) are large and attractive predators. They feed on almost any living insect, both destructive and beneficial insects. Their value as beneficial insects is thus questionable (Horn, 1988). All spiders (Araneida) are reported to be predacious and probably impact on many pest populations. Riechert and Lockley (1984) suggested that the impact of the entire community is likely to be beneficial and should be encouraged. Amalin *et al.* (1996) evaluated the role of spiders as predators of pests on limes. Dipeenar-Schoeman and Berg (2001) demonstrated the spiders as an important component of the natural enemy complex, while Al-Ghamdi (2000) demonstrated the potential of the spider complex as a candidate for biological control against the Asian citrus psyllids, *Diaphorina citri* Kuwayama. Nevertheless, their important role as predators has not been recognized fully (Hill, 1990). Lacewings feed on mealy bugs, scales, mites, aphids, moths and butterfly eggs. They have a wide range of prey (Samways, 1981). Spiders, lacewings, some predatory mites, assasin bugs and mantids, because of feeding on a wide variety of prey species are said to be generalist feeders (Samways, 1981). The predatory efficiency of these insect species is yet to be investigated in Kenya.

1.2.3.2 Parasitic insects (parasitoids)

The Hymenoptera and Diptera orders of insects have a large number of parasitic insects (DeBach, 1974). The hymenoptera (Vespidae and Sphecidae) parasitize larval lepidoptera and flies among the insects. When common, they are reported to reduce the number of caterpillars (Lawson *et al.*, 1961). Some ants (Formicidae) are also predaceous to pests (Horn, 1988). The most significant and best known parasites of citrus pests are wasps (Hymenoptera) or flies (Diptera) (Smith *et al.*, 1997). These parasites develop as larvae inside the body tissue of the hosts or feed on the body tissues of the host from outside (Bohlen, 1973; Moreton, 1968; Smith *et al.*, 1997). Parasitic (wasps) hymenoptera have been recorded as some of the most abundant and efficient natural enemies of all fruit pests (Viggiani, 2000). Majority of the parasitoids in the citrus agro ecosystems with some exceptions are native species. Their different habits allow them to attack the hosts in almost all stages. However, their role is rather variable in relation to the type of the agroecosystem (Rosen, 1993). It is reported that important species belong to the ichneumonoidea, chalcidoidea and proctotrupoidea (Rosen, 1993). The ichneumons parasitize large pests (larvae/caterpillars) and the braconids particularly the aphidiinae, are important parasites of aphids. The chalcids constitute the largest group, which includes the aphelenidae, encytridae, eulophidae and trichogrammatidae. They are among the active parasitoids of several pest species such as the psyllids, aphids, scale insects, whiteflies and the blackflies (Smith *et al.*, 1997; Viggiani, 2000). Of the proctotrupoidea, the scelionidae (egg-parasitoid) and the platygastrid genus, play a major role in regulating pest species such as the whiteflies and the black flies (Rosen, 1993). Waterhouse (1998) has recorded several parasitoids of pests in south East Asia. Smith *et al.* (1997) have a comprehensive list of predators and the parasites of citrus pests compiled from a range of published references and field collections.

Flies (Diptera) have been recorded attacking many of the plant pests. For example, some hover flies (Syrphidae) and Cecidomyidae larvae are important predators of aphids (Samways, 1981). Females lay eggs among their prey, aphids in particular, so that the maggots emerge close to their food (Bohlen, 1973; Smith *et al.*, 1997). Tachnids (Tachnidae) are parasites of large insects pests mainly caterpillars. These include American bollworm, cutworms, armyworms, orange dog, plant bugs, beetles and locusts (Bohlen, 1973). The females deposit eggs or young larvae, depending on the fly species, either on the body of the host or on leaves. The host then eats the eggs or larvae. The maggots penetrate into the hosts' tissues but avoid vital organs until the parasite is ready for pupation (Bohlen, 1973).

1.2.4 Control / Management options

Several options for controlling pests are available. These include cultural control, biological control, chemical control, use of resistance varieties and integrated pest management.

1.2.4.1 Chemical control

Since citrus orchards are perennial, they harbour a wide range of insect and mite pests within the orchard environment. Chemical control is one of the main components of crop protection used to prevent serious damages because of the large numbers of insect pests involved. It has been widely practised by citrus producers in the world (Davies and Albrigo, 1994). However, chemical control has shown varying degrees of success in field management of insect pests. In Kenya, pesticides have been recommended for the control of citrus pests as well (Beige *et al.*, 1984). Among the recommended chemicals for use on citrus in Kenya are dimethoate, diazinon, fenitrothion, endosulfan and synthetic pyrethroids such as lambda cyhalothrin and alpha cypermethrin. While pesticides are powerful tools to use against pests (Smith *et al.*, 1997) the indiscriminate use of chemical pesticides is unwise (Bishop *et al.*, 1983). The chemicals destroy both destructive and beneficial insects. Continued calendar use of pesticides, particularly, broad-spectrum types, lead to the development of resistance of pests to chemicals and increased costs of developing and producing other pesticides products (Pimmentel *et al.*, 1984).

Environmental contamination, pesticide residues on and in fruit and potential health hazards to the farmers and workers are other problems that arise as a result of regular pesticide use (Croft, 1990; Pimbert, 1991).

Virtually, all classes of insecticides have been used for the control of insect pests of citrus (Gravena *et al.*, 1988; Theiling and Croft, 1988; Croft, 1990; Bedford *et al.*, 1992; Dahiya *et al.*, 1994). These include organochlorines, organophosphates, carbamates, synthetic pyrethroids, botanicals, and bio-pesticides. All have had varying efficacy with specific chemicals being recommended in most major production areas (Davies and Albrigo, 1994). Since most of the citrus insects are sucking insects, Viggiani (2000) has reported their effective control using systemic insecticides. The insect complex on citrus poses diverse and unique requirements for pesticide application (Carman, 1975). Many approaches to pesticide applications in orchards have been implemented. These were determined by the ability to allow the distribution of pesticides to exert maximum pressure/impact on the pest species. The methods used include foliar sprays, dusting, injections on to the trunk and soil drenching. However, foliar spraying is the most commonly used method of spraying (Carman, 1975; Beattie, 2000). As a result, a lot of non-target organisms are affected. Public concerns about the safety of pesticides and other chemical residues on fresh or processed horticultural products are forcing the production industry to develop or use pest management practices that require fewer chemical inputs (Roberts and Stanley, 1993). Because of the concerns for public safety and awareness of the risks of environmental contamination, efforts are mounting to increase pesticide regulation. Therefore, there is increased interest in IPM systems designed to reduce pesticide applications (Dent, 2000). There has been no deliberate effort directed towards utilizing IPM in the management of citrus pests in Kenya.

1.2.4.2 Biological control

Biological control is the use of natural enemies either exotic or indigenous to control pests. It is an alternative method that can help reduce dependency on pesticide. The technique is selective with no side effects, is cheap and self-propagating. Development of resistance of pests to biological control is unlikely (Emden, 1990; Hoy, 2000). The method also meets environmental health concerns regarding the use of pesticides on foods.

Biological control is one of the oldest methods of pest control involving the use of other animals as carnivores to reduce pest numbers. It has a long history in citrus (Browning, 1992; Debach and Rosen, 1993). For example, the use of the weaver ant, *Oecophylla smaragdina,* to manage caterpillars and large boring beetles on citrus by ancient Chinese (Debach, 1974; Emden, 1989; Barzman *et al.*, 1996). However, the first real landmark in modern biological control dates from the 1880's when a ladybird beetle (*Rodolia cardinalis*) was used to control the cottony cushion scale (*Icerya purchasi*) on citrus in California (Caltgirone and Doutt, 1989). Recently, other biological organisms such as insects, diseases and plants, which are resistant to pest attack, have been used for pest control (Emden, 1989). Much of it has been developed from indigenous knowledge (Jacobson, 1990) or unplanned introduction of control agents (McHoy, 1985). Now, biological control strategy is a widely recognised component in crop pest management, particularly where control has previously failed as a result of insecticide resistance (Lake *et al.*, 1992). Numerous predators and parasites are known to attack all life stages of pests and majority of these are native species with some exceptions in citrus agro ecosystems. However, their role in regulating pests remains uncertain in such agro ecosystems (Hoy, 2000). Studies on population dynamics have shown that there is always a time lag between the development of an insect pest population and that of an associated predator or parasite. Thus, successful bio-control action requires time for establishment. Perennial crops are suitable for best biological control because of their long lasting nature (Hill, 1997). The citrus agro-ecosystem is particularly unique for its richness of parasitic hymenoptera mainly Aphelenidae and Encytridae (Viggiani, 1997). Conservation of their role is crucial in IPM programming (Hoy, 2000). In Florida, IPM utilizes biological control as a key tactic (McHoy, 1985; Browning and McCoy, 1994). However, there are limiting factors to the success of many biocontrol attempts to date. These include inadequate taxonomy of the pests and their host ranges, poor information on the origin, lack of consideration of the overall pest complex and crop management practices (Nyambo *et al.*, 1994).

In Kenya the strategy has not been widely used to control citrus pests. Except that in 1959 and 1966, two parasitoids *Eretmocerus serius* and *Prospatella opulenta* were imported and released in the Kenya coast and Kibos near Kisumu, respectively. These were released to control citrus blackflies (*A. woglumi*) (Beige *et al.*, 1984). Lohr *et al.* (1997) undertook some trials on the utilization of an encytrid parasitoid (*Cales noacki*) in controlling the citrus wooly whitefly (*Aleurothrixus flocossus*) in eastern Uganda and eastern Kenya. Waterston (1922) recorded and described the chalcids that are native to Kenya, some of which are *Tamarixia (Tetrastichus) dryi*, *T. radiatus*, *Aphidencyrtus species* and *Psyllaephagous species*. Beige *et al.* (1984) reported of chalcid wasps attacking aphids. Imported chalcid parasitoid, *Tetrastichus dryi*, from South Africa, has been used successfully to control the two citrus psyllids, *T. erytreae* and *D. citri* in the Re-Union Islands (Aubert, 1987). However, many aspects of these parasitoids have not been studied. The seasonal searching ability and efficiency of the insects have not been investigated in Kenya. Similarly, the effects of cultural practices and chemical application on their abundance are not clear.

Apart from predators and parasitoids, many kinds of pathogens (fungi and bacteria) have long been known to suppress various citrus insect pests such as mealy bugs, whiteflies, aphids, mites and psyllids (Catling, 1969; Cohen, 1975). The pathogens include *Aschersonia spp.* (Cohen, 1975; Elizando and Quezda, 1990), *Verticillium lecanii, Beuvaria bassiana*, *Bacillus spp* (Hill, 1997; Emden, 1989) *Paecilomyces fumosa* (Smith, *et al.*, 1997), *Capnodium citri* (Aubert, 1987), *Metarhizium spp.* (Emden, 1989) *Fusarium spp.* (Agudele and Falcon, 1977) and *Hirsutella thompsoni* (Horn, 1988; Smith *et al.*, 1997). In Florida, the yellow and red *Aschersonias* have been reported to effectively control citrus whiteflies in Florida (Cohen, 1975) and citrus blackflies in south East Asia (Agudele and Falcon, 1977; Elizando and Quezda, 1990). Samways and Grech (1984) assessed the fungus *Cladosporium oxysporium (Verticilium lecanii)* as a potential bio-control agent against certain homoptera (mealy bugs, scale insect, aphids, and citrus psyllids). They reported that the fungus had considerable impact on aphids (*T.*

citricidus) and the citrus psyllid (*T. erytreae*) in the field and that an unidentified toxin was instrumental in causing the deaths other than hyphal growth. Hill (1997) has listed various pathogens that are commercially available as bio-control agents in spore suspensions or wettable powders. These include *Verticillium lecanii, Beauvaria bassiana, Bacillus thuringiensis, Hirsutella thompsoni* and granulosis viruses. Fungal pathogens are sensitive to desiccation and are density dependent hence their limitation as biocontrol agents (Aubert, 1987). A high number of natural enemies of pests are reported to be active in the citrus orchards, particularly in Florida USA (Hoy, 2000). These have not yet been exploited in Kenya to benefit citrus farmers. Their use should be encouraged to help reduce pesticide usage before it is widely adopted for controlling pests on citrus as is currently being practiced in other horticultural crops.

1.2.4.3 Cultural control

Before the advent of modern synthetic pesticides, cultural measures were used as man's chief weapons against insects. Though providing control inferior to that of pesticides, cultural control is a valuable restraint on the average pest density. It is valuable in reducing the challenge of high pest densities (Emden, 1989). There are various cultural control methods. These include: crop rotation, trap cropping, sanitation, manuring, soil cultivation, strip farming and intercropping, water and humidity management and sowing and harvesting practices.

Intercropping, a practice of raising two or more crops in the same field at the same time (Souie, 1992) is utilized in Australia. It involves planting Rhodes grass in between citrus rows to help control mite pests. This helps by increasing the impact of predatory mites, which utilize the nectar source from the grass flowers (Smith *et al.*, 1997). Intercropping has many benefits such as enhancing the efficiency of land use (Soule, 1992) and in the management of destructive insects, diseases and weeds (Liebmann, 1988). It offers a habitat management (approach) strategy where the environment is modified in such a ways that the pest population densities are lowered below the economic threshold levels (Minja, 1990; Altieri, 1994; Landis *et al.*, 2000). This results from enriched biodiversity of plants and the pests' natural enemies in and around the cropping environment thus increasing their impact (Emden, 1989; Emden and Dabrowski, 1994). Pests may also be attracted to a less valuable crop or the insect's host-plant finding behaviour is disrupted by close juxtaposition of two or more plant species (Emden, 1989). Intercropping is not presently practised for the management of citrus insect pests in Kenya. Many small-scale citrus orchards are intercropped for purposes of enhancing efficiency of land use. Insect pest management is secondary or unknown. Since many small-scale farmers often cannot afford insecticides, and labour is relatively cheap, cultural control is still a major weapon for pest management in the orchards (Emden, 1989). Bishop *et al.*, (1983) recommended the use of cultural technologies to minimize adverse effects on the environment while conserving natural control agents.

1.2.4.4 Plant resistance

Little work has been done on improving the resistance of citrus to pest attack worldwide. However, McCollum *et al.* (1995) in a bid to enhance resistance of citrus to fungal and insect pest attack studied the pathogenesis-related proteins expressed by plants in response to pest attack. They demonstrated that treating citrus (grapefruit) with gibberellic acid, salicylic acid or Keyplex 50 resulted in significant although transient increases of chitinases and beta- 3- glucanases enzymes known to have anti-fungal characteristics that are active in all citrus tissues. Citrus germplasm have also been screened for their resistance against the leaf miner *Phyllocnitis citrella* Stainton on the basis of leaf infestation (Batra *et al.*, 1992). Of the 134 citrus cultivars screened, varieties Carrizo, Sacaton, Savage, Troyer, Yama citrange, Citrumello, Campbell Valencia, Pomary, Rubidoux and *Murraya koeniggi* were resistant to leaf miner leaf infestation. The rest were fairly resistant to slightly susceptible whereas Jatti Khatti (*Citrus jambiri*) was highly susceptible to leaf miner leaf infestation.

Most single alternative methods of pest control have disadvantages, which prevent them from becoming general alternatives to pesticides, in relation to several pests that often attack one crop (Emden, 1989). Integrated pest management has sought to reduce reliance on pesticides utilising a multiple control measure approach. As a multidisciplinary pest management approach it utilises a combination of biological, genetical, cultural, physical and chemical technologies to hold pest populations below economic threshold levels (Emden, 1989; Dent, 2000). Due to the diversity of insect species present on citrus, careful selection and use of various methods of pest control together with judicious chemical use will help control insects. Integrated pest management maybe the solution to pest management on citrus. It will balance between controlling pests and conserving both environment and natural enemies to increase production and economically produce citrus in Kenya.

1.3 GENERAL MATERIALS AND METHODS

1.3.1 Location and description of the study area

These studies were conducted in two highland districts that were selected to represent a cross-section of the citrus growing areas in the country (Appendix I). These were Bungoma district in the western region and Machakos in the eastern region of the country. Bungoma is a high potential district whereas Machakos is a semiarid district with medium potential. The two districts receive bi-modal rainfall pattern, March through July as the first season and October through to December as the second season. The rains are distributed such that almost one half falls within one season and the rest in the second. Contact visits were planned to the Division offices with citrus cultivation. After surveying the area, under the guidance of extension agricultural staff, the districts were stratified according to the major agro-ecological zones within them. These are classified as Lower highlands (LH), Upper Midlands (UM) and Lower Midlands (LM) (Jaetzold and Schimdt, 1983) (Table1.1).

Table 1.1 Characteristics of the main agricultural ecological zones within Bungoma and Machakos districts.

Zone	Altitude	Mean Temp	Rainfall	Remarks
Lower Highlands (LH)	1800 -2400m	15°c-18°c	1000-1800mm	Low evaporation < 1400mm/yr
Upper Midlands (UM)	1300 -1900m	18°c- 21°c	700- 1800mm	Low evaporation < 1400mm/yr
Lower Midlands (LM)	800 -1300m	21°c- 24°c	700-1800mm	High evaporation 1800-2000mm/yr

(Jaetzold and Schimdt, 1983)

Lists of farmers obtained from the division offices were used as sampling frames. Hence a stratified random sampling procedure was used to select sixty-three farms, twenty-one from each stratum/zone. The farms were drawn to incorporate a fair representation of the farmers growing citrus in the districts. The selected farms were used for the survey work, monitoring and pesticide experiments. The survey and experiments were carried out in two seasons.

For monitoring and pesticide experiments, Machakos district was selected for the following reasons: It had a good representation of the range of agro-ecological zones LH, UM and LM already used for stratification, proximity to and accessibility to Nairobi and resources available to conduct the field work. Table 1.2 below shows the exact locations of the farms used in Machakos for monitoring and pesticides trials.

Table 1.2 Location of the farms that were monitored and where the pesticides trials were carried out in Machakos, 2002

AEZ	Farmer code	Location	Latitude	Longitude	Altitude
UM	1	Khayewa	E 37° 21.650'	S 1° 29.927'	1354m
UM	2	Khayewa	E 37° 21.361'	S 1° 28.169'	1400m
UM	3	Khayewa	E 37° 21.363'	S 1° 28.165'	1390m
UM	4	Khayewa	E 37° 20.170'	S 1° 25.390'	1428m
LM	1	Kithimani	E 37° 26.965'	S 1° 11.549'	1362m
LM	2	Kithimani	E 37° 25.854'	S 1° 10.964'	1354m
LM	3	Kithimani	E 37° 26.119'	S 1° 09.381'	1307m
LM	4	Kithimani	E 37° 27.636'	S 1° 10.811'	1292m

AEZ- Agro ecological zone, UM- Upper midland zone, LM- Lower midland zone

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AEZ- Agro ecological zone, UM- Upper midland zone, LM- Lower midland zone

The studies were conducted from January 2002 to February 2003. To start, preliminary informative contacts were made with the district agricultural extension officers of the Ministry of Agriculture Rural Development (MOARD). The purpose of the study and the various components were explained. This was followed by preliminary visits to the areas where citrus is grown within the districts. Three ecological zones were chosen for the administration of the questionnaire (Appendix II) and sample specimen collection based on criteria related to: altitude, availability of five mature citrus trees within the farms and available resources to carry out the study. The farms were selected from within LH, UM and LM zones found within the two districts (Table 1.1). While farms were chosen at random, care was taken to ensure that each household had at least five mature citrus trees.

1.3.2 Identification of specimens

After collection the samples/specimens were identified using field handbooks with coloured pictures such as Bohlen (1973), Beige *et al.* (1984) and Smith *et al.* (1997), and insect collection boxes in the University of Nairobi (College of Agriculture and Veterinary Sciences entomology laboratory) and National Agricultural Research Centre (NARC), Kabete. Analytical keys outlined in several basic entomological books such as Borror and Delong (196O) were also used. A technician trained on identification of insects by the Kenya National Museum, assisted in the identification.

CHAPTER TWO

2.0 SURVEY OF CITRUS INSECT PESTS AND THEIR MANAGEMENT IN BUNGOMA AND MACHAKOS DISTRICTS IN KENYA

2.1 INTRODUCTION

Agriculture is a major sector of the economy in Kenya. It provides employment for approximately 80% of the population (MOARD, 2001). Horticultural production has become increasingly important in the recent years. The sub-sector is now ranked second after tea in generating foreign exchange earnings. It makes a substantial contribution to food production and security especially in the rural areas where poverty levels are high (MOARD, 2001). Citrus production, a component of the horticulture industry, has a potential in the provision of employment, generation of income and improving the nutritional status for the Kenyan people. Nevertheless, the industry faces a lot of constraints. These include high incidences of pests and diseases, lack of high quality planting materials, inadequate capital, water stress/drought and poor orchard management (Obukosia *et al.*, 1999). As a result, on-farm production ranges from 4-10 tonnes per hectare on average. This production is low compared to 50 tons and 80 tons per hectare in areas where Integrated Pest Management (IPM) is practiced (FAO, 1996a) and in high density citrus planting in North America (Obukosia and Waithaka, 2000), respectively. The faculty of Agriculture of the University of Nairobi, with the assistance of the Netherlands government undertook rapid production of disease free planting materials utilizing tissue culture technology, as a step toward solving the problem associated with inadequate planting materials. These seedlings are already being supplied to the farmers and the activity is on-going. However, there exists a knowledge gap on the type of insect pests prevalent in the farmers' fields that cause damage to citrus and the manner in which farmers control them. In the past, chemical control has been recommended (Beige *et al.*, 1984). The recommendations rely a lot on the results from other countries and screening results for new products introduced in the country. This technology has, however, not been widely adopted. Besides, few farmers that use these chemicals apply them indiscriminately, often leading to hazardous effects to the environment and poor net gains or profits (Erbaugh and Kyamanywa, 1998). Scientists need to be aware of what the farmers know and practice in order to help facilitate the development of improved management options for pests and diseases (Bentley and Andrews, 1996). Surveys provide a useful tool for obtaining ideas and opinions of farmers about pest and disease management, at the same time documenting their current practices. This study was carried out to determine important insect pests of citrus and their natural enemies and to evaluate the management practices employed by the farmers to control the pests.

2.2 MATERIALS AND METHODS

The survey on citrus pests in Machakos and Bungoma districts was conducted using a questionnaire (Appendix 1) in two seasons, January/February and July/August 2002. A stratified sampling technique was employed to randomly select farms/farmers from lists of citrus farmers provided by the extension agents in the respective administrative divisions. Twenty-one farmers were selected from each stratum giving a total of sixty-three households or experimental units. The research team (comprising of the student and two officers from the division / locality) administered the questionnaire in Kiswahili and

English. In a few cases the extension officers used the local vernacular terms for clarification. In addition, field handbooks with insect pictures (Bohlen, 1973; Beige *et al.*, 1984; Smith *et al.*, 1997) and some specimens helped farmers recognize the insect pests being dealt with. It took 45-60 minutes to cover a household depending on the complexity of explanations by the respondents. Baseline data were gathered from the household heads (farm owners), wives, children or workers well acquainted with citrus production in the farms. Data collected included constraints that hindered citrus production, insect pests observed and ranking them in order of importance, methods of pest control, pesticide products used and how decisions to control pests were made. Source of seedlings, farm size and size of farm under citrus, experience of farming and age of the farmers were also some of the information sort for in the survey. Data obtained was analysed using the Statistical Package for Social Scientists (SPSS) for descriptive analysis.

During the survey, an on-the-spot assessment of the pests in the orchards was also done. In each of the selected households, a maximum of three trees were randomly selected and sampled for the arthropod pests and beneficial insects associated with citrus. This procedure was done once in each growing season. Samples collected were transported to the laboratory (CAVS entomology laboratory) for identification. The two sampling methods used were visual counting / observation for any pests that would not dislodge from the trees with shaking or spraying and the use of the "knockdown" method as described by Chiarrapa (1971) using a synthetic pyrethroid – cypermethin. The health status of the citrus trees was also observed and scored from 1-3. Where 1= healthy, 2=

moderately healthy and 3= unhealthy. The data was analysed to determine important pests of citrus and assess the control methods that were practised by the farmers. In addition a logistic regression using Statistical Package for Social Scientists (SPSS) was used to analyse the factors determining the health status of the citrus trees in the farmers' fields, using the information gathered in the questionnaire. The study categorized the citrus in the farmers' fields into those that were healthy and those that were attacked by pests and diseases. The logit or probit models are recommended when the dependent variable is dichotomous (Maddala, 1983; Gujarati, 1995). In this study the logit model was used to analyse the factors determining the health status of the citrus crop on a farmer's field. The model is generally formulated as follows: $Y = \beta X_i + \varepsilon_i$

Where Y is the decision of the *i*th individual, β is a column vector of unknown parameters, X is a matrix of known variables while ε is a stochastic disturbance term. The individual either has a healthy citrus crop (Y= Yes) or otherwise (N = No).

This can then be modelled as follows;

$$Y = 1/ [\ 1 + \exp.\ (Z)]$$

$$Z = X\beta_i$$

Where Y = probability that a particular farmer has a healthy citrus crop.

X = regressor matrix (farmer attributes in this case).

β = Vector of model parameters.

When β_i is zero, then Z is also zero and exp. (Z) which measures the odds of occurrence will be equal to one. A unit value here means that factor Xi has no effect on the odds that the citrus crop will be healthy. The dependent variable for the model was the probability that the citrus on the farmer's field was healthy and the independent variables included farmer/farm socio-economic characteristics and institutional factors postulated to influence citrus health status.

2.3 RESULTS

2.3.1 Range of insect species associated with citrus in Bungoma and Machakos

Results of all identified insect species associated with citrus trees are summarised in the tables 2.1, 2.2 and 2.3. Taxonomically, the insect species were classifiable into ten orders namely: Araneida (various), Acarina (3) Diptera (10), Coleoptera (35), Hemiptera (34) {Heteroptera (17) and Homoptera (17)}, Hymenoptera (10), Lepidoptera (5), Neuroptera (1), Orthoptera (10) and Thysanoptera (1). These insects belong to approximately 58 families. A summary of occurrence and abundance of these insects in the two seasons is shown in Tables 2.1a and 2.1b. Hemipteran pests were the most frequently encountered whereas the spiders (Araneida) were the most abundant beneficial insects (Tables 2.1a and 2.1b). Tables 2.2 and 2.3 give the families and the scientific names of the insect species and an indication of the relative abundance (% frequency) in the agro ecological zones where the insect pests occurred. Species richness varied with agro ecological zones and seasons (Table 2.2 and 2.3). From the lists, it is observed that some insect species were distributed in all the three agro-ecological zones studied. Others were limited in their distribution. The large majority of the species collected showed low frequencies of occurrence with no difference in incidence between agro ecological zones (Tables 2.2 and 2.3). There was strong evidence that the insect species had some significant association with the agro ecological zones in both seasons ($P<0.001$).

Table 2.1a Insect species abundance on citrus by taxonomic orders in Bungoma district, January-February, 2002 and July-August 2002 (% frequency)

	PESTS			BENEFICIALS	
Order	**Season 1 (SR)**	**Season 2 (LR)**	**Order**	**Season 1 (SR)**	**Season 2 (LR)**
Diptera	2.4	16.1	Diptera	26.7	13.9
Coleoptera	8.0	9.4	Coleoptera	0	23.8
Heteroptera	1.2	7.6	Hemiptera	0	1.0
Homoptera	54.9	26.0	Hymenoptera	13.3	31.7
Hymenoptera	15.0	21.1	Neuroptera	0	4.0
Lepidoptera	5.0	7.6	Lepidoptera	0	0
Orthoptera	5.5	9.4	Orthoptera	26.7	4
Acarina	1.0	0	Araneida	33.3	21.8
*Others	7.3	2.2			

*Other include Brown snails, cockroaches, cercospora fruit and leaf spots, SR=Short rains, LR=long rains
No. of pest species, **SR** = 29, **LR**= 41, No. of beneficial species, **SR**= 6, **LR** = 12.

Table 2.1b Insect species abundance on citrus by taxonomic orders in Machakos district, January-February, 2002 and July-August 2002 (% frequency)

	PESTS			BENEFICIALS	
Order	**Season 1 (SR)**	**Season 2 (LR)**	**Order**	**Season 1 (SR)**	**Season 2 (LR)**
Diptera	25.7	19.7	Diptera	15.3	0
Coleoptera	20.0	21.7	Coleoptera	26.4	39.1
Heteroptera	6.0	10.2	Hemiptera	1.4	4.3
Homoptera	21.5	17.2	Hymenoptera	11.1	6.5
Hymenoptera	9.4	12.7	Neuroptera	0	2.2
Lepidoptera	7.0	3.2	Lepidoptera	0	0
Orthoptera	6.4	14	Orthoptera	5.7	3.4
Acarina	2.0	0	Araneida	44.4	45.7
*Others	2.9	0			

*Other include Brown snails, cockroaches, cercospora fruit and leaf spot, SR=Short rains, LR=Long rains
No. of pest species, **SR** = 38, **LR** = 33, No. of beneficial species, **SR** = 10, **LR** = 6

2.3.1.2 Insect pest species

Pest species frequently encountered were *Triozae erytreae* Del Guercio (Plate 1), *Toxoptera citricidus* Kirk. (Plate 2)), *Aleurothrixus flocossus* Mask. (Plate 3a and 3b), scale insects (Plates 4 and 5), *Aleurocanthus woglumi* Ashby (Plate 6), attendant ants (various), leaf-eating beetles (*Lagria villosa* F. and *Systates pollinosus* Gerst), flies (various) and grasshoppers (various). Other pests observed in low frequencies were mites and orange dog. Homopteran pest species were more abundant and widely distributed in the three agro-ecological zones. The citrus psyllids were more abundant in the lower highlands and upper midlands whereas the blackflies were more abundant in the lower midlands (Table 2.2). The groundnut hopper (*Hilda patruelis* Stal.) (Homoptera: Tettigometridae) (Plate 7) was one of the pests distributed in all the three zones of Machakos district in the second season. It was fairly frequent. The leaf-eating beetles showed higher frequencies whereas other beetles occurred in low frequencies. Lower highlands had the least number of species whereas the lower midlands had the most. Season one (January-February, 2002) had 46 species compared to the second season (July-August, 2002) that had 58 species. However, the abundance of the species was higher in the first season (Tables 2.2 and 2.3).

2.3.1.2 Beneficial insect species

The beneficial insects observed included spiders, ladybird beetles, parasitic wasps, parasitic flies (Tachnidae), syrphid flies, dragonflies, lacewings, praying mantids and hemipteran bugs (Table 2.3). Frequent beneficial species observed were the spiders (Araneida) and the ladybird beetles (Coccinelidae)). The spiders and the ladybird beetles mainly the Cheilomen (*Plates 8-10*) and the Chilocorus (*Plate11*) genera dominated the natural enemy complex (Table 2.3). However, spiders were the most frequent group of natural enemy observed in both seasons (Table 2.3). Other beneficial species encountered were the reduviid bug (*Phonoctonus principalis*) (*Plate12*), a ladybird beetle *(Platynapsis* *spp) (Plate 13)* and the syrphid flies (*Xanthograma aegyptium*) (*Plate14*). There were no variations in beneficial species richness between the agro-ecological zones. The numbers of species observed were 12 and 13 in the first and second seasons, respectively.

Table 2.2 Pests collected from citrus trees in the three agro-ecological zones in Bungoma and Machakos districts (% frequency)

Order/Family	Scientific name	Relative abundance (% frequency)					
		LH		UM		LM	
		S 1	S 2	S 1	S 2	S 1	S 2
Hemiptera							
Cicadellidae	*Empoasca spp*	0	4	1	3	4	0.8
Pentatomidae	#*Piedozorus hybneri* Germ.			*		*	
Pentatomidae	#*Cletus fuscescens* Wlk.	0.8	1	2	1.8	2.4	0.8
Pentatomidae	*Nezara viridula* L.	0	0	0	1.2	0.8	0
Coreidae	**Leptoglossus spp*			*			
Coreidae	#*Clavigralla horrida* Germ.	0	0	0	0.6	0	0
Coreidae	*Coptosoma spp*	0	0	0	0.6	0	0
Coreidae	**Anoplecnemis horrida* Germ.			*		*	
Coreidae	*Anoplecnemis curvipes* F.	0	0	0	0.6	0	0.8
Diaspididae	**Aonidiella aurantii* Mask.						
Diaspididae	*Lepidosaphes beckii* Newman	0	0	0	0	0.8	0
Diaspididae	*Chrysomphalus ficus* Ashm.	0	0	0.5	0	0	0
Margarodidae	*Icerya purchasi* Mask.	0.8	3	0	0.6	0	0
Coccidae	*Coccus viridis* Green	0	2	0.5	1.2	0	0
Coccidae	*Coccus hesperidum* L.	0	0	2	1.2	0.8	1.6
Coccidae	**Ceroplastes destructor* Newst.					*	
Coccidae	**Saissetia oleae* Olivier						*
Pyrrhocoridae	*Dysdercus spp*	0	1	0	0	0.4	0
Miridae	**Helopeltis schoutedeni* Reuter		*				
Psudoccocidae	**Pseudoccocus longispinus* Targ T.		*		*		
Aphididae	*Toxoptera citricidus* Kirk.	8	9	3	3	3.6	3.2
Aphididae	*Toxoptera aurantii* Boy de F.	0	0.6	0	0	0	0
Aphididae	**Aphis gosypii* Glover				*		
Tettigometridae	*Hilda patruelis* Stal.	0	1	0	3	0	3.2
Aleyrodidae	*Aleurocanthus woglumi* Ashby	0.8	0	3	0.6	4	0.8
Aleyrodidae	**Aleurocanthus spiniferus* Quant.						
Aleyrodidae	*Aleurothrixus flocossus* Mask.	14	6	9.5	3	7.6	6.4
Psyllidae	*Trioza erytreae* Del G.	19.2	11	14.7	6.6	5.6	3.2
Cercopidae	*Ptyelus grossus* F.	0	1	0	0	0	0
Miridae	*Lygus spp*	0	1	0		0	2
Lygyiidae	*Lygaeus pandurus* Scop.	0	1	0	0	0	2
Coreidae	**Mictis spp*			*			
Orthoptera							
Tettigonidae	*Homorocorphus nitidulus* Wlk.	0	1	0	1.8	0	3.6
Gryllidae	*Gryllus spp*	0	0	1	3	1.2	0
Acrididae	*Chrotogonus senegalensis* Bol.	0	0	0	0	0	0.8
Acrididae	*Trillophidia conturbata*	0	0.8	0	0	0	0
Acrididae	*Ornithacris spp*	5.2	0	4.5	0	4	0
Acrididae	*Phorosia spp*	0	6	0	1.8	0	4
Acrididae	**Catantops spp*					*	
Acrididae	**Zonocerus elegans* Thunb.	*		*		*	

Table 2.2 cont'd

Order/Family	Scientific name	Relative abundance (% frequency)					
		LH		UM		LM	
		S 1	S 2	S 1	S 2	S 1	S 2
Termitidae	**Odontotermes spp*					*	
Thysanoptera							
Thripidae	*Unidentified spp.			*			
Diptera							
Diopsidae	*Diopsis thoracica* Westw.	0	0	1	2.4	0	0
Tephriditae	*Ceratitis capitata* Wied.	0.8	2	1.5	6.6	0.8	11.2
Tephriditae	*Ceratitis rosa* Karsch	0	0	0.5	0	0	0
	&*Paedorus sabaeus*	4.8	0	10	3.6	10	1.6
Muscidae	Unidentified spp.	0	7	1.5	4.2	0.8	4
	Unidentified flies	7.4	2	7.5	0	6.4	0
Agromyzidae	Unidentified spp	0.8	0	0.5	4.2	1.2	0
Lepidoptera							
Noctuidae	**Heliothis armigera* Hubner						*
Noctuidae	*Spodoptera littoralis* Boisd.	1.6	0	0.5	0	3.5	2.4
Noctuidae	*Sesamia calamistis* Hmps.	0	0	0	0.6	0	0
Noctuidae	*Ophideris spp*	0	0	0	0.6	0	0
Yponomeutidae	*Prays citri*	0	0	0.5	0	0.5	0
Pappilionidae	*Papillio demodocus* Esp.	3.7	0	0	1.8	1.2	1.6
Totricidae	*Chryptophlebia leucotreta* Meyr.	0.8	0	0	0.6	1.6	0.8
Gracillaridae	*Phyllocnitis citrella* Staint.	1.6	5	3	4.2	1.6	1.6
Pyralidae	*Olethreutes spp*	1.6	0	0.5	0.6	2.8	0.8
Pyralidae	#*Etiella zinckenella* Treit.	0	0	0	0.6	0	0
Pyralidae	#*Ephestia cautella* Hb.				*		
Coleoptera							
Lygriidae	*Lagria villosa* F.	6	0	7.0	1.2	8.0	1.2
Chrysomelidae	#*Aspidiomorpha spp*	0	0	0	0.6	0	0
Chrysomelidae	#*Ootheca spp*	0	1	0	1.2	0	1.6
Chrysomelidae	#*Chrysolagria metallina*	0	0	0	0.6	0	1.8
Chrysomelidae	#*Oxyrachis spp*	0	1	0	1.2	0	1.6
Chrysomelidae	*Leptaulaca basalis* Erichs.	0	0	0	0	0	0.8
Coccinelidae	#*Epilachna canina* F.	0	1	0	0	0	0
Scarabidae	*Schizonycha spp*	0.8	0	0.5	0	0.4	1.2
Scarabidae	#*Pachnoda sinuata* F.	0	1	0	0	0	0
Bostrychidae	*Apate spp*	0	0	0	0	0.4	0.8
Meloidae	#*Coryna spp*	0	0	0	0	0	0
Cucurlionidae	*Systates pollinosus* Gerst.	2.2	3	6.5	1.8	5.6	4.8
Cucurlionidae	*Nematocerus spp*	0.8	0	1.6	0.6	1.6	0.6
Cucurlionidae	#*Apion spp*	0	0	0	4.8	0.4	0.8
Cucurlionidae	*Otiorynchus spp*	0.8	0	0.8	0	0	0
Cucurlionidae	*Eutinophea spp*	0	0	0	0.6	0	0
Cucurlionidae	#*Sitophilus zeamais* Motsch.	0	1	0	1.2	0	0
Cucurlionidae	*Maleuterpes spp*	0	0	0	0	1.2	0
Gelechiidae	#*Sitotroga cerealella* Ol.	0	0	0	0.6	0	0
Tenebrionidae	#*Tribolium casternum* Herbst.	0	1	0	0.6	0	0

Table 2.2 cont'd

Order/Family	**Scientific name**	**Relative abundance (% frequency)**					
		LH		**UM**		**LM**	
		S 1	**S 2**	**S 1**	**S 2**	**S 1**	**S 2**
Bruchidae	*#Callosobruchus spp*	0	0	0	0	0.4	0
Carabidae	Unidentified spp.	0	1	0	0	0	0
Staphylanidae	Unidentified spp.	0	1	0	0	0	0
Hymenoptera							
Vespidae	*Vespa orientalis*	0.8	5	1.5	0.6	1.6	0
Formicidae	*Oecophylla longinoda* Latr.	0	0	0	0	0.8	0
Formicidae	*Anoplepsis custodiens* F.	9.6	17	9	15.6	8.4	15.2
Formicidae	**Iridiomyrmex spp*						
Formicidae	**Solenopsis spp*						
Formicidae	**Pheidole spp.*						
Acarina							
Phytoseiidae	*Phyllocoptruta oleivora* Ashmd.	0.8	0	2.5	0	1.2	0
Tetranychidae	**Panonychus citri* McGregor			*		*	
Eriophydae	**Aceria sheldoni* Ewing			*		*	
	Hard tick	0	0	0	0	0	0.8

LH- Lower highland, **UM**- Upper midland, **LM**- Lower midland, N = 185 trees,

S 1- Short rain season, **S 2**- long rain season

*Other insects observed in farms but not collected on sampled trees,

[#] Insects known to be major pests of other crops mainly legumes and cereals, respectively

[&] Insect (Nairobi fly) not recorded as crop pest but was abundant in the citrus canopy particularly in the first season.


Plate 1. Citrus psyllids *(Triozae erytreae)* **Plate 2.** Citrus aphids (*Toxoptera citricidus)*

Plate 3a. Citrus wooly whitefly (*Aleurothrixus flocossus*)

Plate 3b. Wooly whitefly damage on citrus trees

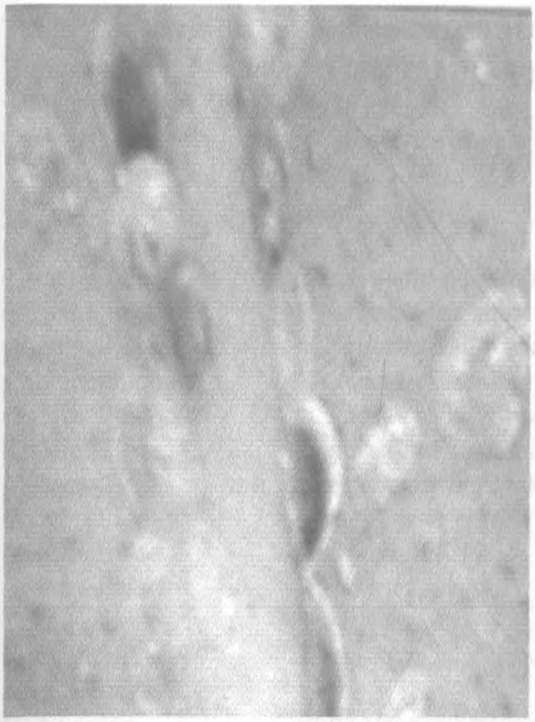

Plate 4. Soft geeen scales (*Coccus viridis*)

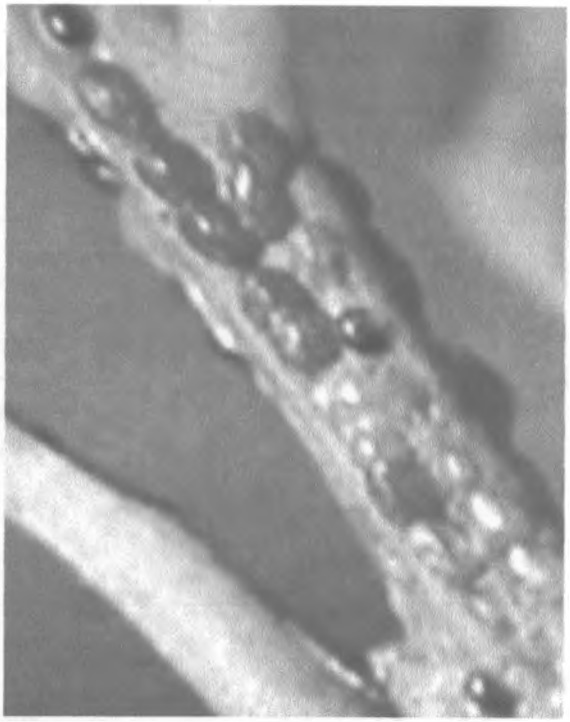

Plate 5. Brown scales (*Coccus hesperidium*)

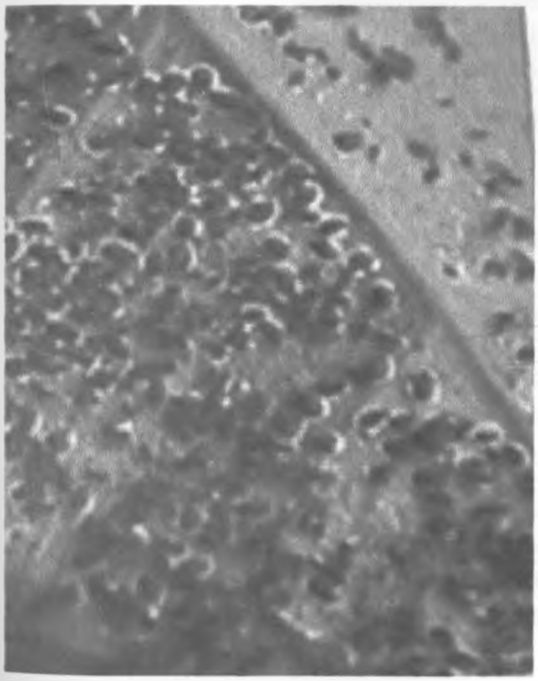

Plate 6. Citrus blackfly nymphs (*Aleurocanthus woglumi*)

Plate 7. Groundnut leafhopper (*Hilda patruelis*)

Table 2.3 Beneficial insects collected from citrus trees in the three ecological zones in Bungoma and Machakos districts (% frequency)

Order/Family	Scientific name	Distribution					
		LH		UM		LM	
		S1	S2	S1	S2	S1	S2
Coleoptera		**4.2**	**8.7**	**16**	**27**	**40.3**	**37.8**
Coccinellidae	*Cheilomenes sulphurea*	0	2.9	12.8	16.2	25.6	16.2
Coccinellidae	**Cheilomenes lunata*						
Coccinellidae	**Cheilomenes propinqua*						
Coccinellidae	*Chilocorus distigma*	0	2.9	0	9.0	14.7	11.6
Coccinellidae	**Chilocorus wahlbergi*						
Coccinellidae	**Chilocorus circumdatus*						
Coccinellidae	**Chilocorus nigritus*						
Coccinellidae	**Platynapsis vittigera*						
Coccinellidae	*Hippodamia spp*	0	2.9	0	1.8	0	1.8
Coccinellidae	*Harmonia spp*	4.2	0	3.2	0	0	0
Coccinellidae	**Scymnus spp*						
Coccinellidae	*Adonia spp*	0	0	0	0	0	8.2
Heteroptera		**20**	**23.2**	**28.6**	**5.4**	**6.2**	**10.8**
Reduviidae	*Phonoctonous principalis*	0	0	3.2	1.8	3.1	1.8
Nabidae	*Nabis spp*	0	0	0	0	0	1.8
Diptera							
Syrphidae	*Xanthograma aegyptium*	4.2	2.9	0	1.8	0	0
Tachnidae	Various unidentified spp	8.4	20.3	22.4	1.8	0	7.2
Tachnidae	Unidentified parasitic flies	8.4	0	3.2	0	3.1	0
Orthoptera							
Mantidae	Unidentified spp	4.2	2.9	6.4	5.4	6.2	1.8
Hymenoptera		**16.8**	**35**	**3.2**	**33**	**0**	**9**
Ichneumonidae	Several unidentified spp	8.4	26.1	0	18	0	7.2
Aphelinidae	**Aphelinus spp*						
Aphelinidae	*Cales noacki*	0	0	0	0	0	1.8
Aphelenidae	**Aphytis spp*						
Braconidae	**Aphidius spp*						
"	Unidentified parasitoids	4.2	5.8	3.2	9	0	7.2
Eulophidae	*Tetrastichus spp*	4.2	2.9	0	5.8	0	5.8
Neuroptera							
Chrysopidae	*Chrysopa carnea*	0	5.8	0	1.8	0	3.6
Araneida							
Araneida	unidentified spider species	42	17.4	38.4	42.5	46.5	30.6

LH- Lower highland, **UM**- Upper midland, **LM**- Lower midland, N = 185 trees,
S 1- Short rain season, **S 2**- long rain season, * Insects observed in farms but not collected on sampled trees

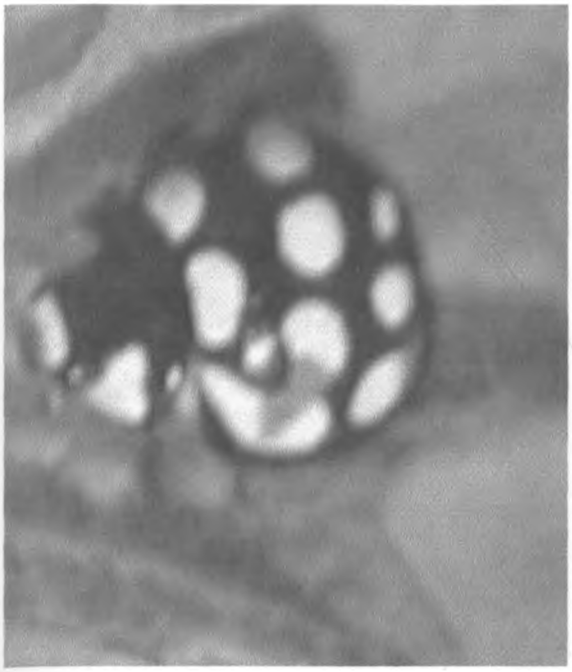

Plate 8. A ladybird beetle
(Cheilomen sulpurea)

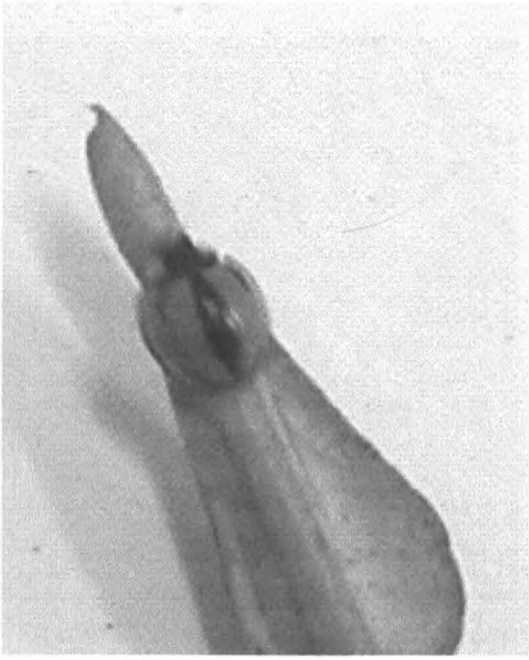

Plate 9. A ladybird beetle
(Cheilomen propinqua)

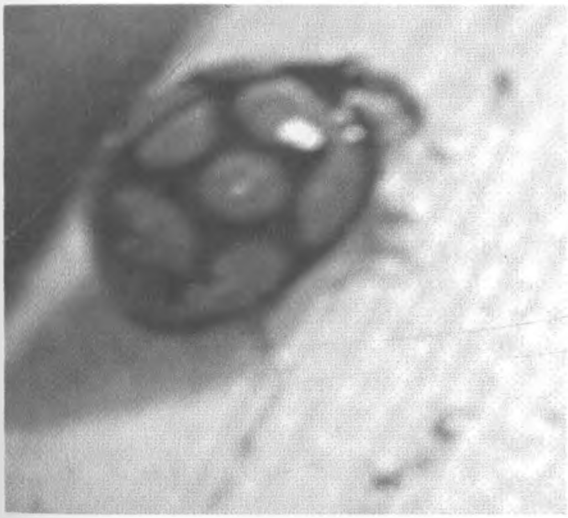

Plate 10. A ladybird beetle
(Cheilomen lunata)

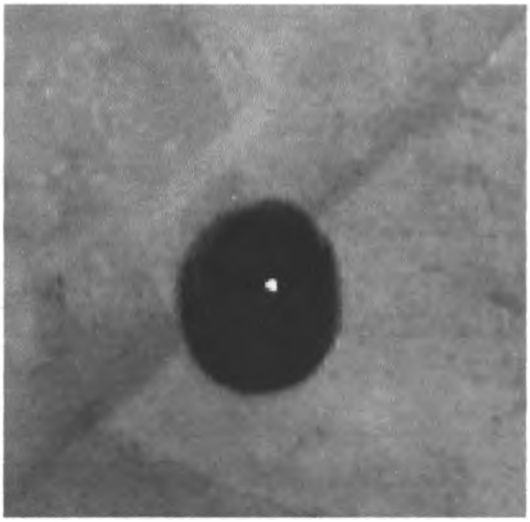

Plate 11. A ladybird beetle
(Chilocorus spp)

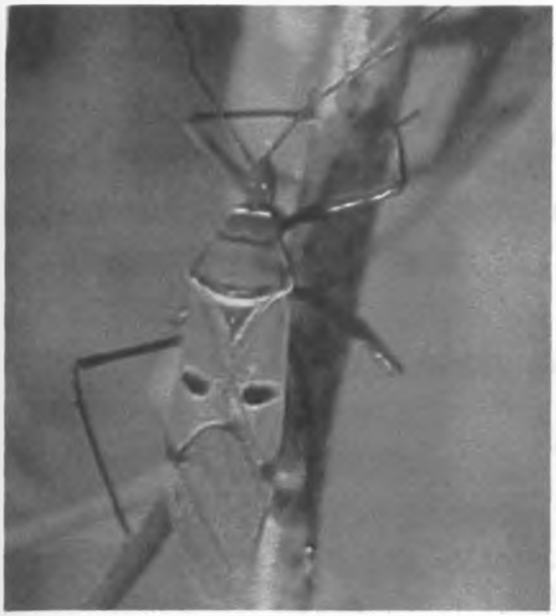

Plate 12. A reduviid bug
(*Phonoctonous principalis*)

Plate 13. A ladybird beetle
(Platynapsis spp.)

Plate 14. Syriphid flies (*Xanthogramma aegyptium*)

2.3.2 Farmer perceptions and practices

Farmer responses analysed showed no significant differences in farmer perceptions of crop protection practices between the agro-ecological zones, LH, UM and LM (P>0.05). Therefore, the results are reported according to the districts.

2.3.2.1 Farm resources and socio-economic characteristics

The minimum age of the respondents interviewed was 14 years and the maximum age was 85years with a mean age of 44years and a standard deviation of 14years. Farming experience ranged from 4years to 42years with a mean of 15 years and a standard deviation of 7 years (Table 2.4a). Eighty percent of them grew citrus as a cash crop. Farmers in Bungoma had larger pieces of land (3.5 ha) compared to those of Machakos (1.9 ha). They all committed approximately 10% of their land to citrus cultivation (Table 2.4a). Land under citrus ranged between 0.01-2 hectares. Sixty five per cent of the orchards were intercropped (Table 2.4b). The crops used for intercropping included maize, pigeon peas, beans, Irish potatoes, sweet potatoes and vegetables (onions, kales and capsicums). Seventy percent of the farmers in Machakos used their own planting materials prepared within their farms and thirty percent obtained the planting materials from seedling nurseries such as that of Tana and Athi River Development Authority (TARDA) (Table 2.4b). On the other hand, 84 percent farmers in Bungoma district derived their citrus planting materials from seedling nurseries such as Mabanga Farmers Training centre (FTC) in Bungoma (Table 2.4b). This seedling nursery is located in the highlands. Further, 82 per cent farmers in Bungoma reported to have had difficulties in obtaining citrus planting seedlings while 57 percent of the farmers reported the same limitation in Machakos district (Table 2.4b).

Table 2.4a Socio-economic characteristics of citrus farms in Bungoma and Machakos districts, 2002

Variable	Range	Mean	BGM mean	MKS mean
Age of respondents (yrs)	14-85	44	41	47
Farm size (ha)	0.4-22.3	2.8	3.5	1.9
Farm size under citrus trees	0.01-5	0.35	0.5	0.17
Number of citrus trees	2-1700	98	80	118
Farming experience (yrs)	4-42	15	14	16
Age of citrus (yrs)	2-42	13	12	15

BGM- Bungoma, MKS- Machakos,

Table 2.4b Characteristics of citrus farms in Bungoma and Machakos districts, 2002(no. of farmers/farms)

Variables	BGM	MKS	Overall
No. of female respondents	16(49)	16 (53)	32 (51)
No of male respondents	17 (52)	14 (47)	31 (49)
No. of female headed households	3 (8)	2 (7)	5 (8)
No. of male headed households	30(92)	28 (93)	59 (92)
No. of farms intercropped	17 (52)	24 (80)	41 (65)
No. of farmers using own seedlings	5 (15)	21 (70)	26 (43)
No. of farmers with difficult in getting seedlings	27 (82)	17(57)	44 (70)
No. of farmers using seedlings from nurseries	28 (84)	9 (30)	37 (59)
No. of farms with unhealthy trees	24 (72)	12 (40)	36 (57)
No. of farmers growing citrus as a cash crop	24 (72)	28 (93)	51 (81)
No of farmers spraying citrus	14 (42)	20 (70)	34 (54)

Figure in brackets is % farms or farmers, BGM - Bungoma, MKS - Machakos,
Overall - both districts considered

Farmers reported that pests and diseases were a major production constraint. Other constraints included inadequate capital, inadequate disease-free planting materials, drought or water stress, marketing, low soil fertility and other social problems in decreasing order of importance (Table 2.5). Aphids, citrus psyllids, citrus blackflies, false codling moth and scale insects were perceived to be of primary importance. Others were whiteflies, fruit flies, mites, leaf miner and orange dogs (Table 2.6).

Table 2.5 Citrus production constraints reported by farmers in Bungoma and Machakos districts in 2002

Pest species	Mean percentage of respondents
Pest and diseases	35
Inadequate capital	22
Inadequate planting materials	18
Drought or water stress	11
Marketing	5
Low soil fertility	2
Others	7

Source: survey data

Table 2.6 Perceived important pests of citrus by farmers in Bungoma and Machakos districts, 2002

Pest species	Mean percentage of respondents
Aphids (*Toxoptera spp*)	16.8 (1)
Black flies (*A. woglumi*)	12.3 (2)
Scale insects (various)	9.6 (5)
Psyllids (*T. erytreae*)	12.3 (2)
Whiteflies (*A. flocossus*)	8.3 (6)
False codling moth (*C. leucotreta*)	11.9(4)
Mites (*P. oleivora*)	7.1 (7)
Fruit flies (*Ceratitis spp.*)	6.3 (8)
Leaf miner (*P. citrella*)	2.7(10)
Orange dog (*P. demodocus*)	3.5 (9)
*Others	6.2

*Others include termites, red fire ant and diseases
Mean: % farmers assessing the relative importance of a pest,
Overall rank in brackets

Citrus psyllids, whiteflies, aphids and leaf miner were also observed to be abundant during on-the-spot assessment of the pests in the orchards (Table 2.7).

Table 2.7 Occurrence of pests on citrus trees in Bungoma and Machakos districts, 2002 (% farms with pest)

Pest species	Percentage of farms with pest
Aphids (*Toxoptera spp*)	42
Blackflies (*A. woglumi*)	25
Scale insects (various)	13
Psyllids (*T. erytreae*)	82
Whiteflies (*A. flocossus*)	59
False codling moth (*C. leucotreta*)	0
Mites (*P. oleivora*)	13
Fruit flies (*Ceratitis spp.*)	0
Leaf miner (*Phyllocnitis citrella*)	40
Orange dog (*Papillio demodocus*)	25

Source: survey data

2.3.2.2 Farmer pest control practices

There were no significant differences between the two districts with regard to the measures used in controlling pests (P>0.05). Chemical control was the most common pest management practice. Fifty four percent of the farmers used chemicals to control pests while the rest (46%) did not practice any pest control measures. Among those using chemicals, 14% practised calendar/routine spraying (2-3week intervals), while 40 % practised periodic application of pesticides (during flowering of the crop) (Table 2.8). A few farmers used locally available materials for pest control. The materials used included ash and/or non-chemical spray formulations such as a mixture of detergent soap with a weed, Mexican marigold (*Tagetes minuta)* in water to control insect pests, particularly aphids.

Table 2.8 Insecticide use and frequency of application of pesticide to control insect pests (% Farmers)

Pest control method	Frequency of application	Percentage of farmers
Chemical control	Calendar	14
Chemical control	Periodic	40
No pest control	N/A	46

A wide variety of pesticide products were used. The most commonly applied chemicals were synthetic pyrethroids such as Karate and Ambush. Others were organophosphates such as Diazinon and Dimethoate, fungicides, carbamates and organochlorines. Eleven percent farmers used fungicides to control insect pests in their farms (Table 2.9).

Table 2.9 Pesticides products used by farmers in Bungoma and Machakos districts, 2002

Trade name	Common name	Percentage of farmers
Karate	Lambda- cyalothrin (I)	40.0
Diazinon	Diazinon (I)	20.0
Ambush	Permethrin (I)	10.9
Fenitrothion	Fenitrothion (I)	7.3
Dimethoate	Dimethoate (I)	3.6
Sumicidin	Fenvaralate (I)	1.3
Dithane M45	Mancozeb (F)	5.5
Bayleton	Triadmefon (F)	3.6
Kocide 101	Copper (F)	1.8
Orthene	Acephate (I)	1.7
Foliar feed	Various nutrients	3.6

I - insecticide, **F** – fungicide

The major source of information on citrus production and pest control for farmers was other farmers. Other sources were government extension service and non-governmental organizations (Table 2.10).

Table 2.10 Sources of information on citrus production and insect pest control for citrus farmers

Sources of farming information	**Percentage respondents**
State agricultural extension officers	43
Non governmental organisations	3
Other farmers	54

In both districts, three quarters of the farmers had not been visited in the last one-year by those who offer agricultural extension information. The rest were visited but not specifically for advice on citrus production. In addition, a half of the 25% farmers were visited only once. Therefore, farmers largely used their own knowledge to manage insect pest situations in their farms. Fifty six percent of the farmers applied chemicals after observing insects on citrus trees while a few relied on advice from extension services. The rest relied on chemical company salesmen and agricultural stockists for advice to control pests in their farms (Table 2.11).

Table 2.11 Reasons for making pest management decisions (% farmers)

Reason for pest management decisions	**Percentage respondents**
Agricultural extension officers' advice	6
After observing insects on citrus trees	56
Others	38

Others: chemical company salesmen, agricultural stockists

2.3.3 Factors influencing citrus tree health

The estimated coefficients and other relevant statistics from the Logistic Regression analysis are presented in Table 2.12 below. The results show that the district of study significantly influenced the health status of citrus trees (P < 0.01).

Table 2.12 Logistic regression likelihood estimates of the factors influencing the health status of citrus in Bungoma and Machakos districts, 2002

Variable	Coefficient Estimate	Standard Error	Significance
District	-1.8963	0.6829	0.0055
Agro-ecological zone	-0.5169	0.3757	0.1689
Gender	0.4541	1.4218	0.7494
Age	0.0139	0.0285	0.6265
Farm size	0.1653	0.1050	0.1154
Number of citrus trees	-0.0012	0.0013	0.3688
Experience	-0.0499	0.0533	0.3484
Citrus seedling source	0.2952	0.6705	0.6597
Traditional control methods (ITK)	-0.8482	0.6813	0.2132
Extension	0.8156	0.7124	0.2523
Constant	1.9091	3.6628	0.6022
Log Likelihood = -71.140			
Goodness of fit = 62.24			
N = 63			

The district of study significantly influenced the citrus health status (P< 0.01) but had a negative effect. This implies that citrus trees in Machakos district had a higher likelihood of being healthy than those in Bungoma. The Logistic regression results tie closely with those obtained from frequency analysis, which shows that 72 percent of the citrus farms in Bungoma were unhealthy as opposed to 40 percent in Machakos district (Table 2.4b). An analysis of the results in Machakos district alone showed that the agro-ecological zone within the district significantly influenced the probability of having unhealthy citrus trees (P=0.05) (Table 2.13). These results imply that citrus trees planted in the lower midlands (LM) and upper midlands (UM) were more likely to be healthier than those grown in the lower highlands (LH).

Table 2.13 Logistic regression likelihood estimates of the factors influencing the health status of citrus Machakos district, 2002

Variable	Coefficient Estimate	Standard Error	Significance
Agro-ecological zone	-2.4238	1.2568	0.0538
Gender	1.7124	5.5481	0.7576
Age	-0.0377	0.0529	0.4764
Farm size	0.9748	0.7561	0.1973
Number of citrus trees	-0.0091	0.0143	0.5259
Experience	0.1283	0.0994	0.1969
Citrus seedling source	-1.5213	1.4071	0.2796
Traditional control methods (ITK)	-0.7632	1.3954	0.5844
Extension	-0.7898	1.4208	0.5783
Constant	8.8299	8.8989	0.3211
Log Likelihood = -23.848			
Goodness of fit = 20.471			
N = 30			

In Bungoma, the results showed that farming experience significantly influenced the citrus health status ($p<0.05$) but had a negative effect (Table 2.14). These results imply that farmers with less citrus farming experience have a higher likelihood of growing healthy citrus plants.

Table 2.14 Logistic regression likelihood estimates of the factors influencing the health status of citrus in Bungoma district, 2002

Variable	Coefficient Estimate	Standard Error	Significance
Agro-ecological zone	0.1439	0.8917	0.8718
Gender	6.9473	67.3610	0.9179
Age	0.0194	0.0737	0.7919
Farm size	-0.1140	0.3189	0.7206
Number of citrus trees	0.0101	0.0071	0.1544
Experience	-0.4863	0.2297	0.0342
Citrus seedling source	0.7822	1.6190	0.6290
Traditional control methods (ITK)	-1.1861	1.6643	0.4761
Extension	1.9010	1.6527	0.2500
Constant	-6.5589	67.7593	0.9229
Log Likelihood = -20.109			
Goodness of fit = 18.35			
N =33			

2.4 DISCUSSION

2.4.1 Insects associated with cultivated citrus

One hundred and seventeen insect species were observed to be associated with citrus. Eighty-seven species belonging to approximately fifty-eight families were pest species. Thirty species belonging to ten families were observed as beneficial insect species. Smith *et al.* (1997) have reported most of the insect pests and beneficial insects identified on citrus in Australia. Similar pests and beneficial insect species have been reported on citrus in the Mediterranean region (FAO, 1996a). There were no insect species new to science recorded.

Although many pest species were recorded only a few were important pests of citrus. The homopterans were the most important pests. The citrus wooly whitefly, citrus blackfly, citrus brown aphid, citrus psyllids and leafhoppers (*Empoasca spp* and *Hilda patruelis*), were some of the frequently encountered pests distributed throughout the three zones. Beattie (2000) reported whiteflies; aphids, blackflies, citrus psyllids and leaf miner as serious insect pests of citrus in south east Asia and China. Tsedeke (1985) reported scales (*Aonidiella aurantii*), psyllids (*Triozae erytreae*) and aphids (*Toxoptera aurantii*) as the major pests of citrus encountered while investigating the cause of citrus decline in Ethiopia. Homopterans have also been recorded as major pests of citrus in other countries (Deluchi, 1975; Samways and Grech, 1984). The groundnut leafhopper (*Hilda patruelis*) (Homoptera: Tettigometridae) was the only pest observed that has not been recorded in many places. It is not among the 100 pests recorded by Smith *et al.* (1997), neither is it reported in Israel's citrus pests list by Avidoz and Isaac (1969) nor in the list of citrus pests in the Mediterranean region (FAO, 1996a). It is also missing in the lists given by the researchers in Kenya (Gonzalez, 1980; Farell *et al*., 1995; Mailu, 1996). It was however, recorded as a citrus pest in Tanzania (Le Pelley, 1959; Bohlen, 1973) and synthetic insecticides recommended for its control (Bohlen, 1973). Probably it is limited in its distribution, confined mainly in warm regions such as those of central Tanzania and Machakos (Eastern Kenya) where the pest was observed in this survey. Among the major pests, citrus psyllids, citrus aphids and leafhoppers (sharpshooters) are vectors of diseases. The citrus psyllid (*T. erytreae*) is a vector of HLB (McClean and Oberholzer, 1974; Aubert, 1987); citrus aphids (*T. citricidus* and *A. gossypii*) are vectors of tristeza (Rocha-Pena *et al*., 1995) and psorosis (Portillo and Bena-tena, 1989) while the leafhoppers (sharpshooters) are vectors of citrus variegated chlorosis (Aldlerz *et al*., 1989; Roberto and Yamamoto, 1998; Lopes, 1999). On the other hand, leaf miners through their feeding action are reported to encourage the spread of the citrus canker caused by a bacterium *Xanthomonas axonopodis pv citri* (Rodrigues *et al.*, 1998; Marcon *et al.*, 2000). Huanglongbing diseases of citrus, citrus psorosis and citrus tristeza have been reported to occur in Kenya (Seif and Whittle, 1984; Seif and Hillock, 1993). It is possible that a complex of these diseases could exist in the citrus trees and cause yield losses, in addition to the direct damage on trees caused by the insect pests. Many disease vectors have been encountered in this study. This points out to the need for proper management of citrus pests particularly the disease vectors. Further investigations are necessary which should target the control of these disease vectors.

Certain pest species observed in this study and reported elsewhere and in Kenya are also pests of other crops. For example, *Piedozorus hybneri*, *Nezara viridula*, *Etiella zinkenella*, Apion species, Agromyzid flies, Coryna species, Lygus species, *Helicorverpa armigera*. Clavigralla species are known as pests of legumes (Lateef and Reed., 1990; Minja *et al.*, 1999; Rao and Shanower, 1999). Sesamia species are known as pests of cereals (Hill and Waller, 1996) while Bruchids (*Callosobruchus spp*), *Sitotroga cerealella*, *Sitophilus zeamais*, and *Tribolium casternum*, are storage pests of legumes and cereals (Singh and Emden, 1979; Hill, 1990; Hill and Waller, 1996). These may have found a refuge on citrus trees after the annual crops were harvested. Although these pests occurred in low frequencies, the field pests of legumes are capable of infesting the crops as soon as they are planted or as the crops mature. Storage pests such as bruchids and maize weevils are reported to start infestation from the field (Hill, 1990). In such agro-ecosystems, citrus orchards may be a source of infestation because of the insect pests that take refuge on citrus trees. This raises the question of appropriate crops for intercropping.

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It is generally recognized that in natural ecosystems, greater diversity leads to greater chance of stability (Emden and Williams, 1974,) and the possibility of controlling insects, diseases and weeds (Liebman, 1988). However, diversity from intercropping which bridges gaps in host plant species sequences directly creates upsurges of some pests (Way, 1976). The same author, Way (1976) concluded that the right kind of diversity is fundamental to insect pest control. These investigations reveal a situation where current intercropping may create an upsurge of pests in the future. Investigations are necessary to come up with the right kind of intercropping to avoid favouring some insect species that may become pests.

The weevils were another group of pests that was observed to be abundant and diverse. Nevertheless, they occurred in low frequencies. These have not received a lot of attention in terms of research (Davies and Albrigo, 1994). Grasshoppers were also abundant and widely distributed. However, the damage of weevils and grasshoppers is not viewed as being significant considering the canopy of a mature citrus plant.

Hemipteran pests were the most abundant. Of these, the homopterans, particularly the citrus psyllids (*T. erytreae)*, the aleyrodids, (*A. flocossus* and *A. woglumi)*, aphididae (*T. citricidus)* and scales particularly, the soft green scale (*Coccus viridis* Green.) were the most widely distributed and abundant in both seasons making them major pests in these zones. Citrus wooly whitefly (*A. flocossus)* from Asia, is a fairly recently introduced pest into many countries including Kenya. In Israel, the pest was first recorded in 1991 (Argov, 1994). The pest is also recorded as a recent introduction in Britain (Malumphy,

1995) and the Mediterranean region (FAO, 1996a). Hill (1975) recorded it as a pest of citrus in the tropical regions in Central and South America and not Africa. In Kenya, there are no records of when the pest was first introduced or observed. Nevertheless, the pest is now widely distributed and appears to be a major pest of citrus in the country. In a survey of citrus pests in Njoro area, Macharia *et al.* (1999) recorded the pest as one of those that were constraining citrus production in Rongai area, Nakuru. Kenya Agricultural Research Station at Njoro has since gone ahead to recommend synthetic insecticides for the control of the citrus wooly whitefly. In this study, the pest was frequently encountered in Bungoma as well as Machakos district. The pest was widely distributed in all the three agro-ecological zones studied. This point to the need for strict quarantine control measures to prevent both entry and spread of insect pests and diseases. Homopteran pests have been recorded as the most notorious pests afflicting citrus orchards in the world over (Davies and Albrigo, 1994; Smith *et al.*, 1997; FAO, 1996a; Nguyen, 2000; Leong *et al.*, 2000). The desire to control these insect pests has been high because of the threats they pause to many industries particularly the citrus industry. These pests have received a lot of attention for their control worldwide, particularly in the major growing areas such as Florida, North America and China (Beattie, 2000).

Attendant ants and flies were frequently encountered. These do not cause direct damage to citrus. They mainly enter the citrus canopy in search of honeydew produced by the homopteran pests. However, some species particularly ants at high densities interfere with predators and parasites that seek out and destroy the pest species. Such ant species can severely disrupt IPM programs (Smith *et al.*, 1997).

High pest densities and pest types were found in the lower midland zones. The ecological zone probably provides the most favourable environmental conditions the pests need for their survival. In this study homopterans pests, which include citrus wooly whiteflies, citrus psyllids, citrus black flies, citrus brown aphids, and scale insects, have emerged as important. Further investigations are required in order to develop acceptable and sustainable management strategies.

Beneficial insects comprised of predators and parasitoids. They consisted of a wide array of coccinellids, spiders, tachnids, syrphids, mantids, chrysopids and reduviid bugs. The spiders were the most abundant in the two seasons suggesting that they form an important and conspicuous part of the natural enemy complex in the citrus orchards. Dipennar - Schoeman and Berg (2001) demonstrated that spiders are an important part of the natural enemy complex in macadamia orchards. Al-Ghamdi (2000) reported spiders as having a potential in the control of the Asian citrus psyllid (*Diaphorina citri* Kuwayama) in Saudi Arabia and Amalin *et al.* (1996) have evaluated the role of spiders in suppressing the leaf miner in lime groves. While testing the effect of imidacloprid on the arthropod complex on the bean canopy, Marquini *et al.* (2002), reported that spiders were an important component of the natural enemy complex that was most abundant in the common bean canopy. Unfortunately the role of spiders as predators has not been recognized until recently. Their potential role in suppressing citrus pests requires investigations in Kenya. Coccinellids, particularly the Cheilomen and Chilocorus genera were the second in abundance after spiders. These are the natural enemies mainly recorded as predators of aphids, whiteflies, blackflies and scales (Cardosa, 1990; Smith *et al.*, 1997; Amitava, 1998). Since the homopteran pests were abundant, it is probable that the coccinellids were present to play their role in suppressing the pest species. However, the frequencies of occurrence were low compared to those of the homopteran pests suggesting that there could have been pest species that were not under adequate control by these predators. It is also probable that the coccinellids only played a secondary role in suppressing the pest populations.

Noteworthy is the low frequencies of occurrence of parasitoids in this study. Probably the indigenous parasitoids are found in very low densities. It is probable also that the sampling method used was not the best to capture these tiny insects. There is no universal sampling method that suits all insects and Millar *et al*. (2000) suggested that the knockdown method is not the best for parasitoid sampling. A survey of indigenous parasitoids as a component of the natural enemy complex is required using appropriate sampling methods in order to comprehensively document those that are present in the country. Reduviids, chrysopids and the syrphid flies were the least frequent in occurrence. *Phonoctonous* species (Reduvidae) recorded by Bohlen (1973) in central Tanzania was also observed here but in very low frequencies.

2.4.2 Farmer perceptions and practices

There were no significant differences in the farmer perceptions and practices obtained from the areas surveyed (P>0.05). This indicated homogeneity in the behaviour of the farmers. The implication is that farmers encounter similar problems and that they apply similar practices in solving insect pest problems within their farms. Farmers in both districts perceived constraints to citrus production in a similar trend with pest and diseases being ranked the highest. This agrees with results of a PRA carried out in Machakos and Kakamega districts in 1998 to determine the socio-economic characteristics that influence adoption of tissue culture technology citrus seedlings (Obukosia *et al.*, 1999). The study confirms that farmers are experiencing problems in citrus production and that the priority problem is pests and diseases.

Various insect pests have been confirmed present ten of which are a problem to the farmers (Tables 2.6and 2.7). Five of these are homopterans, three lepidopterans, one dipteran and the other an acarina. Homopteran insects have from time to time threatened valuable major industries particularly citrus in the world for which reason motivation to control them has been high (Samways, 1981). From assessment on the trees in the farms, psyllids, whitefly, aphid and leaf miner occurrences were high at 83%, 59%, 42% and 40% respectively (Table 2.7). However, whiteflies and leaf miner were ranked lower unlike the citrus psyllids and aphids. Farmer ranking of the pests did not relate to actual occurrence levels of pests observed. Their ranking may have been related to their knowledge of the pests and the extent to which they were capable of controlling the pest in the farms. The role of insects as vectors of diseases or predators/parasites of other insects was unknown to the farmers. This finding is in line with results obtained in other parts of the world. Kenmore *et al.* (1987) while dealing with rice farmers in the Philippines reported that the farmers had no information about the rice leafhoppers being vectors of diseases. Similarly, Ewell *et al.* (1990) while dealing with Andean potato farmers reported that the farmers had no knowledge about other insects being capable of controlling others. Richard (1980) while working with African smallholder agro ecosystems concluded that the farmers were unaware of pests being vectors of diseases.

The chemical pesticides were used to kill a whole spectrum of insects on the citrus crop and were mainly used periodically (at flowering period) apart from a few commercial farmers who utilized pesticides on a calendar basis (Table 2.8). A few farmers practiced the use of Indigenous Traditional Knowledge (ITK), this, together with hand picking of pests such as orange dog, was felt to be limited in effectiveness. Pesticide use was viewed as the most effective pest control measure regardless of the insect pests. This is because pesticides are easy to use (Smith, *et al.*, 1997) and are viewed as an easy route to achieving farmer objectives of reducing or destroying the insect pests. However, their use may have been limited by financial constraints. In the study, pesticides were used broadly to kill insects with total disregard of whether they were beneficial or not. A large proportion of farmers in Machakos used chemicals to control insect pests and 93 percent of these farmers grew citrus as a cash crop (Table 2.4b). This indicates the possibility of farmers rapidly adopting insecticide use as a primary method of pest management like it is in other horticultural crops. This calls for the development of sustainable pest management technologies and training of the small-scale citrus farmers before pesticide use is widely adopted. This is against the background of environmental repercussions and ecological imbalances associated with pesticide use.

The range of chemical products used was wide. However, synthetic pyrethroids and organophosphates were the commonly used chemicals (Table 2.9). They are toxic and broad-spectrum in action, killing destructive pests and beneficial insects alike. Bedford *et* *al.* (1992) while screening pesticides for use in an IPM program in citrus recommended the use of endosulfan in low doses and not the organophosphates, carbamates or synthetic pyrethroids because of their long residual toxicity. These chemicals have been reported to cause new serious out breaks of the pests controlled (Furuhashi, 1990; Smith *et al.*, 1997). Eleven per cent of the farmers used fungicides to control insects. Fungicides are recommended for combating fungal diseases and not insect pests. The fungicides were not the right chemicals for pest control. This indicates lack of knowledge on the use of pesticides by this section of farmers.

While government extension was the main source of farming knowledge known to the farmers, only a quarter of the farmers were visited in the last one year. Among those visited, over half were visited only once. This indicates that the farmers received little or no advice on the management of citrus. Farmers also had no idea about scouting or monitoring, an important component of pest management, which assists in achieving effective use of pesticides. The current pest control practices overlook the importance of timely pesticide application based on pest monitoring, pest complex, pest diversity and activity of the natural enemies. Chemicals as are currently used by farmers are not the only solution to insect pest management problems in citrus farms. Generally, there is inadequate insect pest control within the citrus farms. This is probably the reason farmers considered insect pests as a priority problem.

2.4.3 Factors influencing citrus health in farmer fields

Machakos district had a higher likelihood of citrus trees being healthy than those in Bungoma. This health status trend could be explained by the source of the citrus planting materials. Seventy percent of the farmers used their own planting materials (2.4b). Since most of the region is low in altitude, it is likely that diseases, particularly HLB, did not infect the orchards from which the scions were derived. This is partly the reason why citrus trees in Machakos were likely to be healthier. Aubert (1987) reported HLB disease and its vector as being unable to thrive well in low elevations with high temperatures. Majority of Bungoma farmers obtained their citrus seedlings from Mabanga FTC seedling nursery. Being a government seedling nursery the scions were obtained from National Horticultural Research Centre, Thika that was providing true-to-type plant materials. Unfortunately, this nursery is one of those that were located in the highlands and was reported to be infected and propagating diseases particularly the HLB and was recommended for destruction (MOA, 1982). This is partly the reason why citrus trees in Bungoma were unhealthy (Table 2.4b). These results point to the fact that grafting propagated HLB disease of citrus among other diseases. The results are consistent with the record by Obukosia and Waithaka (2000) that 90 percent of the orchards in the lower lands had HLB because of grafted materials obtained from the highlands, particularly the seedling nursery from National Horticultural Research Centre, Thika. Planting materials from Thika did not only spread disease to the lower lands but did spread diseases in the highlands. Further, in Bungoma, more farmers had difficulties in obtaining citrus planting materials compared with Machakos farmers. Moreover, farmers in Machakos district sprayed their citrus trees since they perceived it to be a cash crop. The government extension service was also reported to be more active in Machakos than in Bungoma district.

In Bungoma, the results showed that farming experience significantly influenced the citrus health status. This outcome was contrary to the expected that as farmers gain more experience; their decision-making would be positively affected (Adesina and Zinnah, 1993). Experience is closely correlated with age and it generates or erodes the confidence among farmers and hence they become more or less risk averse to new technologies (Nzuma, 2001). In this study, farmers had undergone various experiences such as having a company (Ndalalapo) promote citrus production only to abandon them after they had invested with no benefits. In addition, the farmers purchased unclean seedlings through this company from Mabanga FTC, which over the years have become unhealthy and the citrus trees are slowly dying. The farmers have had no profits. This experience may have contributed to the results that farmers with little experience in citrus farming had a higher likelihood to adopt and cultivate healthy citrus unlike the experienced farmers. The study also underscored the importance of extension in determining the health status of citrus trees.

The analysis points out the importance of disease-free citrus planting materials in determining the health status of citrus trees in the farmers fields. It is necessary to emphasize the roles played by improved technologies such as tissue culture citrus planting materials and pest and disease control measures in improving the health status of citrus trees in the farmers' fields. More efforts should be directed towards training farmers to use disease-free planting materials as well as pest and disease control measures to improve production of citrus in Kenya.

CHAPTER THREE

3.0 OCCURRENCE AND SEASONAL DISTRIBUTION OF HOMOPTERAN INSECT PESTS (*Aphididae, Pysllidae, Aleyrodidae* and *Coccidae*) OF CITRUS IN MACHAKOS DISTRICT, EASTERN KENYA

3.1 INTRODUCTION

Homopteran pests are reported on citrus crops worldwide (Davies and Albrigo, 1994). They include leafhoppers (*Cicadellidae* and *Delphacidae*), psyllids (*Psyllidae*), whiteflies (*Aleyrodidae*), aphids (*Aphididae*), cottony cushion scales (*Margarodidae*), mealy bugs (*Pseudococcidae*) soft scales (*Coccidae*) and armoured scaled (*Diaspididae*) (Samways, 1981; Hill, 1997). These homopteran insects have from time to time threatened valuable major industries, particularly citrus in different parts of the world (Davies and Albrigo, 1994). Scales and mealy bugs, have an enormous reproductive potential. They leap in numbers, when they escape geographically from their natural enemies or when pesticides used upset their natural balance (Samways, 1981). Leafhoppers, psyllids, whiteflies and winged forms of aphids are highly mobile. They are often dispersed on wind currents. As opportunists, they reproduce rapidly and exploit the food resources where they land. Some aphids and psyllids are also vectors of plant diseases (Samways, 1981). Hence their control must be rapid and effective.

Insects have the potential to increase and adjust their numbers in response to the dynamic environment in which they occur (Ridgeway and Vinsen, 1977). Hence, population fluctuations are influenced by important biotic and abiotic factors. These include weather and other physical factors, food, interspecific and intraspecific competition, natural enemies and spatial or territorial requirements (DeBach, 1974). Rarely do these factors act alone. In a given situation, one may be the key regulatory factor responsible for a particular pest population density. Emden (1978) emphasised the importance of all ecological information from basic biology of a pest to the full dynamics of a species or community in pest management programmes. The information determines when and whether an insect pest management programme is necessary or not. Unfortunately, crop monitoring or scouting a cornerstone of any successful pest and disease management programme is a missed out element by many smallholder growers who are unaware of this important aspect of pest management (Vambe, 1997). In many cases problem pests are only identified after they have reached very high population levels and is exaggerated by in-correct pest identification. Pesticides, the commonly used weapons against pests are not given a chance of success because of incorrect timing, use of low dosages and use against incorrectly identified pest targets (Camel and Way, 1987). In order to have an effective management programme, information on population dynamics and seasonal occurrence of pest species is an important pre-requisite. It determines when and whether a pest management programme is necessary or not. These studies were undertaken to monitor the homopteran pest population fluctuations in relation to the seasonal weather changes (rainfall and temperature), citrus tree phenology and the abundance of natural enemies. This information would contribute to the understanding of the population changes of homopteran pests and recommend appropriate time for their control.

3.2 MATERIALS AND METHODS

3.2.1 Site

These studies were conducted in Machakos, a semi-arid district with medium potential for food production in Eastern Kenya, for 8 months from June 2002-February 2003. The district was stratified according to the agro-ecological zones within it. That is the LH, UM and LM (Table 1.1). A stratified sampling technique was employed to randomly select farms from lists of citrus farmers provided by the Agricultural extension offices at Kathiani and Yatta divisions in Machakos district. Farms were earlier surveyed to establish the locations of citrus farms and the extent of pests as a citrus production constraint. Three farms in the UM zone (Kathiani division) and four farms in the LM zone (Yatta division) were selected for use in the studies (Table 1.1). The farms had mature citrus (*Citrus sinensis*), 12-14 years old with a spacing of 5 x 5m and an average height of 2-3m tall. Exact locations of the farms monitored are shown in Table 1.2

3.2.2 Pest sampling

Four trees were marked per farm for monitoring and pest species sampling on a fortnightly basis. Pest sampling was done on the four marked trees in each farm to record the presence and to quantify the population of the homopteran pest species. These pests included aphids, whiteflies, blackflies, scales and psyllids. Sampling methods were modified from those of Sutherland *et al.* (1996), Smith *et al.* (1997) and FAO (1996a). Using the visual/direct counting technique, total number of adults and nymphs of aphids, whiteflies, blackflies, scales and psyllids were counted. The counting was done on ten randomly selected, 15cm long growing shoots from all four quarters of a tree for all the four trees in a plot. Adults and nymphs were counted since they are the destructive stages of these pests on citrus. Natural enemies present on the selected shoots were also counted. Records for each shoot and each pest species were kept. In addition, flush growth on the trees was monitored during the same period. Weather data was obtained from the meteorological stations nearest the farms (in the divisions). Data on pest densities were transformed into square root (x+1) and analyses of variance done to determine differences in population densities between the agro-ecological zones and the sampling periods. Where values from analysis indicated significant differences LSD at 5% level was used to separate the means.

3.3 RESULTS

3.3.1 Pest situation in the farms

Homopteran pest species targeted were observed in both agro-ecological zones and seasons. These included the citrus aphid (*Toxoptera citricidus* Kirkaldy), citrus psyllid (*Trioza erytreae* Del Guercio), citrus wooly whiteflies (*Aleurothrixus flocossus* Maskell), citrus blackflies (*Aleurocanthus woglumi* Ashby) and scales (*Coccus viridis* Green). There were significant differences in population development (densities) between the two agro-ecological zones for aphids ($P=0.02$), black flies ($P<0.001$) and psyllids ($P<0.01$). High aphid populations were found in LM zone (122) compared to those in UM (13). Blackflies populations were higher in the LM zone (6) compared to UM (1). The psyllid populations were higher in the UM (5) compared to LM (1) (Fig 3.1).

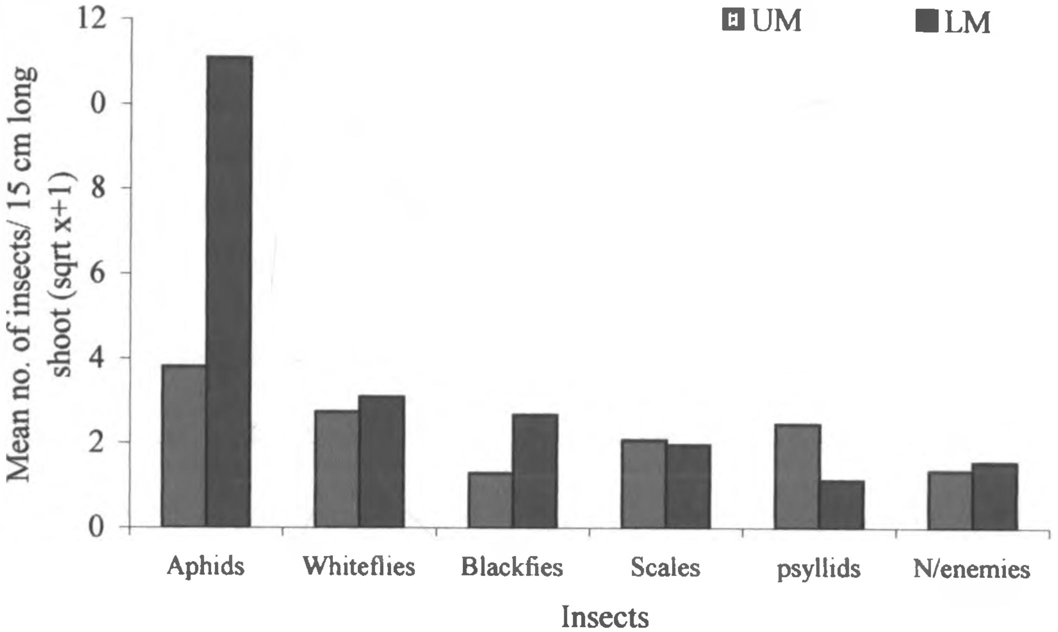

Fig.3. 1 Comparison of insect population densities in the UM and LM agro-ecological zones in Machakos district

3.3.2 Insect species occurrence

Figs. 3.1 and 3.2 show the population fluctuations for each pest species in each agro-ecological zone. Population trends for the natural enemies (mainly the coccinellids) encountered during the monitoring period are also included. There was a significant variation in the fluctuation of populations from one sampling period to another for aphids ($P<0.001$), whiteflies ($P=0.04$), and citrus psyllids ($P< 0.001$) in the upper midland (UM) zone. Only citrus psyllid populations fluctuated significantly ($P<0.001$) between the sampling periods in the lower midland (LM) zone.

3.3.2.1 Upper Midland zone (UM)

The aphid population densities exhibited two peaks, one in June and the other in January. In between, the population levels reduced to zero in September, October and November (Fig.3.2). There were significant differences in the population fluctuations between sampling periods (P<0.001).

Three peaks were observed for whiteflies, in July, September and January-February period. The first peak was the highest whereas the third was the lowest (Fig.3.2). Between September and January, the whitefly populations steadily decreased to reach the lowest densities in December. Higher population densities of the whiteflies were observed in the UM zone.

Blackflies and scales occurred in low densities. Blackfly density increased slightly in August- September while, scale populations increased slightly in August-October (Fig.3.2). There were no significant fluctuations of both blackfly and scale population densities between the sampling periods (P>0.05) in this zone.

Low densities of the citrus psyllid were observed throughout the monitoring period. However, there was one low peak observed in January (Fig.3.2). The populations fluctuated significantly between sampling periods (P<0.001). The peak coincided with the vigorous flush growth.

Natural enemies (mainly coccinellids) were observed in low densities and remained low throughout the monitoring period (Fig. 3.2). There were no significant variations of the natural enemy populations between sampling periods (P>0.05).

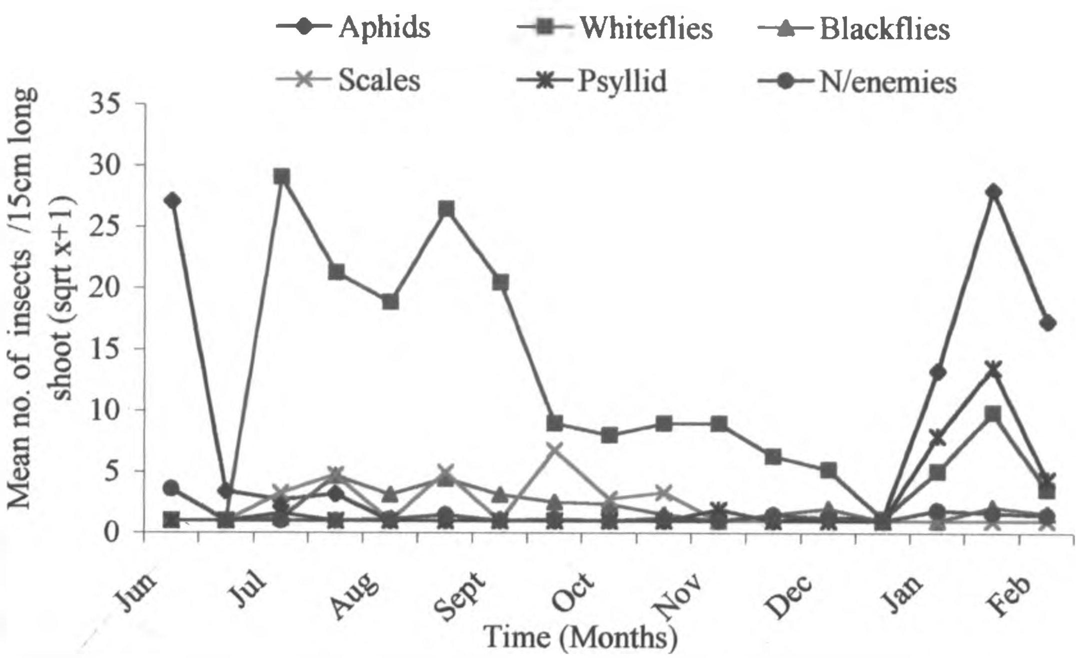

Fig. 3.2 Insect populations on citrus tree, June 2002-February 2003 in the Upper midlands of Machakos district

3.3.2.2 Lower Midland zone (LM)

The aphid population densities exhibited three peaks of populations in June, September-October and January-February periods. In between the peaks, there were very few aphids observed (Fig.3.3). There were no significant differences in the population densities during the sampling periods (P>0.05). Population densities in this zone were higher than those of the UM zone.

Populations of citrus whiteflies oscillated between high and low throughout the monitoring period (Fig.3.3). Two peaks were however observed in August-September and November-December. There were no significant differences in population densities between the sampling periods (P=0.05). The pest population densities were lower than those of the UM zone.

Blackflies were encountered throughout the monitoring period. They exhibited two peak densities in July and November. The first peak remained high up to September followed by a sharp population decrease to a low in October. The population increased steadily to reach the second peak in November. Later the population decreased slowly to another low in January that remained constant into February (Fig. 3.3). There were no significant differences in populations between the sampling periods (p>0.05). The blackflies were present through out the monitoring period. The densities were higher than those of the UM. Low densities of scales were encountered during the monitoring period. There were very slight increases in July (Fig. 3.3).

Densities of citrus psyllids were very low. These remained low except for a slight increase in January (Fig. 3.3). There were significant differences in the population changes between sampling periods (P<0.01). Citrus psyllid populations were higher in the lower zone than in the UM. Very low densities of natural enemies were observed during the monitoring period. The population densities were not significantly different between sampling periods (P>0.05).

In both agro-ecological zones, pests appeared to give way to one another. For example as the aphid populations reduced in July, the whitefly population rose sharply to reach a peak in August/September in the LM zone (Fig.3.3). Later as the whitefly population reduced, the blackfly population rose to reach a peak in October (Fig.3.3).

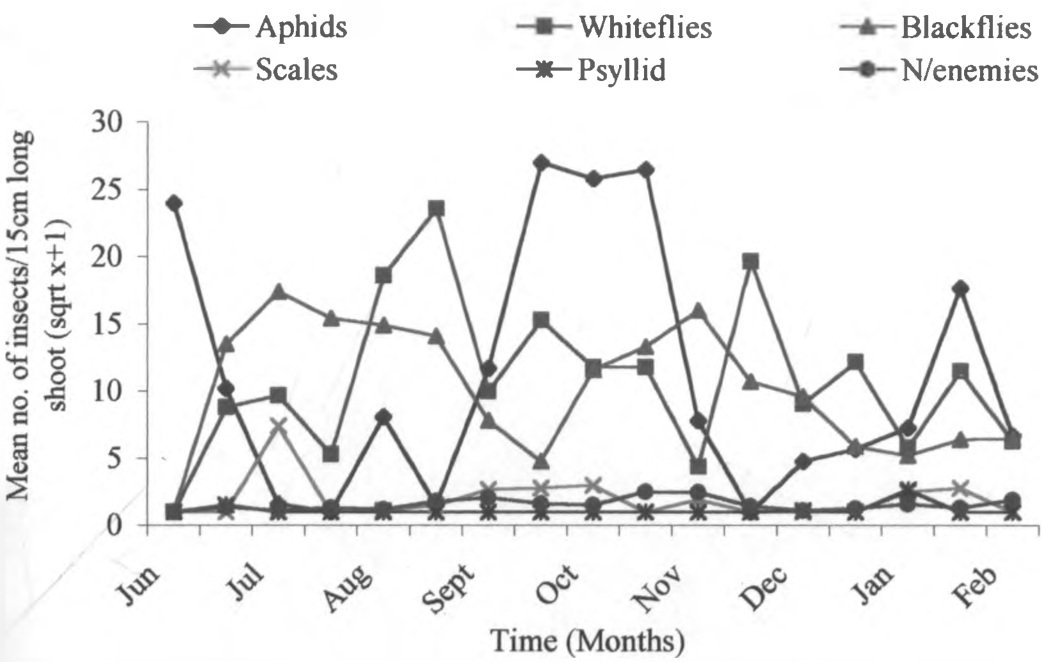

Fig.3.3 Insect populations on citrus, June 2002-February 2003 in the Lower midlands of Machakos district

The trend was similar in the upper midland zones (Fig.3.2). There was no single time the trees were completely free from infestation. The pest load was lowest between September and November, a period that is relatively hot and dry. The pest load was highest in July/August and December/January, a period characterized by vigorous flush growth (Figs.3.2 and 3.3). Flush growth peaks that occur as a result of rainfall received preceded the pest high-density peak periods.

3.3.3 Flush growth occurrence

Plate 15 below shows flush growth on citrus trees as observed during the cool and wet period. One major flush period was observed in each zone. In the UM zone, there was one major flush growth period in November followed by a small flush growth as the rains continued to fall. The rains received in September preceded this main flush period (Fig.3.4). June and November peaks of flush growth preceded the peak population densities of aphids in the UM (Fig 3.4).

Plate 15. A citrus tree with flush growth during the cool and wet season.

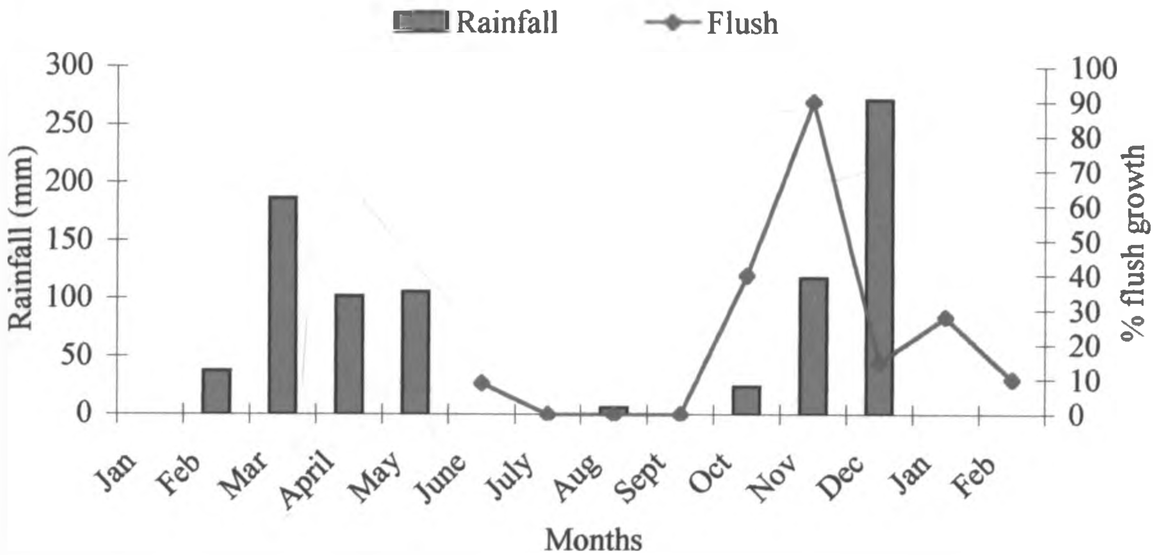

Fig.3.4. Flush growth occurrence and rainfall received in the Upper midlands of Machakos district in 2002

In the LM zone, there was one major flush period in October. Rains received in August and September preceded this flush growth (Fig.3.5). There was a minor flush period in August preceded by rains in July and pruning after the harvest of fruits by the farmers (Fig.3.5). A little flush growth was also observed in January as the rains continued to fall (Fig.3.5). In the LM, rains were received in all months of the year, with the least amounts in June, July and August (Fig.3.5). Flush growth in August, October and January preceded peaks of aphid populations in the LM. Vigorous flush growth of December-January coincided with the citrus psyllids population peak in January. The main flush period in the LM zone set in a month earlier than that in the UM zone. The pest high-density peaks, particularly the aphids and citrus psyllids, were preceded by rainfall and flush growth peaks.

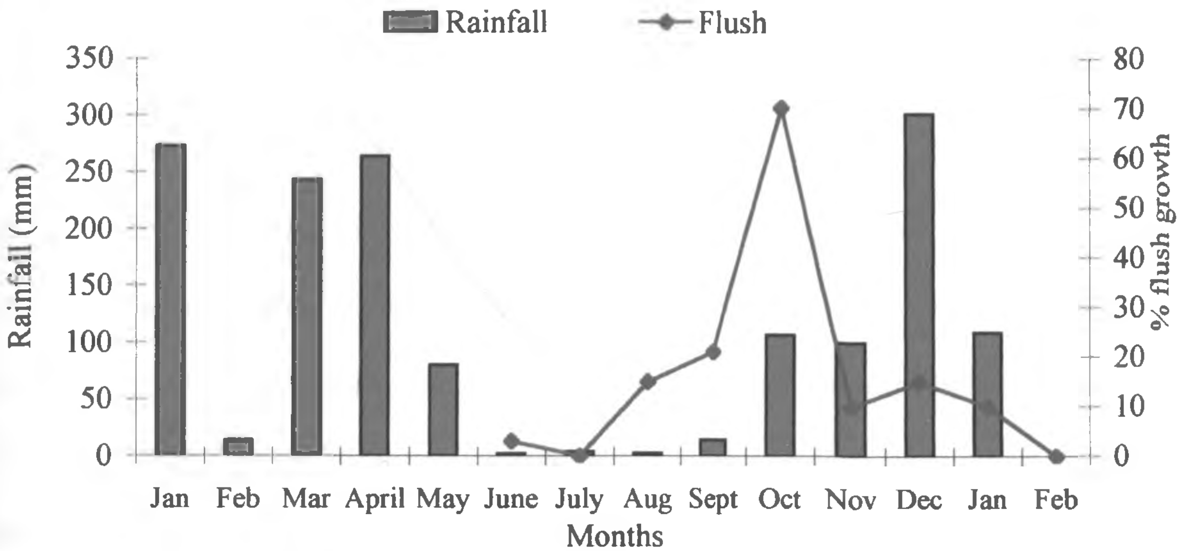

Fig. 3.5 Flush growth occurrence and rainfall received in the Lower midlands of Machakos district in 2002

3.4 DISCUSSION

Monitoring revealed that homopteran pests that attack citrus in these two agro-ecological zones include blackflies and whiteflies as key pests, aphids, citrus psyllids and scales as occasional pests. In the process of infesting the trees, the pest species attacked at different times appearing to hand over to one another e.g. as aphid populations reduced, the whiteflies and black flies populations increased (Figs.3.2 and 3.3). The trees were infested throughout, with the pest load at the lowest during the months of September, October and November, which were hot and dry. Though the study did not assess yield loss, continued infestation of the trees by these pests evidently indicates that losses would occur overtime.

All the pest species were active when there was vigorous flush. Whiteflies and blackflies colonized and utilized both the "feather" flush growth and less than a year old expanded young citrus leaves. Their densities increased with increase in temperature as the rainfall period tailed off giving way to a favourable warm climate that preceded the hot dry spell. Gonzalez (1980) reported that particular combinations of weather and site conditions lead to an increase in the suitability of tree foliage for herbivorous insects. This, through an increase in insect survival, gives rise to insect pest outbreaks. Camel and Way (1987) also reiterated the fact that in perennial crops, the abundance and distribution of insect pests are closely related to the growth pattern of the trees. Hence, the unlimited food supply to phytophagous insects causes them to multiply rapidly without restriction and with minimum exposure to hazards of dispersal (Southwood and Way, 1970). Although, the study did not investigate the movements of insect pests between habitats, it is reasonable to assume that there was a flow of these pests from alternative hosts and other orchards (Samways and Manicom, 1983). The importance of the surrounding environment particularly for citrus psyllids has already been highlighted in the past. Samways and Manicom (1983) suggested that there was influx of the citrus psyllid from the source of infestation and that the increase was almost a perfect exponential during the first weeks of infestation. In addition, the plants in the direction of the source were more infested. Thus, insect pest species that are generally mobile such as whiteflies, winged aphids and psyllids that are easily dispersed on wind currents. As opportunists, they reproduce rapidly and exploit the food resources on which they land.

Natural enemies of these pests (mainly coccinellids) were observed and counted. Their densities were very low compared to the pest population densities. These tended to increase slightly with increase in pest densities, particularly the aphids (Figs.3.2 and 3.3).

The natural enemies did not appear to have a great role in regulating the abundance of the pest species. Intra-specific competition and abiotic factors (weather changes in this case) appeared to be the major limiting factors regulating the pest densities. While discussing advantages and disadvantages of biological control Emden (1989) mentioned that in many situations, natural biological control is inadequate to keep herbivores below pest status. Price (1984) reported that natural enemies tend to respond to pest population changes rather than cause the changes, and that plant herbivores interaction was more important in regulating pest populations than the role of natural enemies.

Weather patterns played an important role in causing pest population fluctuations in the two zones. The least pest load occurred during the hot and dry spell (September, October and November). DeBach (1974) reported that, population fluctuations are influenced by important biotic and abiotic factors. These include weather and other physical factors such as competition, natural enemies and spatial as well as territorial requirements. Rarely do these factors act alone, although one may be the key regulatory factor responsible for a particular pest population in a given situation. Hot and dry weather determines the geographical distribution of pests and sustained adverse conditions dictate the seasonal abundance of the species (Samways, 1987). The results here also support this observation. During the hot and dry months (September-November) when rainfall was low or absent, pest populations were low compared with the months (June-August and December-February) when the weather conditions were favourable (cool and moist). Drought by definition means low or no rainfall. Good rains therefore provided enough ground water while pruning helped to conserve water, which encouraged good root growth and vigorous flush growth. Such a flush permits immediate peaks of egg production. These high densities of eggs lead to large numbers of nymphs and later adults. This suggests that good rains promote pest species outbreaks on a seasonal basis because of providing abundant food resources. It follows then; during good rains and flush growth an upsurge of pests is inevitable. Control measures must respond to this increase in pest numbers. Such measures should target to protect the flush growth, which is the desired site of infestation by these pest species. Applying systemic synthetic pesticides as suggested by Viggiani (2000) would help protect the flush growth. Pyle (1977) recommended the use of dimethoate as a soil drench just at the beginning of flush growth to protect it. Another alternative would be to spot spray the flush growth that is infested as opposed to spraying the whole tree or orchard. Conservation of the natural enemies to compliment pesticide applications is also an alternative by exerting the natural control to help protect the flush growth. Scouting as a component of pest management should be encouraged to help the farmers detect the presence and populations levels of the insect pest to help them take action.

CHAPTER FOUR

4.0 FIELD MANAGEMENT OF MAJOR CITRUS HOMOPTERAN PESTS (*Aphididae, Aleyrodidae, Coccidae and Psyllidae*) USING SELECTED SYNTHETIC INSECTICIDES IN MACHAKOS, EASTERN KENYA

4.1 INTRODUCTION

Chemical insecticides have been considered an essential component of insect pest control in the world (Dent, 2000). A lot of literature is available for the control of insect pests with the use of pesticides. However, excessive use of insecticides has created many problems, which include development of resistance of insect pests to pesticides, resurgence of pests and the toxic and persistent residues in food and the environment (Gunn and Steren, 1976; Gips, 1987; Conway and Pretty, 1991; Godase and Patel, 2001). The repeated use of these insecticides represent a sequential insecticide use strategy, so called because of the pattern observed in chemical management of using an insecticide constantly until it no longer provides adequate control, then moving on to another product in sequence. This is a practice commonly used by the farmers.

Farmers commonly use organophasphates (OP's) such as dimetheoate and diazinon to control insect pests. Organophosphates are highly toxic and are currently facing restrictions due to the Food Quality Protection Act 1996 (Zalom *et al.*, 1999). The OP's also have long residual toxicity (Bedford *et al.*, 1992). Leicht (1993) and Ishaaya and Horowitz (1998) have reported nitroguanidines (novel compounds) such as imidacloprid (Confidor ^{R}) to be new and relatively safe insecticides. Imidacloprid (Confidor ^{R}) is reported to be effective against sucking insects as well as some coleopteran and lepidopteran species (Elbert *et al.*, 1998; Yamamoto *et al.*, 1998). Under field conditions, levels of control that can be expected have equally been tested (Boiteau *et al.*, 1997). In Kenya, the pesticide is recommended for sucking insect pests and termite control and as a seed dress. It is not widely used because it is expensive. DC Tron, a narrow range is specifically formulated to control pests in place of broad-spectrum synthetic pesticides. Beattie (2000) presented it as a biorational pesticide suitable in IPM strategies for a range of crops, in a workshop for launching the pesticide product in Kenya. DC Tron was launched in Kenya to introduce the concept of using Petroleum Spray Oils' in IPM and assist the horticultural industry meet the requirements of maximum residue limits (MRL's) particularly for the European Union market.

Chemical insecticides have been reported to be effective against major pests and diseases of citrus (Davies and Albrigo, 1994). In Kenya, the use of insecticides to control pests of citrus has been recommended (Beige *et al.*, 1984). These include diazinon, dimethoate, fenitrothion, endosulfan, lambda cyhalothrin and alpha cypermethrin, Ambush and white oils. However, in Kenya where the majority of citrus growers are resource poor, (Seif, 1996), the use of insecticides is limited and has not been widely adopted as a technology. Besides the few farmers, (both large and small scale) that use these chemicals apply them indiscriminately often leading to hazardous effects to the environment and poor net gains/profits. Use of other restraints on pests other than pesticides, an approach often referred to as pest management is important (Burns *et al.*, 1987). It is therefore, necessary to develop, need-based application technologies that are environmentally friendly and cost effective. One way of deciding need-based use is threshold level but this may not be feasible in farmers' point of view and may not be practical where many pests are dealt with at any one time. This study was conducted to determine the efficacy of various insecticides and investigate the rational treatment schedule for their use in the control of citrus pests.

4.2 MATERIALS AND METHODS

4.2.1 Site

The field experiments were carried out for two seasons, long rains and short rains, of 2002 in Machakos District, Kenya. The area receives an average rainfall of 750-1200mm and experiences an average minimum 16°C and maximum 26°C temperatures (Jaetzold and Schimdt, 1983). Soils are reported to be of variable fertility. The studies were carried out simultaneously in two locations the upper midland (UM) and lower midland (LM) agro ecological zones described in Table 1.1. Each agro-ecological zone had three farms whose locations are shown in Table 1.2.

4.2.2 Field layout

Mature citrus orchards in farmers' fields were used for the experiment. The experimental crop was citrus (*C. sinensis*) sweet orange variety selected for being the most common variety grown in Kenya (70%) particularly the Washington Navel. Three mature Washington navel orchards per agro ecological zone/location were used. The trees aged 12-14 years old, with a spacing of 5x5m and an average tree height of 2-3m were used. The orchards each with approximately 100 trees were divided into 15 plots of four trees each. Fifteen treatments were allocated to each plot randomly within the farms. Plant stands for the trials were 50-60 per orchard. The plots were separated by rows of trees to reduce spray drift. The field lay out was a randomised complete block design with three replicates (three farms) having fifteen treatments inclusive of untreated control. All other orchard practices were done, except addition of commercial fertiliser in all farms and pruning in two farms in the UM zone.

4.2.3 Insecticides

The following formulations were used, Metasystox (oxydementon-methyl) 40 EC 250g active ingredient/litre, Confidor (Imidacloprid) 200SL 200g active ingredient/litre, a petroleum spray oil (PSO) DC Tron (98.8% refined) and a mixture of Metasystox and DC Tron. Metasystox and DC Tron were from Bayer Limited while DC Tron was from Caltex Limited. The following rates were applied:

Metasystox 20mls/20 litres water spray liquid for four trees.

Metasystox 10ml/ 5litres/m^2 canopy area – soil drench

Confidor 5ml/20 litres water foliar spray/4 trees

Confidor 10ml/ 5 litres water/m^2 canopy area – soil drench

DC Tron 100ml/20 litres water foliar spray/ 4 trees

DC Tron treatment 100mls oil+20mls OP/20 litres water foliar spray/4 trees

The application rates of the insecticides were constant in their respective treatment for all the trials. These were in line with the recommended field rates by the manufacturers.

4.2.4 Insecticide applications

The treatments used in the study were selected to represent insecticide classes with different modes of action. The treatments were continuous applications of Metasystox, Confidor, DC Tron and DC Tron and Metasystox mixture. DC Tron and Metasystox mixture was used to determine whether there is enhanced insecticide action (synergism) above that of the products applied singly. The repeated use of these four insecticides within their respective plots represents a sequential insecticide use strategy. This is a common practice among the farmers. The treatment schedules were as shown in table 4.1 below. Insecticide applications commenced on the week of 23rd June 2002 and the trials were run for 12 weeks in the first season and another 12 weeks in the second season from 29th November 2002. Application of insecticide being tested was done fortnightly or monthly using a lever operated knapsack sprayer (Hardi CP 15) with a hollow cone nozzle calibrated to deliver 0.61itres/min of spray liquid.

Table 4.1 Details of the treatment schedules used in the experiments.

Insecticide	Method of application	Frequency of application	Abbreviation
Metasystox	Foliar	Fortnightly	MFF
Metasystox	Foliar	Monthly	MFM
Metasystox	Soil drench	Fortnightly	MSF
Metasystox	Soil drench	Monthly	MSM
DC Tron Plus	Foliar	Fortnightly	DFF
DC Tron Plus	Foliar	Monthly	DFM
Confidor	Foliar	Fortnightly	CFF
Confidor	Foliar	Monthly	CFM
Confidor	Soil drench	Fortnightly	CSF
Confidor	Soil drench	Monthly	CSM
DC Tron + Metasystox	Foliar	Fortnightly	DMFF
DC Tron + Metasystox	Foliar	Monthly	DMFM
Water	Foliar	Fortnightly	WFF
Water	Soil drench	Fortinightly	WSF
Untreated control	Control	Control	Control

4.2.5 Pest sampling

Fortnight sampling of homopteran pests was done per treatment plot. The sampling was done on 10 randomly selected 15cm long growing shoots drawn from all four corners of the tree. All the pest counts were recorded separately. Data on pest densities were transformed into square root (x+1) and analyses of variance done to determine significance of treatment schedule effects. Where values from analysis indicated significant effects, LSD at 5% level was used to separate the means.

4.3 RESULTS

4.3.1 Insect pest situation on citrus

Major pests at the sites during the two cropping seasons (April-October 2002 and November 2002-March 2003) on citrus were aphids (*T. citricidus*), whiteflies (*A. flocossus*), blackflies (*A. woglumi*), scales (*Coccus viridis*), citrus psyllids (*T. erytreae*), groundnut leafhopper (*H. patruelis*), fruit flies (*C. capitata*) and mites (*P. citri*). Cercospora leaf and fruit spot disease was also prevalent. Whiteflies and blackflies were the most prevalent, present in varying densities throughout the period of study. Aphids, psyllids and the soft green scales were encountered occasionally only in the presence of tender flush growth on the trees. Overall pest load on citrus trees was higher in the first season compared to the second season. Natural enemies (mainly coccinellids) were encountered in low densities.

4.3.2 Effects of the treatment schedules on homopteran pests of citrus

The treatment schedules effectively reduced the pest populations. They showed varied effects on the different pests dealt with. MFF achieved lower pest populations than all other treatments schedules in the upper midlands but had varying effects in the lower midlands. The treatment schedule effects on the pests and natural enemies are shown in the tables that follow for both agro-ecological zones and seasons.

4.3.2.1 Upper Midland Zone

4.3.2.1.1 Citrus aphid species

In season 1, all treatment schedules significantly lowered aphid populations (P<0.001). However, there were no significant differences (P>0.05) among the treatment schedules. The exceptions were DFF, MFM, WSF and the control, which were not significantly different from each other. DFF had the highest aphid population. Similar results were achieved in season 2. The exceptions MSF, DFM, WFF and WSF that had the highest aphid numbers were significantly different from all other treatment schedules (Table 4.2).

Table 4.2 Effect of insecticide treatment schedules on the population of citrus aphids (*T. citricidus*) in the upper midland zone of Machakos district

Treatment	Mean number of citrus aphids on treated citrus per 15cm long growing shoot			
	2002 A		2002 B	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.077	1.011c	1.000	1.000d
MFM	1.181	1.081a	1.076	1.012d
MSF	1.035	1.007c	1.010	1.101bc
MSM	1.058	1.013c	1.000	1.026cd
DFF	1.447	1.083a	1.011	1.006d
DFM	1.060	1.017c	1.012	1.101bc
CFF	1.084	1.023c	1.012	1.023d
CFM	1.180	1.028bc	1.037	1.016d
CSF	1.211	1.037b	1.000	1.012d
CSM	1.204	1.033b	1.003	1.002d
DMFF	1.119	1.020c	1.000	1.006d
DMFM	1.027	1.007c	1.006	1.004d
WFF	1.032	1.008c	1.003	1.148b
WSF	1.134	1.037b	1.010	1.343a
Control	1.085	1.062ab	1.043	1.018d

Transformations as square root (x+1) used for analysis of data
2002 A period from June-Oct 2002, F-test = 3.75, P<0.001, l s d (0.05)= 0.036
2002 B period from Nov-Feb 2003, F-test = 10.92, P<0.001, l s d (0.05) =0.077
Means followed by the same letter in the column are not significantly different from each other.

4.3.2.1.2 Citrus wooly white flies

MFF schedule had the least whitefly population. It was significantly different from all other schedules (P<0.001) except DMFM (Table 4.3). MSF had the highest number of whiteflies and was significantly different from all the other schedules including the control. The exception was WSF. In season 2, all treatment schedules were not significantly different (P>0.05) except MFM, MSF, and MSM. MSM had the highest number of whiteflies but was not different from MFM, MSF (P>0.05) (Table 4.3).

Table 4.3 Effect of insecticide treatment schedules on the population of citrus woolly whitefly (*A. flocossus*) in the upper midland zone of Machakos district

Treatment	**Mean number of citrus whiteflies on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.879	1.294f	1.019	1.006d
MFM	2.769	1.586cd	1.019	1.073ab
MSF	1.727	2.062a	1.062	1.067ab
MSM	2.340	1.789bc	1.000	1.100a
DFF	1.761	1.531de	1.025	1.044bcd
DFM	1.960	1.721bd	1.003	1.047bcd
CFF	2.339	1.704bd	1.000	1.046bcd
CFM	1.627	1.618cde	1.015	1.012cd
CSF	1.859	1.729b	1.040	1.051bcd
CSM	2.104	1.770b	1.032	1.022cd
DMFF	1.735	1.646c	1.090	1.014cd
DMFM	2.222	1.397ef	1.013	1.013cd
WFF	2.586	1.782b	1.001	1.023cd
WSF	1.653	1.930ab	1.023	1.053bc
Control	1.637	1.604c	1.092	1.040bcd

Transformations as square root (x+1) used for analysis of data

2002 A period from June- Oct 2002, F-test = 5.55, $P<0.001$, l s d (0.05)=0.226

2002 B period from Nov-Feb 2003, F-test = 3.17, $P<0.001$, l s d (0.05) =0.041

Means followed by the same letter in the column are not significantly different from each other.

4.3.2.1.3 Citrus blackflies

All treatments lowered the blackfly population effectively. CSF had the highest blackfly numbers and was significantly different from all the other treatments ($P<0.001$). WSF had the second highest blackfly population but was not different with MSM, DFF and DMFF. All treatments were not significantly different ($P>0.05$) except MSM in season 2. MFM had the least blackfly numbers while MSM had the highest blackfly population (Tables 4.4).

Table 4.4 Effect of insecticide treatment schedules on the population of citrus black fly (*A. woglumi*) in the upper midland zone of Machakos district

Treatment	**Mean number of citrus blackflies on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.000	1.000d	1.019	1.003b
MFM	1.000	1.012cd	1.000	1.000b
MSF	1.002	1.008cd	1.001	1.006b
MSM	1.000	1.021bcd	1.000	1.033a
DFF	1.002	1.019bcd	1.000	1.000b
DFM	1.003	1.012cd	1.001	1.004b
CFF	1.000	1.005d	1.003	1.000b
CFM	1.000	1.011cd	1.011	1.007b
CSF	1.000	1.126a	1.000	1.010b
CSM	1.002	1.006cd	1.000	1.000b
DMFF	1.000	1.029bc	1.000	1.001b
DMFM	1.003	1.003d	1.001	1.001b
WFF	1.002	1.011cd	1.001	1.005b
WSF	1.006	1.042b	1.002	1.009b
Control	1.007	1.015cd	1.002	1.002b

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 13.31, $P<0.001$, l s d (0.05)=0.024
2002 B period from Nov-Feb 2003, F-test = 4.06, $P<0.001$, l s d (0.05) =0.012
Means followed by the same letter in the column are not significantly different from each other

4.3.2.1.4 Soft green scales

Treatment schedules lowered scale populations effectively, in season 1. DFM achieved the least scale population. It did not differ from all the other treatments ($P>0.005$). The exceptions were MFF, WSF and the control. Control had the highest scale numbers and was significantly different from all the other treatments. In season 2, very low densities of scale insects were encountered. No comparisons were possible (Table 4.5).

Table 4.5 Effect of insecticide treatment schedules on the population of scales (*C.viridis*) in the upper midland zone of Machakos district

Treatment	Mean number of soft green scales on treated citrus per 15cm long growing shoot			
	2002 A		2002 B	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.163	1.084bc	1.000	1.000a
MFM	1.209	1.043bcd	1.000	1.000a
MSF	1.000	1.016d	1.000	1.000a
MSM	1.071	1.008d	1.000	1.001a
DFF	1.247	1.045bcd	1.000	1.000a
DFM	1.000	1.000d	1.000	1.000a
CFF	1.113	1.024cd	1.000	1.000a
CFM	1.090	1.034cd	1.000	1.000a
CSF	1.000	1.021cd	1.000	1.002a
CSM	1.121	1.033cd	1.000	1.000a
DMFF	1.000	1.007d	1.000	1.000a
DMFM	1.000	1.011d	1.000	1.000a
WFF	1.000	1.000d	1.000	1.000a
WSF	1.039	1.108b	1.000	1.002a
Control	1.276	1.189a	1.000	1.000a

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 4.65, P<0.001, l s d (0.05)=0.066
2002 B period from Nov-Feb 2003, F-test = 1.16, P=0.301, l s d (0.05) =0.002
Means followed by the same letter in the column are not significantly different from each other

4.3.2.1.5 Citrus psyllids

The treatment schedules reduced citrus psyllid populations effectively. In season 1, CFF had the highest citrus psyllid population and was significantly different from all the other treatments (P<0.001)) except CSM. DMFM, DFM, CSF and CSM did not differ. The rest of the treatments did not differ from each other (P>0.05). In season 2, there was little psyllid activity. However, MSM had the highest citrus psyllid population but was not different from CFF, DMFM and DMFF (P>0.05). All the other treatments were not significantly different (Table 4.6).

Table 4.6 Effect of insecticide treatment schedules on the population of citrus psyllid (*T. erytreae*) in the upper midland zone of Machakos district

Treatment	Mean number of citrus psyllids on treated citrus per 15cm long growing shoot			
	2002 A		2002 B	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.004	1.001c	1.000	1.000c
MFM	1.002	1.000c	1.000	1.001c
MSF	1.000	1.000c	1.000	1.002c
MSM	1.000	1.000c	1.001	1.012ab
DFF	1.000	1.000c	1.000	1.000c
DFM	1.038	1.012bc	1.000	1.000c
CFF	1.185	1.040a	1.042	1.010ab
CFM	1.000	1.004c	1.000	1.000c
CSF	1.073	1.012bc	1.000	1.002c
CSM	1.173	1.028ab	1.000	1.000c
DMFF	1.000	1.000c	1.010	1.007ab
DMFM	1.093	1.023b	1.020	1.004bc
WFF	1.000	1.000c	1.000	1.000c
WSF	1.000	1.000c	1.000	1.000c
Control	1.000	1.000c	1.000	1.000c

Transformations as square root (x+1) used for analysis of data

2002 A period from June- Oct 2002, F-test = 4.81, P<0.001, l s d (0.05)=0.016

2002 B period from Nov-Feb 2003, F-test = 1.16, P=0.040, l s d (0.05) =0.008

Means followed by the same letter in the column are not significantly different from each other

4.3.2.1.6 Natural enemies (Coccinellids)

There were no significant differences between treatment schedules (P>0.05) in season 1. However, CFF had the highest number of coccinellids. WSF had the highest number of coccinellids in season 2 and was significantly different from all the other treatments (P<0.001) (Table 4.7)

Table 4.7 Effect of insecticide treatment schedules on the population of natural enemies (coccinellids) in the upper midland zone of Machakos district

Treatment	**Mean number of natural enemies on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.014	1.002a	1.000	1.000b
MFM	1.004	1.001a	1.008	1.001b
MSF	1.000	1.002a	1.000	1.002b
MSM	1.007	1.005a	1.000	1.001b
DFF	1.000	1.001a	1.000	1.000b
DFM	1.039	1.005a	1.004	1.001b
CFF	1.000	1.008a	1.000	1.001b
CFM	1.000	1.004a	1.000	1.001b
CSF	1.000	1.003a	1.000	1.000b
CSM	1.000	1.001a	1.000	1.000b
DMFF	1.000	1.001a	1.000	1.001b
DMFM	1.026	1.004a	1.030	1.005b
WFF	1.000	1.000a	1.000	1.001b
WSF	1.000	1.005a	1.000	1.016a
Control	1.000	1.001a	1.000	1.000b

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 1.51, P= 0.099 NS, l s d (0.05)=0.007
2002 B period from Nov-Feb 2003, F-test = 2.6, P<0.001, l s d (0.05) =0.003
Means followed by the same letter in the column are not significantly different from each other

4.3.2.2 Lower Midlands zone

4.3.2.2.1 Citrus aphid species

In season 1, Control had the highest aphid population and it differed significantly from all other treatments (P<0.001). In season 2, WSF had the highest aphid population but did not differ with the control. MFM, MSF, CFF, DMFF and DMFM did not differ from the control. In both seasons, DFF had the least aphid populations (Table 4.8).

Table 4.8 Effect of insecticide treatment schedules on the population of citrus aphids (*T. citricidus*) in the lower midland zone of Machakos district

Treatments	**Mean number of citrus aphids on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.000	1.043bc	1.004	1.028de
MFM	1.000	1.001c	1.003	1.063bc
MSF	1.006	1.122b	1.247	1.066bc
MSM	1.000	1.000c	1.004	1.031cde
DFF	1.000	1.000c	1.003	1.003e
DFM	1.000	1.003c	1.003	1.028de
CFF	1.000	1.000c	1.003	1.055bc
CFM	1.000	1.000c	1.004	1.008de
CSF	1.000	1.000c	1.004	1.005de
CSM	1.000	1.137b	1.000	1.032cde
DMFF	1.000	1.060bc	1.293	1.057bcd
DMFM	1.000	1.006c	1.000	1.040bcde
WFF	1.000	1.000c	1.003	1.013de
WSF	1.000	1.038bc	1.003	1.132a
Control	1.000	1.355a	1.174	1.088ab

Transformations as square root (x+1) used for analysis of data
2002 A period from June-Oct 2002, F-test = 6.95, P<0.001, l s d (0.05)= 0.101
2002 B period from Nov-Feb 2003, F-test = 3.64, P<0.001, l s d (0.05) =0.052
Means followed by the same letter in the column are not significantly different from each other

4.3.2.2.2 Citrus wooly whiteflies

In the first season, WSF had the highest whitefly population and was significantly different from all other treatments (P<0.001) except DMFF. DFF had the least whitefly population but was not significantly different from MFF, MFM CFF, CFM, CSM and WFF. In season 2, all treatments controlled the whiteflies effectively compared to the Control except WSF. CSF had the least whitefly populations and was significantly different from all the other treatments. The rest showed no significant differences from each other (P>0.05) except MFM (Table 4.9).

Table 4.9 Effect of insecticide treatment schedules on the population of citrus wooly whitefly (*A. flocossus*) in the lower midland zone of Machakos

Treatments	**Mean number of citrus whiteflies on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	2.554	1.261bc	1.174	1.134cd
MFM	1.327	1.148c	1.371	1.227c
MSF	1.128	1.264b	1.331	1.103de
MSM	2.281	1.335b	1.100	1.067de
DFF	1.373	1.060c	1.056	1.065de
DFM	1.785	1.317b	1.112	1.083de
CFF	1.641	1.141c	1.165	1.079de
CFM	1.348	1.107c	1.027	1.034de
CSF	1.858	1.332b	1.044	1.023e
CSM	1.438	1.224c	1.022	1.091de
DMFF	2.473	1.679a	1.046	1.098de
DMFM	2.213	1.268b	1.046	1.105de
WFF	1.895	1.246c	1.035	1.042de
WSF	1.731	1.848a	1.387	1.557a
Control	1.306	1.467b	1.092	1.341b

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 7.78, P<0.001, l s d (0.05)=0.211
2002 B period from Nov-Feb 2003, F-test = 14.69, P<0.001, l s d (0.05) =0.102
Means followed by the same letter in the column are not significantly different from each other

4.3.2.2.3 Citrus blackflies

In season 1, MFM had the highest blackfly population. It was significantly different from all the other treatments. CSM had the least population and was different from all other treatments. Similarly, MFM had the highest blackfly population while CSM had the least population (P<0.001) (Table 4.10).

Table 4.10 Effect of insecticide treatment schedules on the population of citrus blackfly (*A. woglumi*) in the lower midland zone of Machakos district

Treatments	**Mean number of citrus blackflies on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.040	1.088de	1.143	1.072cde
MFM	1.024	1.352a	2.064	1.475a
MSF	1.040	1.088de	1.120	1.043cde
MSM	1.102	1.075de	1.267	1.084cd
DFF	1.024	1.204b	1.205	1.073ce
DFM	1.024	1.161bc	1.283	1.099c
CFF	1.090	1.051de	1.017	1.032de
CFM	1.040	1.088de	1.129	1.103c
CSF	1.040	1.189bc	1.028	1.043cde
CSM	1.000	1.016e	1.029	1.019e
DMFF	1.003	1.085de	1.000	1.031de
DMFM	1.000	1.188bc	1.019	1.026de
WFF	1.024	1.117cd	1.129	1.051cde
WSF	1.224	1.206b	1.068	1.065cde
Control	1.040	1.122cd	1.533	1.262b

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 10.20, P<0.001, l s d (0.05)=0.072
2002 B period from Nov-Feb 2003, F-test = 26.39, P<0.001, l s d (0.05) =0.062
Means followed by the same letter in the column are not significantly different from each other

4.3.2.2.4 Soft green scales

In season 1, all treatments lowered the scale numbers effectively except CSF, which had the highest scale numbers and was significantly different from all the treatments including Control (P<0.001). CSM, DMFF had the least scale populations but were not different from all the other treatments except DFM, CFM, WSF, CSF and Control. In season 2, CSF had the highest scale numbers and was significantly different from all the other treatments except WSF. WSF is, however, not different from WFF and DFF. DMFF and DMFM had the least scale populations but were not diff from all except MSM, DFF, CSF, WFF, WSF and Control (P<0.001). DFF and MSM were not different from the Control (P>0.05) (Table 4.11).

Table 4.11 Effect of insecticide treatment schedules on the population of soft green scales (*C. viridis*) in the lower midland zone of Machakos district

Treatments	Mean number of soft green scales on treated citrus per 15cm long growing shoot			
	2002 A		2002 B	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.006	1.078e	1.000	1.006ef
MFM	1.004	1.013e	1.000	1.038ef
MSF	1.006	1.006e	1.000	1.043ef
MSM	1.418	1.074de	1.000	1.170cd
DFF	1.208	1.095de	1.000	1.230bc
DFM	1.266	1.240bc	1.000	1.062ef
CFF	1.023	1.048de	1.000	1.004ef
CFM	1.012	1.177c	1.000	1.012ef
CSF	2.774	1.492a	1.000	1.398a
CSM	1.002	1.002e	1.000	1.020ef
DMFF	1.002	1.002e	1.000	1.002f
DMFM	1.002	1.004e	1.000	1.002f
WFF	1.004	1.067de	1.000	1.245b
WSF	1.606	1.224bc	1.000	1.282ab
Control	1.195	1.247b	1.000	1.100dce

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 7.00, P<0.001, l s d (0.05)=0.143
2002 B period from Nov-Feb 2003, F-test = 12.79, P<0.001, l s d (0.05) =0.098,
Means followed by the same letter in the column are not significantly different from each other

4.3.2.2.5 Citrus psyllids

CFM treatment plot was the only one infested by psyllids during the study in season 1. In season 2, more citrus psyllid activity was observed. WSF had the highest citrus psyllid population. The treatment was, however, not different from MSF, WFF and CFF. CSM and DMFF had the least numbers. WSF, CFF MSF and WFF were significantly different from all the other treatment schedules (P<0.001) (Table 4.12).

Table 4.12 Effect of insecticide treatment schedules on the population of citrus psyllid (*T. erytreae*) in the upper midland zone of Machakos district

Treatments	**Mean number of citrus psyllids on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.000	1.000a	1.001	1.007b
MFM	1.000	1.000a	1.000	1.022b
MSF	1.000	1.000a	1.000	1.047ab
MSM	1.000	1.000a	1.000	1.004b
DFF	1.000	1.000a	1.000	1.004b
DFM	1.000	1.000a	1.012	1.028b
CFF	1.000	1.000a	1.040	1.050a
CFM	1.008	1.011a	1.001	1.007b
CSF	1.000	1.000a	1.001	1.016b
CSM	1.000	1.000a	1.000	1.001b
DMFF	1.000	1.000a	1.000	1.001b
DMFM	1.000	1.000a	1.000	1.010b
WFF	1.000	1.000a	1.020	1.045ab
WSF	1.000	1.000a	1.353	1.091a
Control	1.000	1.000a	1.096	1.025b

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 1.12, P= 0.340, l s d (0.05)=0.011
2002 B period from Nov-Feb 2003, F-test = 2.16, P=0.007, l s d (0.05) =0.047
Means followed by the same letter in the column are not significantly different from each other

4.3.2.2.6 Natural Enemies (Coccinellids)

In season 1, CFM had the highest number of coccinellids. It was significantly different from all the other treatments ($P<0.001$). DMFM had the least coccinellids population in season 1 but was not different from all the other treatments except CFM. In season 2 WSF had the highest number of coccinellids but was not significantly different from CFM, CSF, DFF and the Control. CFF had the least number of coccinellids and was not different from all the other treatments except WSF, CFM, CSF, DFF and Control ($P>0.05$) (Table 4.13).

Table 4.12 Effect of insecticide treatment schedules on the population of citrus psyllid (*T. erytreae*) in the upper midland zone of Machakos district

Treatments	**Mean number of citrus psyllids on treated citrus per 15cm long growing shoot**			
	2002 A		**2002 B**	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.000	1.000a	1.001	1.007b
MFM	1.000	1.000a	1.000	1.022b
MSF	1.000	1.000a	1.000	1.047ab
MSM	1.000	1.000a	1.000	1.004b
DFF	1.000	1.000a	1.000	1.004b
DFM	1.000	1.000a	1.012	1.028b
CFF	1.000	1.000a	1.040	1.050a
CFM	1.008	1.011a	1.001	1.007b
CSF	1.000	1.000a	1.001	1.016b
CSM	1.000	1.000a	1.000	1.001b
DMFF	1.000	1.000a	1.000	1.001b
DMFM	1.000	1.000a	1.000	1.010b
WFF	1.000	1.000a	1.020	1.045ab
WSF	1.000	1.000a	1.353	1.091a
Control	1.000	1.000a	1.096	1.025b

Transformations as square root (x+1) used for analysis of data

2002 A period from June- Oct 2002, F-test = 1.12, P= 0.340, l s d (0.05)=0.011

2002 B period from Nov-Feb 2003, F-test = 2.16, P=0.007, l s d (0.05) =0.047

Means followed by the same letter in the column are not significantly different from each other

4.3.2.2.6 Natural Enemies (Coccinellids)

In season 1, CFM had the highest number of coccinellids. It was significantly different from all the other treatments (P<0.001). DMFM had the least coccinellids population in season 1 but was not different from all the other treatments except CFM. In season 2 WSF had the highest number of coccinellids but was not significantly different from CFM, CSF, DFF and the Control. CFF had the least number of coccinellids and was not different from all the other treatments except WSF, CFM, CSF, DFF and Control (P>0.05) (Table 4.13).

Table 4.13 Effect of insecticide treatment schedules on the population of natural enemies (coccinellids) in the lower midland zone of Machakos district

Treatments	Mean number of natural enemies on treated citrus per 15cm long growing shoot			
	2002 A		2002 B	
	Pre-spray	Mean/6samplings	Pre-spray	Mean/6samplings
MFF	1.027	1.006b	1.034	1.007b
MFM	1.001	1.003b	1.009	1.004b
MSF	1.001	1.006b	1.008	1.002b
MSM	1.001	1.004b	1.008	1.004b
DFF	1.001	1.004b	1.001	1.014a
DFM	1.031	1.002b	1.033	1.006b
CFF	1.001	1.002b	1.001	1.001b
CFM	1.056	1.020a	1.056	1.020a
CSF	1.015	1.012b	1.015	1.015a
CSM	1.000	1.003b	1.010	1.010b
DMFF	1.000	1.005b	1.010	1.003b
DMFM	1.000	1.000b	1.018	1.003b
WFF	1.001	1.002b	1.017	1.005b
WSF	1.066	1.020b	1.082	1.025a
Control	1.056	1.020b	1.049	1.018a

Transformations as square root (x+1) used for analysis of data
2002 A period from June- Oct 2002, F-test = 3.89, P< 0.001, l s d (0.05)=0.010
2002 B period from Nov-Feb 2003, F-test = 3.05, P< 0.001, l s d (0.05) =0.012
Means followed by the same letter in the column are not significantly different from each other

4.4 DISCUSSION

On-farm trials have demonstrated that homopteran pests do infest citrus and that these pests infest the trees at different times within the season. These pests have been reported to attack citrus elsewhere in the world (Davies and Albrigo, 1994; Huang *et al.*, 2000). Their importance as pests varies from country to country. Davies and Albrigo (1994) have reported that chemical control is the main method used by citrus growers all over the world to control pests and diseases. Smith *et al.* (1997) emphasises that synthetic insecticides remain a major technique and an easy tool for controlling pest populations on citrus trees. In the farmers' fields the treatment schedules had varying effects on individual pests. While OP's and Confidor lowered aphids and citrus psyllids, the mixture of DC Tron and Metasystox best lowered scales. This could be attributed to the source of active ingredient and the mode of action of the pesticides. Higher whiteflies populations were recorded than other pests in both zones. This could be attributed to the nature of the insects. Aphids and citrus psyllids are soft bodied while a hard wax layer and a mealy wax layer covers the scales and whiteflies, respectively. No treatment schedule was superior to others in their effect of controlling the pest complex singly. Neither method of application nor frequency of application also emerged as superior. Monthly foliar applications of Confidor (CFM), DC Tron and Metasystox mixture (DMFM) and fortnightly foliar applications of confidor (CFF), DC Tron (DFF) had high counts of natural enemies. This indicates their ability to conserve natural enemies.

Confidor and DC Tron were as effective as Metasystox in reducing homopteran pest populations on citrus. These results agree with others achieved elsewhere in the world. Leong *et al.* (2000) concluded that all insecticides provided similar effective control when they compared petroleum spray oils (PSO's) and conventional pesticides for the control of major citrus pests in Malaysia. These major pests included the Asiatic citrus psyllid, citrus leaf miner, black citrus aphids, armoured scales, mealy bugs and whiteflies. Huang *et al.*, (2000) on the other hand concluded that the PSO's lowered populations of major insects better than the conventional insecticides. Whereas the OP's have superb control of the major pests of citrus, Bedford *et al.* (1992) have recommended that OP'S and pyrethroids should not be used in IPM programs because of their long residual toxicity. In addition, the OP's are under restriction because of their toxicity to man and the environment (Zalom *et al.*, 1999).

The re-discovery that petroleum derived spray oils can be used to control leaf miner by Beattie *et al.* (1995) has had a major impact in the development of the use of spray oils in multiple spray programs at low concentrations as opposed to the single doses promoted in Australian IPM programs since the 1970's. Recent emphasis has focused on using PSO's as alternatives to synthetic chemicals to reduce the negative impact of the synthetic chemicals on the biodiversity of the citrus ecosystem and human health (Nguyen, 2000). The use of DC Tron in this study was in step with the worldwide focus. PSO's have been reported to be efficient against citrus mites, scales, whiteflies, citrus psyllids and leaf miners (Cen Yijing *et al.*, 1999). DC Tron can be used as an alternative to synthetic pesticides such as pyrethroids and organophosphates.

In this study, Confidor (imidacloprid) effectively reduced pest populations. This agrees with Elbert *et al.* (1998) and Yamamoto *et al.* (1998) who reported the pesticide to be effective against sucking insects. Nakaro *et al.* (1999) reported the high efficiency of various concentrations and formulations of Confidor for the control of the citrus psyllid (*Diaphorina citri*) in Brazil. Marquini *et al.* (2002) however, reported the negative impact of imidacloprid (Confidor) on the overall arthropod abundance while assessing its temporal effectiveness and environmental safety to the arthropod community associated with the canopy of the common beans.

Apart from reducing the pest populations, the treatment schedules also reduced natural enemy populations, an undesirable effect. Theiling and Croft (1988) demonstrated that pesticides impacted negatively on all types of natural enemies with insecticides having the most negative impact. Bellows *et al.* (1985) reported a range of impacts from no impact to 50% mortalities up to one month after treatment when testing various organophosphates for their impact on natural enemies. Metasystox is reported to have negative effects on natural enemies (Gravena *et al.*, 1988). Casterner *et al.* (1988) have demonstrated its negative effect on the ladybird beetle (*C. Montzeouri* Muls.) a predator of scales and the mealy bug (*P. citri*).

In this study, PSO (DC Tron) and imidacloprid (Confidor) had higher natural enemy (coccinellid) numbers than oxydementon methyl (Metasystox) suggesting that they can preserve natural enemies while effectively reducing the pest populations. PSO's have been proved effective against citrus pests such as mites, scales, whiteflies, citrus psyllids, leaf miner and aphids while they were safe on natural enemies (Cen Yijing *et al.*, 1999; Leong *et al.*, 2000; Beattie, 2000). Marquini *et al.* (2002) reported low toxicity of imidacloprid on natural enemies exemplified by spiders. Tanaka *et al.* (2000) reported similar results. However, the same authors, Tanaka *et al.* (2000) reported the high toxicity of imidacloprid to the predator *Cytorhinus lividipennis* (Heteroptera: Miridae) and the parasitoid wasp *Naplogonatopus apicalis*. Its high toxicity to *Rodolia cardinalis* (Coleoptera: Coccinellidae), a predator of scales, and the encytrid *Leptomastix dactylopii* has also been reported (Viggiani *et al.*, 1998). However, the same authors reported that Confidor did not prevent the emergence of braconids (parasitoids) and chalcids (hyperparasitoids) from mummies of the aphid (*Aphis spiraecola*) on mandarins. Results of this study reinforce the idea of low ecotoxicity of imidacloprid on natural enemies.

However, these results may or may not occur in other agro-ecosystems inhabited by more susceptible species.

Water application on a fortnightly basis to the leaves or as soil drench had high homopteran populations suggesting that there was enough moisture available for the plant to sustain the plant sap utilized by the homopteran pests. The coccinellid populations were also high suggesting that latent pest populations are capable of sustaining natural enemies to exert natural control on the pests and prevent pest outbreaks (Vickerman and Wratten, 1979). These results are consistent with the reports that in a crop that has not been sprayed with pesticides various predatory insects are expected (Clausen, 1940; Nyambo *et al*., 1994). They also reinforce the idea that enough moisture in the soil encourages active citrus growth which in turn supports high densities of insect pest populations as has been observed in the monitoring studies (Chapter 3).

Methods of applications did not differ significantly suggesting that, either method can be used with high efficiency in reducing pest populations. Soil drench is a more desirable method in an IPM approach to help conserve natural enemies that are important in the agro-ecosystem. A disadvantage of the method is that the effect of an insecticide may be reduced by climatic conditions, particularly when it is hot and dry (Boiteau *et al*., 1997). DC Tron and Confidor foliar applications schedules had the high natural enemy numbers indicating there ability to conserve natural enemies. Fortnightly and monthly frequencies of application did not differ significantly suggesting that any frequency can be used with maximum effect in reducing pest populations. The frequency that ensures 'restraint' for pesticide use is the most desirable. Hence the monthly schedule is more appropriate. High natural enemy numbers were recorded in the monthly schedules suggesting that this frequency has the ability to reduce pests while conserving natural enemies present in the agro-ecosystem. Treatment schedules (insecticide + method + frequency) used as independent treatments can be used to incorporate the rational use of insecticides in pest management strategies that are designed to practice pesticide restraint.

CHAPTER FIVE

5.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 DISCUSSION

This study has shown that many insect species are associated with cultivated citrus in Kenya. Their abundance and distribution varied with location and season. This appeared to be related to the altitude. A hundred and seventeen insect species were identified, eighty-seven of which were pest species and thirty were beneficial insect species. The insect complex is similar to that reported elsewhere in the world (Vyas, 1994; FAO, 1996a; Smith *et al.*, 1997; Kalita, 1998). The exception is the groundnut leafhopper *Hilda patruelis* which seems to be a pest of Tropical Africa having been reported in Tanzania (Le Pelley, 1959; Bohlen, 1973) and now recorded by this study on citrus in Kenya. Many of these pest species are known as pests of other crops such as grain legumes (Rao and Shanower, 1999). They occurred in low frequencies suggesting that they are under adequate natural control. This natural control is sometimes disrupted by pesticide use (Nyambo *et al.*, 1994). The pest complex was influenced by cultural practices particularly the practice of intercropping for maximum land use. Crops used to intercrop are legumes, cereals, tuber crops, fruit trees and vegetables. Pests of importance are the citrus psyllids, citrus aphids, citrus wooly whiteflies, leafhoppers, leaf miner, scales and the citrus blackflies. These results are similar to others reported elsewhere (Beattie, 2000; Huang *et al.*, 2000; Leong *et al.*, 2000; Nguyen, 2000). Some of these major pests are vectors of serious diseases such as HLB disease, citrus tristeza, psorosis, citrus variegated chlorosis and citrus canker, which have been reported in Kenya (Seif and Hillock, 1993). This implies that an effective management strategy is required aimed at controlling disease vectors as well.

Results also indicate farmers perceived pests and diseases as the major citrus production constraint a finding consistent with that of Obukosia *et al.* (1999) during a participatory appraisal to identify citrus production constraints in Kenya. They relied on their own knowledge to control insect pests and used conventional pesticides to control citrus insect pests. The choice of pesticides depended on popularity and perception of its efficiency by the farmers. Commonly used pesticide products were synthetic pyrethroids (e.g lamda-cyhalothrin) and organophosphates such as dimethoate and diazinon. These have been used with great efficiency against crop pests. However, their use in IPM programmes is discouraged (Bedford *et al.*, 1992). They are also facing restriction by the Food Quality Protection Act (Zalom *et al.*, 1999). For lack of adequate information, the pest management strategies taken by the farmers were inadequate to deal with citrus insect pest problems. It is necessary to train farmers on identification of insect pests and associated natural enemies before pesticide use is adopted on a wide scale like it is in other horticultural crops.

This study has also shown that many insects associated with cultivated citrus are beneficial species either predators or parasitoids. These included the araneae, coccinellidae, syrphidae, chrysopidae, anthocoridae, staphylinidae, tachnidae, mantidae and reduviidae. Smith *et al.*, (1997) has a similar list of natural enemies compiled from collections and published work from all over the world. Spiders and the coccinellids were the most abundant and conspicuous component of the natural enemy complex. These findings are consistent with those of Marquini *et al.* (2002) while dealing with the common bean canopy arthropod complex. Dippenar-Schoeman and Berg (2001) have reported spiders as a conspicuous natural enemy component in Macadamia orchards. Unfortunately, the importance of spiders as predators has not been studied in many crops and little is known about their contribution to biological control of citrus pests. The role of natural enemies in checking pest populations cannot be overemphasised. However, the modern farmer with efficient insecticides to help him protect his crop little realises the dangers of chemicals to natural enemies. Reed and Lateef (1990) highlighted the importance of farmers becoming familiar with insects and other animals that inhabit crops and not simply treating plants with pesticides as soon as they see a few insects. The natural enemy role could be enhanced through conservation provided that sound citrus pest management programmes are established. The challenge now is to determine how these can be conserved to exert maximum potential in checking pest populations.

Fortnightly field monitoring of homopteran pests of citrus has shown that pest populations fluctuated with location and season, affected mainly by weather conditions. Heavy pest loads occurred in June-August and December-February, the cool and wet periods of the year, characterized by heavy and active flush growth development. Lighter pest loads occurred in September-November, the hot and dry months of the year with low densities of flush growth. Flush growth provided plenty of food resources that supported the build up of pests to high levels. Major pest declines occurred during the hot and dry periods of the year. This finding is consistent with that of Southwood and Way (1970) who reported that unlimited food supply to phytophagous insects causes them to multiply rapidly. Flush growth appears to be the target infestation site. By virtue of favouring and supporting high densities of insect pest population flush growth requires protection. This will prevent build up of pests, reduce losses and risks of disease infection and spread by disease vectors. Active flush growth seems to be the most effective spray period. Pyle (1977) recommended soil drench dimethoate in the orchards in order to protect the flush growth for six weeks. Unfortunately, while using this method, the effect of an insecticide may be reduced by climatic conditions, particularly when it is hot and dry (Boiteau *et al.*, 1997). Dimethoate is also harmful to rough lemon plants. Rough lemons are widely used as rootstocks in Kenya.

During the study, monitoring revealed low densities of natural enemies (mainly coccinellids). Potts and Vickerman (1974) reported similar results while determining the effect of various control strategies on cereal aphids. Some authors believe that coccinnellids require certain threshold densities of pests to remain and breed in a field, but unfortunately, these thresholds are not known (Vickerman and Wratten, 1979). Low density occurrence of the natural enemies suggests that they did not have a significant role in the pest population fluctuations. The key factor responsible for pest population variation was the weather.

Citrus farmers in Kenya are unaware of monitoring, and its benefits. Monitoring is useful for indicating the presence of pests and early identification of pests. It also provides an estimate of the pest population levels involved for pest management actions to be taken.

Adopting pest monitoring would aid better use of pesticides on citrus in Kenya. Scouting involves counting of pests on sufficiently representative number of plants in the crop. However, Camel and Way (1987) have reported monitoring as being time-consuming and expensive. Elsewhere traps are increasingly being used by farmers for monitoring since it takes less time for them to visit a set number of traps regularly than to walk in the field and scout individual plants (Emden, 1989). Training farmers on scouting will help incorporate monitoring in their citrus pest management strategies. In this study, scouting involved actual counting of individual pests on representative number of plants, a process that took a lot of time. This could be modified further to suit the farmers by establishing some form of economic threshold based on simple measures such as per cent growing shoots infested by the pests. For example, an economic threshold of 5% stems of beans infested in a field, used in England to control black bean aphids (Emden, 1989).

Conventional pesticides are expensive and unaffordable in developing countries (Keilany, 2002). In addition, problems related to pesticide use are well known. Steps have been taken to reduce the negative impact of synthetic insecticides on the biodiversity of the citrus ecosystem and human health. Recent emphasis has focused on the use of Petroleum Spray Oils (PSO's) as alternatives to synthetic chemicals (Beattie, 2000). In addition, need-based applications of pesticides have been suggested in IPM (Godase and Patel, 2001). The one way of deciding need-based use is 'threshold levels'. However, its practical feasibility is doubtful in farmers' point of view. In this study, efforts have been made to rationalize spray schedules so that only sprays that impart maximum protection can be suggested at specific periods of crop growth. The treatment schedules tested using Metasystox, DC Tron and Confidor applied as foliar or soil drench at fortnightly or monthly intervals demonstrated the ability to reduce homopteran pest populations on citrus. Although metasystox (OP) best reduced the population densities, it is very toxic and is facing restriction (Zalom *et al.*, 1999). It is also harmful to the natural enemies (Theiling and Croft, 1988). DC Tron and Confidor can be used as effective alternatives. Cen Yijing *et al.* (1999) reported DC Tron as being effective in controlling homopteran pests while conserving natural enemies. Similarly, Confidor has been reported to be effective on sucking pests (Elbert *et al.*, 1998; Tanaka *et al.*, 2000; Marquini *et al.*, 2002). However, Tanaka *et al.* (2000) reported the negative effect of confidor on a predator *Cytorhinus lividipennis* (Heteroptera: Miridae) and the parasitoid wasp *Naplogonatopus apicalis*. Results from this study have, however, demonstrated the low ecotoxicity of both pesticides, DC Tron and Confidor. Foliar and soil drench methods of applications and fortnightly and monthly regimes did not show any advantages over each other in controlling the pest complex dealt with. This suggests that either could be used in a citrus pest management programme. Soil drench method of application and the monthly regimes are more appropriate in IPM programmes to help conserve natural enemies and reduce pesticides use as well as the risks of toxicity to the farmer and the environment. Monthly schedules of either DC Tron or Confidor can be used to protect the flush growth identified as the critical period for protection of citrus, in monitoring studies. Confidor soil drench will be suitable for all the cultivars unlike dimethoate, which had harmful effects on rough lemon.

Synthetic chemical pesticides will continue to play a role in citrus pest management strategies because of the number of pests involved which require more than a single strategy for control (Nyambo *et al.*, 1994). To optimise the benefits of pesticide use, farmers should be educated and encouraged to use the pesticides properly and judiciously. IPM should be the future path towards improved environmental conservation, increased food and cash income and reduced pest pressure and losses in citrus. IPM is a flexible approach that utilises a combination of suitable techniques to hold pest populations below economic threshold levels. It aims at encouraging judicious use of chemical pesticides at low cost and with minimum hazard to the environment and non-target organisms.

5.2 CONCLUSIONS

Citrus is an important fruit crop that has a potential of reducing poverty among the small-scale farmers in Kenya. It is associated with many insect species both destructive and beneficial belonging to ten orders and fifty-eight families. Important citrus pests constraining citrus production include citrus aphids, citrus wooly whiteflies, citrus blackfly, citrus psyllids, scales, leafhoppers and leaf miner. Aphids, psyllids, leafhoppers and leaf miner are also vectors of serious citrus diseases, which are HLB disease, tristeza, psorosis, citrus variegated chlorosis and citrus canker, known to be present in Kenya. An effective pest control strategy to prevent direct damage or the spread of diseases is urgently needed. Farmers mainly used chemical control as a strategy to deal with citrus pest problems; but for lack of adequate information, the control strategies taken were inadequate. In addition, the citrus canopy has a rich and diverse natural enemy complex, which is conspicuously dominated by the spiders and the coccinnellids. The implication is that most citrus pests are currently under some form of natural control that prevents outbreaks from occurring. The challenge remains in conserving the natural enemies in order to exert their potential in checking pest populations on citrus. This calls for a sound pest management programme that caters for the whole citrus agro-ecosystem.

Pest scouting on growing shoots demonstrated that homopterans pests favoured flush growth as a site for infestation and that the pest populations fluctuated with season and location. The fluctuations were influenced mainly by the weather patterns. Pests were more abundant during the cool and wet seasons characterized by heavy density of flush growth and declined during the drought period. Since the flush growth is the desired site of infestation by these pests, it requires protection to reduce losses that may occur due to continued infestation and to reduce risks of disease spread. The scouting method used in the study can be refined further, to suit the farmers' conditions.

Since citrus harbours many insect pest species that may not be addressed by a single strategy for control, synthetic insecticides use, as a tool for control will remain important. Training farmers on proper and judicious use, to optimise the benefits of pesticides is necessary. In this study, efforts were made to rationalize spray schedules to use pesticides only when they are needed. It was demonstrated that monthly foliar and soil drench spray schedules of DC Tron and Confidor have the ability to reduce pest populations in the farmers' fields. These schedules can be used to protect the active flush growth period identified to support high pest populations in cool and wet seasons of the year. Synthetic pesticide use is however, limited for small-scale citrus growers who are the majority (70%) because of high costs, lack of technical expertise, unavailability, stockists' abuse, user and environmental concerns. IPM would provide a better option for citrus pest management where synthetic pesticide use would only be part of the strategy.

5.3 RECOMMENDATIONS

This study did not extend to fruit harvesting period. Fruit quality is an important aspect of citrus production. Further studies focusing on fruit pests of citrus would help complete the information needed to facilitate a proper crop protection package for profitable commercial production of citrus in Kenya.

This study did not address biological control of citrus pests. Biological control is an important aspect of IPM on perennial crops such as citrus. It would be necessary to map out the indigenous natural enemies present and evaluate their effect in checking citrus pest populations. The information would help evaluate biological control as a component of IPM on citrus.

The results of the study reflect conditions in the agro-ecological zones studied and hence may be used to package IPM technologies that are sustainable and acceptable to the farmers in these areas. Studies in other agro-ecological zones are necessary to generate complete information for all the citrus growing areas in Kenya.

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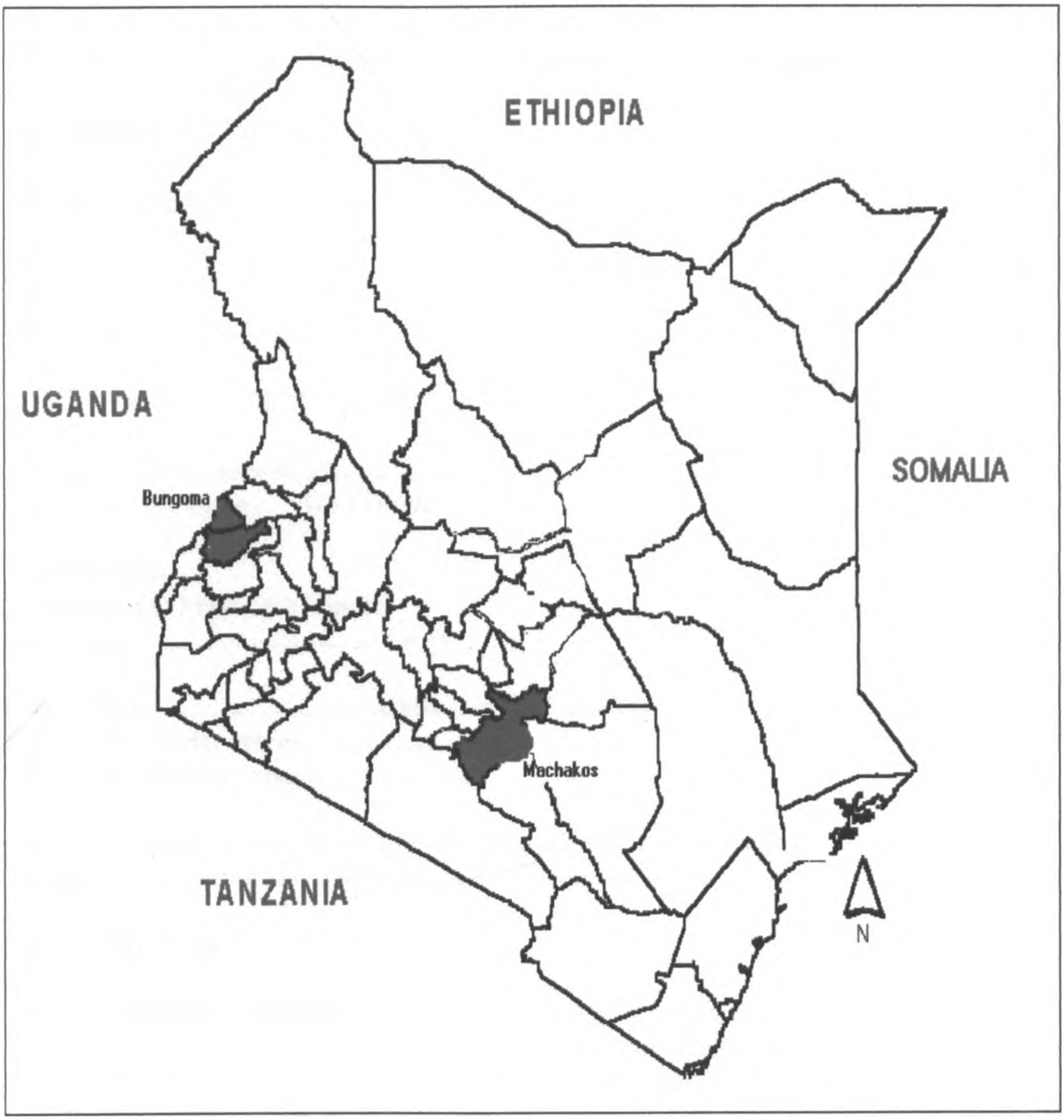
APPENDIX I

Fig.1 Map of Kenya showing the locations of Bungoma and Machakos districts



APPENDIX 1I

CITRUS PESTS SURVEY QUESTIONNAIRE

Objectives:
1. To determine the most important pests of citrus
2. To evaluate the pest control measures being used by the farmers

A. Background information

Date of sampling:

District: (1) Machakos (2) Bungoma

Division/Loc/s/Loc:...

Agro-ecozone: (1) LM (2) UM (3) LH

Head of the household ....(NAME)
Gender (1) Male (0) Female

Respondent
Gender (1) Male (0) female
Age ....Years

Farm size: ....Units (acres/Hectares)
Farm size under citrus ....
Number of citrus trees..................

Cropping pattern/system: (1) Monocropping (0) Intercropping
Experience in citrus farming ....years

Age of the trees: ....years

Source of citrus seedlings: (1) Kabete (Citrus project)
(2) Seedling nursery (name it)
(3) Own seedlings

State of the citrus trees:

State	Code	Tick
Healthy	1	
Moderately healthy	2	
Severely attacked	3	

B. Pest control measures

2. What are the main citrus production constraints on your farm?

Constraint	Yes	No	Important four constraints (Rank 1-4 in order of importance)
1. Weeds			
2. Pests			
3. Diseases,			
4. Lack of planting material			
5. Marketing,			
6. Water			
7. Soil fertility			
8. Others (specify)			
9. Capital constraints			

3. Which of the following pests and insect damages (use photographs or actual specimens) have you observed on the farm?

Insect	Yes	No	Most important five pests (Rank 1-5 in order of importance)
1. Psyllids			
2. Aphids			
3. Mites			
4. Scales			
5. White flies			
6. Black flies			
7. Leaf miners			
8. Fruit flies			
9. Med flies			
10. Orange dog			
11. Others (specify)			

4. What damage does the most important pest above cause (describe)?

----

5. What control measures do you use on insect pests?

Insect	Chemical/Traditional measures	Efficacy	Remarks
1. Psyllids			
2. Aphids			
3. Mites			
4. Scales			
5. white flies			
6. Black flies			
7. Leaf miners			
8. Fruit flies			
9. Med flies			
10.Orange dog			
11 Other (specify)			

NB: For Efficacy please use the key below.

(1) Effective
(2) Moderately effective
(3) Not effective

6. For those who spray from above,
What chemicals do you use?

----

7. Who advised you on which chemical to spray?

Adviser	Tick ()
Extension officer	
Own Experience,	
Neighbour	
Others (specify)	

8. How do you decide when to spray?

Methods	Tick
After observing pests	
Advice from extension officer	
Other reasons (specify)	

8. How often do you spray?

Frequency	Tick
Following the pre-harvest interval	
When the insects are present	
Other ways (specify)	

10. Is it profitable to apply the chemicals? Yes/No (1) Yes (0) No.

11. While using traditional knowledge (ITK) how often and when do you control the insects?

Frequency	Tick
When the insects are present	
Weekly	
Other ways (specify)	

12. Why do you grow citrus?
    - A) As an agro forestry measure
    - B) As a cash crop
    - C) Requires no inputs
    - D) Other reasons

13. Did extension agents visit you last year? (1) Yes (O) No.

14. Where do you get extension advice?
    - (1) Government extension service
    - (2) NGO's
    - (3) Church

15. How often were you visited last year?
    (1) Once (2) Twice (3) Thrice (4) Other specify.

16. Did you get credit to purchase inputs?
    (1) Yes (o) No.

17. What is the source of credit?
    - (1) Commercial Banks
    - (2) Co-operative
    - (3) Neighbors

18. If you did not acquire credit last year what constraints hindered you from accessing credit?

(1) Lack of Collateral
(2) Risk of default
(3) Not interested
(4) Credit not available
(5) Lack of awareness

19. What measures do you think can improve the control of citrus pests?

(1) ……………………………………….

(2) ……………………………………….

(3) ……………………………………….

20. Why is citrus production low?

(1) …………………………………………..

(2) …………………………………………..

(3) …………………………………………..

21. What measures can be undertaken to improve citrus production?

(1) …………………………………………..

(2) ……………………………………………

(3) ……………………………………………

Thank you for your patience and willingness to participate.