INTEGRATION OF SOIL FERTILIZERS, SELECTIVE INSECTICIDES AND PREDACIOUS MITES FOR THE MANAGEMENT OF COFFEE INSECT PESTS IN KENYA

By

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DECLARATION BY CANDIDATE

This thesis is my original work and has not been presented for award of a degree in any other University.

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DECLARATION BY SUPERVISORS

This thesis has been submitted as original work with our approval as University supervisors.

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ABSTRACT

Overreliance on residual insecticides to manage insect pests such as Coffee Berry Borer (CBB), *Hypothenemus hampei* (Ferrari) a primary pest of coffee, has resulted in many environmental and human health problems. Such problems related to CBB management among other pests signified the need to develop improved and effective insect pests control strategies. Poor plant health compromises crop yield and quality while possible temporal and spatial changes in the distribution of pests affect choice of insecticides used by farmers. Current study investigated the viability of a three-pronged coffee farm management strategy that combines use of selective insecticides, conservation of biocontrol agents and improved plant health through a field trial that was laid out at Coffee Research Station (CRS) for three years (2006- 2008). The study focused on *H. hampei,* a primary/major coffee insect pest and Coffee thrips, *Diarthrothrips coffeae* Williams as secondary/minor one. Prior to this, common insect pests and predacious mites present in coffee growing agro-ecozones (UM1, UM2 and UM3) were established and their distributions determined using a field survey. Existence of predacious mites with resistance to chlorpyrifos commonly used in coffee to control primary pests was determined from mites populations collected from coffee farms and multiplied in the laboratory before bioassay on their sensitivity to chlorpyrifos was conducted.

The coffee agro ecosystem exhibited a complex of insect pests. Twenty one (21) insect pest species attacked coffee according to the survey. Among these, ten (10) were common and adapted themselves to the three coffee growing agro-ecozones. The agro-ecozones were rich with biological diversity of predacious phytoseiid mites. A total of twenty nine (29) species inhabited coffee and are known for predating secondary insect pests such as *D. coffeae. Euseius kenyae* (Swirski and Ragusa) was most common species and adapted to the three coffee agro-ecozones. Some strains of *E. kenyae* were resistant to Chlorpyrifos and other similar chemical compounds regularly used in management of primary insect pests. Strains with resistance ratio of 39 times and also resistant to 200% field rate of chlorpyrifos when compared with susceptible strain were detected.

The relationships between *E. kenyae* and *D. coffeae* on coffee farm showed a negative correlation. Chlorpyrifos was found safe to use in coffee especially where strains of *E. kenyae* resistant to Chlorpyrifos occurred. The use of Spinosad and chlorpyrifos when integrated with balanced compound fertilizers (N.P.K. 17:17:17, Organic compost and N.P.K. 22:6:12) were equally effective in controlling the Coffee Berry Borer. The coffee yield and quality had no significant difference ($P>0.05$) under the same integrate. Yields ranged between 1187.5 - 2844.3 kg/ha while coffee grade AA/AB was between 71.1 - 89.2%. The organic compost (9.99 mites per sample) significantly ($P < 0.05$) conserved the predacious mites, *E. kenyae* when compared with N.P.K. 17:17:17 (5.25 mites per sample) under insecticide treatments. The employment of biocontrol agents (predacious mites) to manage secondary pest (thrips) with selective insecticides and balanced crop nutrition incorporated to control the primary pest (Coffee Berry Borer) was established as a suitable integrated pest management system in coffee.

CHAPTER ONE

1.0 INTRODUCTION

1:1 General requirements of coffee and global production

Coffee is a perennial evergreen tropical plant that belongs to the genus *Coffea* in the Rubiaceae family, and is mostly grown in tropical and sub-tropical regions (Berthaud and Charrier, 1988). Commercially important coffee species are *Coffea arabica L. (*Arabica coffee) and *Coffea canephora* Pierre (Robusta coffee). Approximately 100 species belong to the genus. The Arabica coffee is known to produce a high quality beverage with its origin being Ethiopia while Robusta coffee is known for making instant coffee having originated in central and western equatorial Africa (Ferwerda, 1976).

Coffee is a woody shrub or small tree that can reach 10 meters in height but under cultivation it is usually pruned to about 2.5 meters to facilitate harvesting. In the tropics, coffee performs best under good sunshine, moderate rainfall, average temperatures, no frost and at altitudes between sea level and just over 1800 meters (Manion *et al.*, 1999). Coffee tree matures (begins to flower and fruit) within two to three years after planting. One main and one secondary flowering season occur per year with each mature tree producing approximately 2000 cherries per year or 4000 beans (Manion *et al.*, 1999).

Although coffee is relatively easy crop to grow, it is susceptible to many diseases' infection and insect pests' infestation. Globally, approximately 350 different diseases are known to infect coffee and more than 1000 species of insects infest this plant causing problems that reduce production (Manion *et al.*, 1999). Various disease and insect pest management strategies have been developed over time to maintain coffee production above the economic threshold.

Arabica coffee is a typical highland crop adapted to the sub-tropics and high altitude tropics lying between latitudes 21°N and 25°S. The actual elevation above sea level where Arabica coffee is grown differs from country to country. In most cases the elevation corresponds closely with a mean annual temperature of between 17°C and 23°C, which is the range considered optimum for Arabica coffee (Muller, 1966). Temperature affects both growth and yield of coffee through its effects on the plant's photosynthesis and transpiration.

In the coffee growing regions of the world, Arabica is grown under a wide variety of rainfall patterns. As an evergreen plant, its transpiration is continuous and hence it requires adequate moisture throughout the year. The ideal rainfall for Arabica coffee is considered to be between 1600 mm and 1800 mm annually that is well distributed with 1000 mm considered an absolute minimum (Wellman, 1961; Haarer, 1962). Adequate rainfall is normally required to meet the trees evapotranspiration needs as well as losses through evaporation from the soil surface. The soils also require adequate moisture so as to provide a medium for nutrients absorption by the roots. Rainfall greatly influences coffee yield (Dean, 1939; Pereira and Jones, 1954).

Coffee is normally grown in soils developed upon different geographical formations and under variable climatic conditions. The soils may be derived from basalt, granite and gneiss, for example the 'terra rosa' red loam of Brazil or from gneiss and granite as in West Africa and India. They may also be derived from volcanic ash, for example as in Colombia, Java and Central America or from massive lava rocks as in East Africa and Hawaii or, from conglomerates as in Zaire and Ivory Coast (Wellman, 1961). Throughout the world, coffee soils are generally brown, chocolate or red, and moderately to very acidic (Nutman, 1933a, b; Haarer, 1962). However, the physical conditions of the soils are much more important than their origin. An ideal coffee soil is usually described as one with a relatively deep top soil, loamy, slightly acidic and friable with a minimum depth of at least one metre, has good drainage and aeration with a pore space of 60% of which one third is occupied by air when the soil is wet and has ample supply of humus that contains high organic matter and rich in nutrients (Muller, 1966). Natural variations in soil, sun, moisture, disease and pest conditions normally dictate which coffee is most effectively cultivated where in the world. For instance, although Brazil is the second largest producer of both Arabica and Robusta coffee, the former is mostly grown in Latin America while the latter is mainly grown in West Africa and South East Asia.

Coffee plays an important role in the global economy with Brazil (2.27 million ha), Colombia (850,000 ha), Cote d'Ivoire (829,000 ha), Mexico (701,326 ha) and Vietnam (477,000 ha) being the main producers (FAO, 2002) as measured in hectare. Arabica coffee contributes about 70% of the total world coffee production whereas 30% is mainly Robusta coffee. Currently, about 10.6 million hectares are under coffee production with an estimated average annual production of 7.4 million metric tonnes of green or unroasted coffee. The value added coffee industry is worth about US$ 70 billion worldwide, making it the second most important legally traded commodity in the world after oil (ICO, 2009; McEwan and Allgood, 2001). The crop is a major export earner in about 80 tropical and sub tropical countries in Africa, Asia and Latin America. In addition and perhaps more significantly, it supports livelihoods for over 120 million people worldwide (Osorio, 2002). In Africa in particular, it is a primary export crop with 33 million people growing it mainly on their subsistence farms (Kotecha, 2002).

Brazil, Vietnam, Colombia, Indonesia, Mexico, Coted'Voire and Guatemala are the main coffee producers as measured by the volume harvested (i.e total production), and the main coffee exporters as well. However, coffee is also one of the leading exports in a number of countries that arenot among the largest producers or exporters. In 2002, world exports of coffee were projected to reach 81 million bags with stockpiled reserves expected to reach record levels of 27 million bags with production averaging 698 kg per hectare (FAO, 2002).

The two species of coffee that account for the bulk of the coffee produced around the world - Arabica and Robusta, and the improved varieties developed from them, differ in taste, aroma, caffeine content, disease resistance and optimum cultivation conditions.

1:2 Coffee growing in Kenya

In Kenya, coffee was introduced as a cash crop in 1896 by the European settlers. However, commercial coffee farming started in 1904. Since then, the crop has remained one of the most important products of the country's agriculture.

Agriculture is a fundamental pillar of Kenya's economy in term of foreign exchange earnings, offering employment opportunities and income to farmers. Indeed, coffee has been the major prime mover of the Kenyan economy since independence. However, currently it ranks fourth after tourism, horticulture and tea in terms of foreign exchange earnings. It contributes about

20% of the revenue from total domestic exports. It is estimated that out of the 70% of the Kenya's workforce engaged in agriculture. 30% are employed by the coffee industry. The industry is also a major source of livelihood for about 700,000 smallholder farmers and over 3000 medium to large scale growers (Anonymous. 2006; Michori. 1993).

Although the area under coffee in Kenya is small by world standards. the country produces some of the best Arabica (mild) coffee in the world. This is as a result of favorable climatic conditions. good agronomic practices. strict harvesting. good processing practices and. cultivation of varieties with proven genetic constitution. The country contributes 2 to 3% of the world's total coffee.

Coffee production in Kenya grew steadily from 1,200 metric tonnes of clean coffee in 1931 to a level of about 130,000 tonnes in 1988 (Michori. 1993). There are about 145,000 hectares under coffee and the current production is about 50,000 tonnes of clean coffee. an indication of rapid decline in production since 1988. Similarly, coffee quality has been on the decline over the same period (Michori. 1993; Anonymous, 2007). From the current estimated production capacity of 50,000 metric tones. Central and Eastern Provinces produce 82% of Kenyan Arabica coffee. Western and Nyanza 17% whereas Coast province produces only 1% (Figure1) (Omondi and Gichuru. 2006).

The country largely produces Arabica coffee (about 98%) in two sectors: the estates comprising of large commercial farms and contributing about 40% of the national production and. the co-operative / smallholder farms. contributing the remaining 60%. Like in the rest of Africa. coffee production in Kenya has remained low with smallholders averaging 2.8 kg/ tree and estate 5-6 kg/tree compared to yields of 18.4 kg that has been achieved in some estates in other countries (Karanja, 1996).

Kenya lies across the equator, with most of its coffee grown one or two degrees south. It is mainly grown east of the Rift Valley at altitudes ranging between 1400m and 2000m a.s.l. along the dissected eastern flanks of the Aberdare range and. the southern and eastern slopes of Mt. Kenya (Figure1). However, to achieve high yield and good quality, various aspects of ecological requirements have been recommended (Anonymous, 1983). In Kenya coffee is mainly grown in the upper midland (UM) zone which is again subdivided into three sub-zones namely coffee–tea zone (UM_1), main coffee zone (UM_2) and marginal coffee zone (UM_3). The climatic conditions of these sub-zones differ especially in altitude, annual mean temperature and rainfalls.

The UM_1 has an altitude of 1570-1810m a.s.l with an annual mean temperature and rainfall of 18.4^{0}C and 1650mm, respectively. The UM_2 lies between 1395-1675m a.s.l with an annual mean temperature and rainfall of 19.4^{0}C and 1465mm, respectively. At 1330-1560m a.s.l., the UM_3 has an annual mean temperature of 19.9^{0}C and low annual mean rainfall of 1270mm (Ralph and Helmut, 1983). A number of factors prevent coffee farming in some areas. Growing of coffee at altitudes below 1400m a.s.l is limited by drought and severe attack by Coffee Leaf Rust (CLR). At altitudes 2000m a.s.l., growing of coffee is limited by low temperatures and the destructive Coffee Berry Disease (CBD). Within this altitudinal range where coffee is grown in Kenya, daily temperatures seldom exceed 30^{0}C or fall below 10^0 C (Anonymous, 1989).

The rainfall pattern in Kenya is mainly dependent on the south East and North East monsoons from the Indian Ocean. These winds give rise to two well defined wet seasons each year with intervening hot dry periods of great severity. The 'long Rains' usually start at the end of March and continues until early June while the 'Short Rains' start at the end of October and end in the first half of December. Hence, two coffee cropping seasons occur in Kenya with mean annual rainfall generally lying between 890 and 1140 mm (Wallis, 1962).

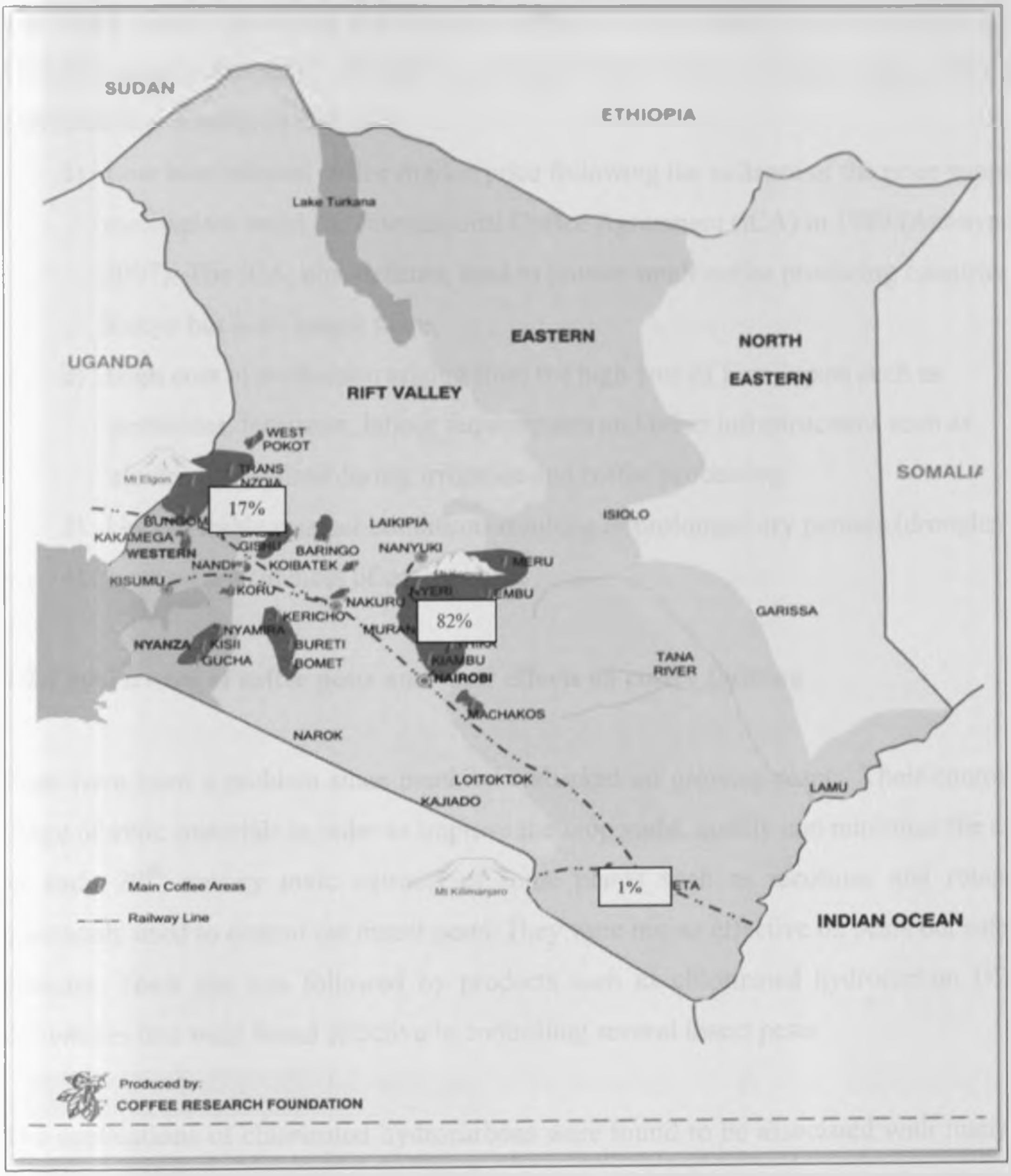

Figure 1: Coffee growing regions in Kenya (The figures in percentage represent national coffee production in different coffee growing regions)
Source: *Coffee Board of Kenya*

The main challenge facing the Kenyan coffee grower today is the declining productivity (130,000 metric tonnes in 1988/89 to around 50,000 metric tonnes today). This decline is attributed to a number of reasons:

1) Low international coffee market price following the collapse of the price support mechanism under the International Coffee Agreement (ICA) in 1989 (Anonymous, 2007). The ICA, now defunct, used to protect small coffee producing countries like Kenya but is no longer there.
2) High cost of production arising from the high cost of farm inputs such as pesticides, fertilizers, labour requirements and other infrastructures such as electricity required during irrigation and coffee processing.
3) Unfavourable weather conditions resulting in prolonged dry periods (droughts) and,
4) Increased incidences of coffee pests.

1.2.1 Incidences of coffee pests and their effects on coffee farming

Pests have been a problem since mankind embarked on growing plants. Their control involved usage of toxic materials in order to improve the crop yield, quality and minimize the crop losses. In early 20th century toxic extracts of some plants such as nicotines and rotenoids were commonly used to control the insect pests. They were not so effective on pests but safe to natural enemies. Their use was followed by products such as chlorinated hydrocarbon DDT and its derivatives that were found effective in controlling several insect pests.

The applications of chlorinated hydrocarbons were found to be associated with many problems faced by the farming communities which included; resistance in primary pests, extermination of natural enemies and upsurgence of secondary pests such as thrips, aphids and red spider mites. The problems due to use of chlorinated hydrocarbons led to the introduction of organophosphorous and carbamate compounds as substitute though the situation never adequately improved.

The increasing incidences of coffee pests and their consequent control and management have significantly constrained economical production of coffee in Kenya. These pests mainly include arthropods (insect pests), pathogenic micro-organisms and weeds.

The Coffee Berry Disease, Coffee Leaf Rust and Bacterial Blight of Coffee (BBC) caused by *Colletotrichum kahawae* Waller and Bridge, *Hemileia vastatrix* Berkeley and Broome and *Pseudomonas syringae* pv. Garcae, respectively, are major coffee diseases of economic importance.

Coffee insect pests of major concern include the Coffee Berry Borer (CBB), *Hypothenemus hampei* (Ferrari); Antestia bugs, *Antestiopsis* spp.; Green scales, *Coccus alpinus* De Lotto and Leaf miners, *Leucoptera* spp. Of the insect pests, the *H. hampei* is the most destructive as it directly infest coffee beans causing both the yield and quality losses.

Couch grass, *Digitaria scalarum* Hochst. ex A. Rich; wood sorrel, *Oxalis* spp. and nut grass, *Cyperus* spp. are known weeds of economic importance in coffee farming. As a result of the above constraints, coffee farmers are increasingly focusing on other enterprises such as horticulture, dairy farming, floriculture and aquaculture which they claim have better returns than coffee.

1.3 Types of coffee pests and their management

In natural ecosystem, there are two groups of agro-pests; primary pests and the secondary pests. Primary pests require application of control strategies in order to stop any damages occurring on the expected crop yield. Where this is the case, the secondary pests are biologically managed and contained below economic injury levels by several biocontrol agents such as predacious mites (Fleschner, 1958). Thus the growers are mostly encouraged to conserve biocontrol agents either by reducing toxic input in the agro- ecosystem or application of environmentally safe compounds (El-Banhawy, 1997).

The natural control factors limit increase in number of an organism in an ecosystem. These factors naturally prevent most of the organisms from becoming pests, a process known as natural control. Natural control consists of two major components: environmental factors (abiotic) and natural enemies (biotic) where natural enemy is an organism that lives at the expense of another organism and which may limit the population of this organism. The natural enemies are used to control the pest populations and number, the strategy referred to as biological control.

Biological control strategies involve classical biological control, conservation, and augmentation. The coffee mealybug, *P. kenyae*, is a good example of classical biocontrol where the pest was introduced to Kenya from Uganda in the early 1920's, and outbreak of this pest occurred shortly afterwards. After several failed attempts of biological control using predatory lady bird beetle from South Africa and a predatory bug from Italy, a parasitic wasp, *A. kivuensis*, from Uganda was released in 1939. This parasitoid achieved good control of the mealybug by 1949 (Le Pelley, 1968).

In a commercial farming system of crops such as citrus, both primary and secondary pests infesting crops exist, and the farmers are required to integrate control of target pest with the secondary ones without obvious negative effects on the other. According to Adan *et al*., (1996) application of selective insecticide for the target pest is recommended while the natural enemies suppress the population of secondary pests with the expectation that little interruption of natural enemies is caused by selective insecticide such as spinosad. On the other hand, following intensive genetic studies of natural enemies like predacious mites, it is now possible to select insecticide resistant strains of predacious mites. These selected strains can be employed in agro-ecosystems like citrus and other crops such as coffee where the predators are biologically expected to manage secondary pests and in the meanwhile the selective insecticide chemically control the primary pest without interference with the behavior of the selected natural enemy (Hoyt, 1969; Hoyt and Caltaginore, 1971; Croft, 1982; Hoy *et al*., 1982).

In a coffee farming system, the primary coffee pests such as *H. hampei* cause enormous yield losses in addition to lowering the quality of coffee. However, to manage them, management approaches such as cultural practices (pruning, sanitation, mulching etc), use of insecticides and bioagents have been developed and used in complex coffee agro-ecosystem. However, integration of bioagents with other control strategies such as plant nutrition and insecticides is rarely applied.

1.3.1 Predacious phytoseiid mites

The coffee leaves have well-developed pit domatia in the primary vein axils on the undersurfaces of the leaves. These morphogenetic structures are commonly occupied by mites. Most of the mites in domitia are from groups in which arboreal representatives are primarily predatory. Such examples are predacious phytoseiid mites which are predators of spider mites and insects like the thrips. Among these predacious mites, some species also feed on nematodes, fungal spores, pollen and exudates from plants, but rarely plant tissue. Several members of phytoseiid mites are of great importance in the biological control of spider mites and thrips in greenhouse crop production.

1.3.2 Plant Nutrition

Plant nutrition affects the infestation levels of some pests. For instance, there are reported cases where intensive nitrogen fertilizer use ends up stimulating the population of sucking insects (Salama *et al.*, 1985; Campbell, 1984), while balanced nutrition (nitrogen, phosphorous, potassium) improve the tolerance of plants against pest infestations (Bruning and Vebel, 1969).

1.3.3 Insecticides use

The coffee farmers widely apply insecticides to manage primary insect pests such as the Coffee Berry Borer. However, whereas coffee farmers depend heavily on insecticides to control the primary coffee insect pests, biological control agents and balanced plant nutrition are rarely used or considered in the integrated management of coffee insect pests in Kenya. Overreliance on insecticides use in pests' management has led to increased environmental contamination and pest pressure. Insecticides use has also led to more frequent outbreaks of new insect pests mainly because of elimination of their associated natural enemies (Gordon 1988). These problems are further compounded by development of insect pest strains that are resistant to the insecticides commonly used, as well as increased health risks to humans and livestock.

In Kenya, the detrimental side effects of insecticides application and use of some cultural approaches in coffee production are well documented. For example, the upsurge of Leaf miner, *Leucoptera meyricki* Ghesquiere was caused by increased use of mulch and copper fungicides (Gordon 1988). Moreover, the widespread use of persistent insecticides such as DDT and Dieldrin is known to have reduced the number of many natural enemies of *Leucoptera* spp. (Gordon, 1988). The indiscriminate use of organophosphorus insecticide sprays, e.g. Parathion, has been reported to cause an outbreak of Giant loopers, *Ascotis selenaria reciprocaria* (Walker), in some coffee estates in Kenya (Wheatley, 1964). Fungicide use for rust control is known to encourage leaf miner infestation (Crowe 1964), while the misuse of Coffee Berry Disease spray schedules lead to increased levels of the disease (Masaba *et al.*, 1993). All these detrimental side effects resulting from heavy use of insecticides and other pesticides have caused deterioration in the coffee agro ecosystems.

The problems associated with current pests' management in coffee, especially the Coffee Berry Borer (primary pest) and thrips (secondary pest) among other insect pests can be addressed by developing improved control strategies that integrate:

1) Selective insecticides to protect biocontrol agents (predacious mites) and enhance their interactions with secondary pests within coffee farming systems. The selective insecticides were aimed to control the primary target pest(s), particularly the Coffee Berry Borer,
2) Employment of predacious phytoseiid mites to control secondary pests especially thrips, scales and spider mites and.
3) Plant nutrition through application of a well balanced organic or mineral N.P.K compound fertilizers on coffee trees.

   Balanced N.P.K. fertilizers make plants less susceptible or tolerant to insects attack (Krauss, 2001). Despite this, balanced organic fertilizer or compost helps in improving soil quality, promoting survival of natural enemies and reduction of toxic materials in soils (Shah *et al.*, 2003).

This study was therefore based on the premise that integration of predacious mites and selective insecticides under the umbrella of a balanced N.P.K. (organic or mineral form), would result in an overall improvement of yield and quality of coffee, improved environment and thus develop and recommend an effective and readily adoptable coffee insect pest's management system(s) or strategies against the Coffee Berry Borer.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Description of coffee

Coffee belongs to family Rubiaceae and the genus *Coffea* (Gordon, 1988). *Coffea arabica, C. canephora* and *C. liberica* Bull ex Hiern (Liberiaca or Liberian coffee) are the major species of economic importance. *Coffea arabica* contribute 80% of the world coffee trade with *C. canephora* making up for the largest proportion of the remaining 20%, whereas *C. liberica* contributes less than 1% (Gordon, 1988).

Rainfall is fundamentally important for cultivation of coffee species (Gordon, 1988). A minimum of 1200 to 1500 mm of rainfall per year is considered adequate for good regular yields. Arabica coffee prefers a sub- tropical, almost temperate climate that is frost free and without strong winds. Robusta and Liberica coffees are commonly found in the tropical rain forest because they are more tolerant to heat and grow favourably at lower altitudes where temperatures hardly fall below 18^0 C with an average of around 26^0 C (Gordon, 1988).

Coffee starts producing berries about three years after planting. In most cases, one main and one secondary flowering season occur annually (Manion *et al.*, 1999). Despite the occurrence of favourable environmental factors that coffee requires for its production, high yield is constrained by a number of factors, which includes poor agronomic practices, insect pest infestations and disease infections. Globally, about 350 and 1000 different diseases and insect pests, respectively, attack coffee (Manion *et al.*, 1999). The insect pests under natural environment are associated with biocontrol agents such as the predacious phytoseiid mites that help to contain and sustain them below the economic injury levels.

2.2 Distribution of coffee insect Pests

Pests' distribution is governed primarily by the distribution of the host plant although in some regions, climatic conditions favour the host plant and not the pest (Hubert, 1959). The relationships between the climatic parameters and agricultural production are quite complex, because environmental factors affect growth and development of the plants under different forms during the growth stages of coffee crop. The temperature, solar radiation and relative humidity influence many physiological processes of coffee tree. They play an important role in defining potential yield or ecological limitations for this crop (Camargo, 2008).

Pests of coffee broadly include insects (arthropods), diseases (pathogenic micro-organisms), weeds and nematodes. These pests are a major constraint to coffee production. Pests cause enormous yield losses and in some cases a clear relationship between some key pests and coffee quality is found. Worldwide, insect pests of coffee are estimated to cause yield losses of about 15% (Bardner, 1978, Oeke *et al.*, 1995). Several insect pests have been reported in coffee, the most important being Coffee Berry Borer (*H. hampei*), *Leucoptera* spp., and *Monochamus leuconotus* (Pascoe) (Vega *et al.*, 2006).

In Eastern Africa, six insect pests: *H. hampei, Antestiopsis* spp., *M. leuconotus, Leucoptera* spp., *Coccus* spp., and *Planococcus kenyae* (Le Pelley) are the major coffee pests (Le Pelley, 1968; Waterhouse and Norris, 1989; Schoeman, 1994; Vega *et al.*, 2006). In Kenya, coffee pests are some of the major factors known to directly reduce crop yield and quality (Mugo, 1994). Under Kenyan coffee growing agroecological zones, over 36 coffee insect pests attack coffee with *H. hampei* being one of the most destructive (Mugo, 1994).

The Coffee Berry Borer is endemic to Central Africa and the most devastating insect pest of commercial coffee globally (Le Pelley, 1973; Damon, 2000; Jaramillo *et al.*, 2006). It is a major pest of both Robusta and Arabica coffees (Le Pelley, 1968). Recent survey conducted among the International Coffee Organisation (ICO) coffee producing member countries on coffee pests and diseases, identified the CBB as the most prevalent pest affecting coffee (ICO, 2009). It heavily attacks coffee beans causing crop loss ranging from 50-100% (Le Pelley, 1968; Waterhouse and Norris, 1989; Vega , 2004).

The economic damage associated with *H. hampei* is premature fall of berries, beans of low commercial value, downgraded quality and flavour of the coffee. This leads to economic losses by the CBB to the coffee sector estimated at around US$ 0.5 billion per year, which is equivalent to more than 3% of the export earnings from coffee by producing countries (Sharon, 2004; ICO, 2009).

The CBB is a small beetle measuring 2mm in length. The females bore galleries in the berry where they oviposit up to 200 eggs, causing qualitative and quantitative losses through larval feeding of the endosperm. Both the adult female and larvae damage the coffee berries of all developmental stages causing defects or the cherry drops off the tree leading to a crop loss, both in yield and quality (Baker, 2002; Le Pelley, 1968). The cryptic nature of CBB inside the berry combined with a skewed sex ratio favouring females (10:1) and sibling mating inside the berry makes this insect quite difficult to control. The Coffee Berry Borer infestation rate varies with altitude. Coffee grown in low altitudes areas is severely affected than at higher elevation (Murphy and Moore, 1990).

2.2.1 Management of Coffee Berry Borer

The Coffee Berry Borer is managed through several approaches that include cultural, biological and use of broad spectrum chemical pesticides (Mugo, 1994). Studies had previously considered inclusion of plant resistance in management of CBB among the cultural and chemical control approaches but no coffee cultivars resistance to CBB have yet been developed. Cultural control component of the CBB involves complete removal of all ripe and over ripe berries after the harvest and during the inter-harvest period thus reducing vital sources of re-infestations. Rigorous collection of berries from the trees and from the ground substantially reduces infestations of the pest (Bustillo *et al.*, 1998). Proper drying of coffee beans also helps in reducing the CBB infestation (Le Pelley, 1968; Baker, 1999).

Use of insecticides as chemical control strategy against the CBB has limited effectiveness because of the biology and feeding behaviour of this pest with nearly the entire life cycle of CBB taking place inside the coffee cherry. For any insecticides to be effective, it must be applied before the CBB adults get into the hardened coffee bean (Mugo, 2006). Thus, the insecticide requires to be sprayed four to five months after coffee has flowered since this is the period when the coffee beans are at hardening stage and suitable for CBB attack (Mugo, 2006). Endosulfan, an organo-chlorine, is the most used insecticide to manage Coffee Berry Borer in many parts of the world. Its frequent use as reported in New Calendonia (Pacific Ocean) has led to the development of some resistance against it (Brun *et al*., 1989; Davis *et al*., 2001).

Biological control against *H. hampei* is regarded as the most promising management option because of CBB, *H. hampei* concealed nature. The majority of CBB biocontrol agents are mainly from Africa. These includes parasitoids such as *Heterospilus coffeicola* Schmiedeknecht (Hargreaves, 1926), *Cephalonomia stephanoderis* Betrem (Ticheler, 1961), *Prorops nasuta* Waterston (Hempel, 1934), *Phymastichus coffea* Lasalle (Borbon- Martinez, 1989), and fungal pathogens, *Beauvaria bassiana* (Balsamo) (Baker *et a*l., 2002) and parasitic nematode (Le Pelley, 1968). A number of these are indigenous to Eastern Africa region with reported parasitism levels ranging from 18 to 59% (Le Pelley, 1968).

In Kenya, three parasitic wasps; *P. nasuta*, P. *coffea* and *H. coffeicola* (Infante *et al*., 1992; Murphy *et al.*, 1989, 1986) have been recorded. These parasitoids have been exported to countries like Colombia, Guatemala, Honduras, Jamaica, El Salvador, Ecuador, India, Brazil and Mexico for the control of CBB (Murphy and Rangi, 1991 Murphy and Rangi, 1991; Baker *et al*., 2002). The *P. coffea* unlike the other parasitoids is considered to be a potentially useful biological control tool in management of CBB as it parasitizes the adults female CBB before it enter the coffee bean (Baker *et a*l., 2002).

Other biocontrol agents of CBB such as predator, *Karnyothrips flavipes* (Jones) and parasitic nematode, *Metaparasitylenchus hypothenemi* n.sp are pronounced to have future potential of biologically controlling the CBB (George *et al*., 2004). The biological control agents when enhanced with effective cultural controls, trapping and selective insecticides application helps to keep CBB in check.

2.2.2 Challenges and successes in managing coffee insect pests

The choice of effective pest control strategies differ between coffee farms. Factors such as economic and ecological considerations, pesticides availability and equipment, season and prevailing value of coffee, determine the control measure to apply.

Culturally, mulching is known to have a direct effect on pest populations. The populations of coffee thrips, *Diarthrothrips coffeae* Williams which thrive under hot, dry conditions are reduced in the cooler, humid conditions of a mulched soil. However, mulching may increase attack by coffee leafminers possibly because it provides a more favourable environment for the pest when it drops to the ground to build its pupal cocoon (Le pelley, 1968).

Heavy and indiscriminate use of chemical insecticides to manage coffee insect pests has been associated with a number of problems such as pesticides resistance, environmental degradation, pests' upsurgence, natural enemies' elimination, and high cost of production. In Kenya, heavy use of organophosphorous insecticides spray has been linked to an outbreak of Giant loopers, *Ascotis selenaria reciprocaria (*Walker) (Wheatly, 1964; Le Pelley, 1968). According to Acland (1971), coffee scale insects, *Coccus* spp. are effectively managed by the predators and parasitoids where less use of persistent contact chemical insecticides exist. Abasa (1983) reported a major success in IPM against Kenya meallybug (*P. kenyae)* through augmentation and field release of its parasitoid, *Anagyrus kivuensis* Compere in combination with restrictions on the application of residual insecticides. *Leucoptera* spp. are controlled through proper management of shade and fertilization, minimal use of insecticides and conservation of natural enemies. All these are important factors that reduce coffee leaf miner outbreaks in coffee plantations (Vega *et al.*, 2006). Other pest such as *Antestiopsis spp* are normally controlled by use of cultural control (pruning of coffee trees making the coffee bushes open leading to limited populations of this pest), biological control (Antestia egg parasitoid, *Telenomus seychellensis* Kieffer), and often use of synthetic insecticides (Anonymous, 1975; Mugo and Ndoiru,1997). Use of cultural (stem smoothening and uprooting of attacked plants), biological (use of pheromones and *B. bassiana)* and insecticides are methods applied to manage the *M. leuconotus* (Oduor, unpublished*)*.

Coffee nematodes are found either in the roots or soils surrounding the roots. Nematodes infested trees are killed by secondary invaders such as fungi or bacteria (Le Pelley, 1968). There are two harmful genera found in coffee: *Meloidogyne* sp e.g *M. coffeicola* (Lordello and Zamith) and *Pratylenchus* spp e.g *P. coffeae* (Zimmerman) (Le Pelley, 1968). Generally parasitic nematodes are difficult to manage. Management of these nematodes mostly depends on use of nematicide applications; although their natural enemies' especially predacious soil mites exist that reduce population of the nematodes to below economic injury level (Le Pelley, 1968; Walter and Ikonen, 1989; El- Banhawy *et al.*, 1998a, b; Afia, 2002). Cultural methods such as use of nematodes free soils for seedlings propagation, and organic (mulch and manure) and inorganic fertilizers are other nematodes control methods recommended for use by the farmers.

Studies have identified several natural enemies (biological control agents) associated with coffee insect pests without establishing their distribution in coffee growing areas (Bess, 1964; Crowe, 1964; Le Pelley, 1968; Crowe and Greathead, 1970; Abasa, 1972; Waikwa and Mathenge, 1977; Kinuthia, 1986; Masaba, 1991; Ndungi, 1994). In Kenya, a number of natural enemies of coffee insect pests have been reported (Wheatly, 1964; Andrade, 1966; Le Pelley, 1968; Abasa and Mathenge, 1974; Kinuthia and Mwangi, 1986; Anonymous, 1991) but information on predacious phytoseiid mites associated with coffee in Kenya is scanty.

2.3 Distribution of predacious mites in coffee

Coffee plants harbour many mite species that may be beneficial or harmful during the cropping cycle. The most important pest mites of coffee are the red coffee mite, *Oligonychus ilicis* (McGregor), and the false spider mite, *Brevipalpus phoenicis* (Geijskes) (Pallini *et al.*, 2008). The natural enemies of these phytophagous mites are predatory mites of the family Phytoseiidae (Pallini *et al.*, 2008). These predators play a major role in controlling pests that attack many plants. However, predacious mites associated with coffee plants in Kenya are not documented.

The Phytoseiidae is a large family of the worldwide distribution with more than 1600 species belonging to over 70 genera (Chant and McMurtry 2003). Several members of this family are of great importance in the biological control of spider mites such as the red spider mite, *O. ilicis* and the false spider mite, *B. phoenicis*, and thrips (Zhang, 2003). The family consists of three sub-families: Amblyseiinae Muma, Phytoseiinae Berlese, and Typhlodrominae Chant and McMurtry. Effective biocontrol agents occur in all the three subfamilies, but most of the commercially available species that are commonly used in greenhouses belong to the genera *Neoseiulus* Hughes and *Phytoseiulus* Evans in the Amblyseiinae (Zhang, 2003).

Parrott *et al*., (1906) first showed that predacious mites are of economic importance. They reported *Seius pomi* Parrot as a valuable predator of the pear leaf blister mite, *Eriophyes pyri* (Pgst). Thereafter, many references of predacious mites feeding on mites of economic importance such as eriophyid and tetranychid have been reported (Gilliant, 1935; Garman, 1948; Nesbitt, 1951).

Phytoseiids among other factors play important role in controlling tetranychids throughout the world (Nesbitt, 1951; Collyer, 1953; Herbert, 1953; Massee, 1954; Collyer and Kirby, 1955). The phytoseiid species are found from all significant land masses except Antarctica, from tropical rain forests to arctic tundra, with greater adaptive radiation of species found in the tropical and subtropics (Chant, 1993; Chant *et al*., 1980).

Predacious phytoseiid mites normally control phytophagous mites and several small insects (Grout and Richards, 1994; McMurtry *et al*., 1970). However, factors such as hot-dry conditions (El-Banhawy, 1995), prey density and time of release (Chant, 1961; Sandness and McMurtry, 1970; Hairyappa and Kurkani, 1988; Zhang *et al*., 1992) and the great sensitivity of phytoseiids to most insecticides (McMurtry *et al*., 1970) limit the efficiency of these biocontrol agents.

The majority of phytoseiid mites are facultative predators that feed on a wide range of prey including red spider mites, gall and rust mites and small insects. Some species also feed on fungal spores, pollen, honey dew and exudates from plants, but rarely plant tissue (Zhang, 2003; Vega *et al*., 2007).

Environmental factors affect the population and behaviour of phytoseiid mites. These factors include biotic (plant conditions, type of vegetation, prey distribution, competition, parasitism, Predation and disease) and abiotic or physical factors (temperature, humidity, photoperiod, rainfall and winds) (McMurtry *et al.*, 1970).

The biology and life history of phytoseiid mites has been described by several authors (Castagnoli, 1989; Hariyappa and Kulkarni, 1989; Zhang and Sanderson, 1994; Zhang, 2003). There are five developmental stages consisting of the egg, larva, protonymph, deutonymph and adult. Eggs generally require very high relative humidity (RH) of 99-100% for them to hatch (Zhang, 2003). Phytoseiids develop faster than spider mites. Most species complete development within a week. Some *Phytoseiulus* species can complete development from eggs to adults within four days. Sex ratio is female-biased with an approximate 3:1 female: male ratio for many species (Zhang, 2003).

Reproductive rates of predacious mites depend on species and other factors such as climatic conditions. Some predacious mite species produce as many as five eggs per day. On average, predator species such as *Phytoseiulus persimilis* Athias-Henriot, *Iphiseius degenerans* (Berlese) and *Neoseiulus fallacis* (Garman) produces more eggs per day than species such as *Galendromus occidentalis* (Nesbitt), *Euseius hibisci* (Chant), *Phytoseius plumifer* (Canestrini and Fanzago), and *Typhlodromus pyri* Scheuten. The oviposition period predacious mites last for 20-30 days and fecundity of most species range between 30 and 40 eggs (Zhang and Sanderson, 1994; Zhang, 2003).

The coffee plants have small cavities called domatia where the predacious mites are found to inhabit. These cavities occur at the acute angle junction between the midrib and secondary veins at the leaf abaxial side (Nakamura *et al.*, 1992). According to Odword (1994) coffee has well developed pit domatia in the primary axils on the undersurfaces of leaves. These domatia are important sites for mites' reproduction and development. Le Pelley (1968) stated that coffee normally suffer an attack from fungal and herbivorous arthropods. However, the role played by domatia to house beneficial mites and influence their numbers and distribution on leaves, increases their likelihood of controlling the coffee pests (Odword, 1994). The mites associated with domatia according to Odword (1994) are predatory, fungivorous or both.

Limited reports of mites inhabiting coffee domatia occurs from Australia, Brazil, Costa Rica, Hawaii and Java with only one species recorded in Java and 30 species in Brazil (Penzig and Chiabrera, 1903; Pemperton and Turner 1989; O'Dowd, 1994; Matos *et al*., 2004, 2006; Mineira *et al.*, 2006a, b; Vega *et al.*, 2007; Pallini *et al.*, 2008). Eight previously unreported domatia-inhabiting mites were reported from *C. arabica* and *C. eugenioides* accessions planted in Costa Rica (Vega *et al.*, 2007). They also stated that most common mites in domatia of coffee belong to the family Phytoseiidae, Tydeidae, and Stigmaidae.

Predacious mites associated with coffee in Kenya are not established. Their distributions in coffee growing agroecozones in Kenya have not been documented. They are not likely to be evenly distributed throughout the coffee growing agroecozones in Kenya because of natural topographical barriers and other limiting factors such as biotic (competition, parasitism, Predation and disease) and abiotic factors (temperature and relative humidity).

2.4 Sensitivity of predacious mites to insecticides

The use of fungicides, insecticides and acaricides are known to have drastic effects on the natural enemies of insects and mites species. Most of the commonly used pesticides have a more or less broad spectrum activity and drastic effects on the predacious mites (Bartlet, 1964; Huffaker *et al*., 1969). Adverse effects can arise from direct mortality of predacious mites or through elimination of their main prey (El-Banhawy, 1976). The effects of pesticides on natural enemies are much more subtle than direct mortality. For instance, application of fungicides for the coffee leaf rust control a times increase the population of scale insects, probably as a result of the destruction of the group of fungi that cause insect diseases hence to some extent keeping the populations of this pest in check (Masaba and Waller, 1992).

Prior to widespread use of synthetic organic pesticides in early 20th century, spider mites were insignificant pests on crops. Heavy toxicity of most insecticides to predacious phytoseiid mites and subsequently their elimination after application of pesticides in the field led to outbreaks of spider mites (Flaherty and Huffaker 1970; Readshow, 1975). As a result, many scientists have searched for selective insecticides that can be used against the primary pests and exhibit low toxicity towards phytoseiids. These kinds of insecticides are rare because most products are known to be designed and marketed on the basis of their wide spectrum action (Croft, 1972). Despite this, studies have shown that strains of phytoseiids are likely to develop resistance particularly to organophosphorous compounds (Croft and Jeppson, 1970; Motoyama *et al.*, 1970; Croft and Stewart, 1973; Croft and Meyer, 1973; Grande and Ingrassia, 1988).

The use of selective insecticides may improve conservation of natural enemies and therefore contribute to the success of integrated pest management (IPM) programmes (Galvan *et al.*, 2006). Study by Galvan *et al.*, (2006) showed that Ladybird beetle, *Harmonia axyridis* (Pallas), was tolerant to Spinosad (Tracer). Insecticides such as chlorinated hydrocarbons are known to be highly toxic to many mite predators. However, some of these products have limited direct effects on certain mite predators (El-Banhawy, 1976). Tolerance to DDT has been observed in larvae of *Chrysopa* spp and *Anthocoris musculus* (Say) and several species of phytoseiids. Phytoseiids such as *Amblyseius fallacis* Garman and *Typholodromus caudiglans* Shuster are known to have acquired resistance to these compounds (Huffaker *et al.*, 1969). El-Banhawy (1997) indicated that several insecticides commonly applied for pest control in fruit trees were not detrimental to the predacious mites where population acquired resistance to these insecticides after many years of application.

The strains of predacious mites resistant to some insecticides are desirable. Most integrated control programmes depend on insecticides to control primary or target insect pests, for instance the Codling moth in apples (Croft, 1982) and the Mediterranean fruit fly in citrus (El-Banhawy, 1997). In these systems of integrated control, predacious mites with developed resistance are able to persist and biologically control small insects and mites while the same insecticides control the target pests such as Codling moth and the Mediterranean fruit fly (Croft and Meyer, 1973; El- Banhawy, 1997). Such resistance may also be present on predacious mites established in coffee, particularly where some organophosphate compounds like Chlorpyrifos (Dursban 480 EC) have heavily been sprayed and over a long period of time (Pers. observ.). Thus, continues use of chlorpyrifos on coffee would have created selectivity where the natural enemies such as predacious mites have become resistance to chlorpyrifos or the chlorpyrifos has become more selective (conventional selectivity) as it has no negative effects on natural enemies such as predacious mites. Under such kind of resistance, the predacious mites control secondary pests like coffee thrips, mites and scales while chlorpyrifos control primary pests eg. *H. hampei*, without interfering with behavior and efficiency of predacious mites. Therefore, among the selective insecticides (Chlorpyrifos and Spinosad) used in this study the sensitivity of the most and widely distributed predacious mite species, *Euseius kenyae* (Swirski and Ragusa) on coffee to the commonly used insecticide, Chlorpyrifos to control various coffee insect pests was investigated. The Spinosad unlike the Chlorpyrifos is not harmful to predacious mites but controls the primary pest hence regarded as selective. The mite species were collected from coffee farms regularly sprayed with Chlorpyrifos and the unsprayed ones.

2.5 Integrated insect pests' management systems

Insect pests and diseases jeopardize the growth in crop output. Oeke *et al.* (1995) estimated that from the total attainable production of eight crops (coffee included) worth US$580 billion, about 42% or US$ 240 billion was lost due to insect pests (15%) followed by pathogens (13%) and weeds (13%). In 1998, a total of US$ 34 billion worldwide was spent by the farmers on protecting plants from insect pests and diseases (Yudelmon *et al.*, 1998).

The consumer pressure, high cost of inputs, pesticides resistance and ban of many chemical pesticides from the market among other factors have directed research interest towards the development of ecologically and economically viable solutions to pest management. Several options exist in the control of pests and diseases (genetics, biological, chemical, cultural and plant nutrition) which can be used alone or combined in an integrated pest management approach. Integrated management practices according to Phiri *et al.* (2007) include use of resistant/tolerant varieties, provision of balanced crop nutrition, use of health planting materials (seeds), quarantine, control of alternative hosts, crop rotation, crop residue management, control of insect vectors, crop management, choosing of clean field, suppressing of pathogens in infected field, prevention of the spread of disease in the field, and use of pesticides.

Biological control involves utilization of natural enemies. Under organic farming, measures and strategies such as crop rotation, biological control, varietals choice, and diversification and resistance management are applied to manage various crop pests. The most important, although also least spectacular approach to biological control in the field is the enhancement of often less specialized natural enemies and beneficial microorganisms through habitat management. This is the basis for most disease management strategies in organic farming (Finckh, 2007). Crop rotation, varietal choice, and diversification and resistance management strategies are all part of the overall habitat management in an agricultural system which can be managed to enhance biological control. Through biological control, the Kenya mealy bug, *P. kenyae* once a major pest of Arabica coffee in Kenya, was reduced to a minor pest by introducing the parasitoid, *A. kivuensis,* from Uganda in 1938 (Le Pelley, 1968). Attempt to use local biological control agents such ladybirds (*Chilocorus nigripes* Mader, *C. angolensis* Crotch and *Hyperaspis senegalensis* Muls) against coffee scale insects and Antestia egg parasitoid, *T. seychellensis* against *Antestiopsis* spp. have been made at Coffee Research Station and their potential determined (Mugo, 1996; Mugo and Ndoiru, 1997). But to effectively manage a key pest like the *H. hampei,* found on coffee in Kenya, integration of cultural strategies, trapping and use of natural enemies is encouranged.

On fruit trees, predacious mites are general natural enemies that feed on a wide range of prey. However, this multi- feeding behavior is supposed to maintain a high population level of predators in absence of the main prey thus controlling any further pest infestation that may occur (McMurtry and Scriven, 1966; El-Badry and El-Banhawy, 1968; El- Banhawy *et al.*, 1999). According to Flescher (1958) the citrus brownmite, *Metatetranychus* (*Panonychus*) *citri* (McGregor) was under satisfactory balance in most citrus orchards in California. This balance was maintained mainly by several species of predators. Rasmy (1971) found that predacious mites prevented injury caused by the citrus brown mite, *Eutetranychus orientalis* (Klein) in citrus orchards in Egypt. Application of insecticides on the other hand destroyed predacious mites and in their absence, mites and several small insects increased (Swift, 1968; Flaherty and Huffaker, 1970; Flaherty and Huffaker, 1970; Croft, 1975). Where most chemical insecticides are used, resistance development in predacious mites occurs but mainly the prey first develops resistance before the natural enemies do the same (Croft and Strickler, 1983; Tabashnik, 1986). Usually after the resistance has developed in the pest population, the pesticide continues to be used for the management of other pests in the system. When the prey began to survive the treatment at appreciable level the associated natural enemy develops resistance population. In some cases the key pests fails to develop resistance while secondary pests such as spider mites, aphids and their associated natural enemies develop resistance strains (Croft, 1982; El-Banhawy, 1997).

For many years, pesticides' sprays especially fungicides, insecticides and acaricides have been known to have devastating effects on the natural enemies of mites and other insect pests (Barlett, 1963; 1964; Patterson, 1966). Long term effects of pesticide may be detrimental to predator complex even at low dosages and when no immediate adverse effects are apparent, reduction in egg production and adult survival is encountered (Ristich, 1956; Van de Vrie, 1962; Daneschwar, 1963; El-Banhawy, 1976). Elimination of a natural enemy a times result from reduction of the main prey or some other food sources essential for the predator to feed on at times when the main prey is unavailable.

In fruit tree orchards, some insecticides are applied for insect pest control but resistance in predacious mite populations has been reported in many cases. This leads to a number of reasons why selections of strains of predators resistant to insecticides are desirable. It is well advocated that most integrated mite control programmess depend on insecticides to chemically control variety of insect pests (Codling moth, *Laspeyresia pomonella L.* in apples and Mediterranean fruit fly, *Ceratitis capitata* Wiedemann in citrus). Under these programmes, it is reported that predacious mites developed resistance and even when sprays were applied severally during the season, the predators were able to persist and biologically controlled the phytophagous mites (azinphosmethyl- *A. fallacis*, Croft and Meyer, 1973; Dipterex- *A. addoensis*, El-Banhawy, 1997). Though these control programmes exist, they are made ineffective particularly where insect pests develop resistance to the chemicals and utilization of other new compounds become necessary so as to achieve pest control. Under such a scenario, the susceptible predator populations' end up being eliminated from the crop system until tolerant populations become selected, a situation likely to take many years or possibly never occurred. In other cases, the presence of predator strain resistance to several chemical groups if occurred allow for increased pesticides flexibility in prevailing chemical programmes and decreased possibilities for resistance developing so rapidly in the target insect pests.

In an attempt to minimize coffee losses caused by pests and diseases, farmers rely heavily on use of insecticides and fungicides. The increasing reliance on broad spectrum chemical pesticides in coffee has caused disruption of natural control mechanisms. Incidences of coffee pests developing resistance to commonly used pesticides have been reported (Okioga, 1976; Bardner and Mcharo, 1988; Brun *et al.*, 1989; Mwangombe, 1994;). Despite these negative effects, pesticides still continue to be the preferred method of pest control by both the smallholder and estate coffee farmers.

Nutrition of plants substantially impact on the predisposition of plants attack by pests and diseases. This contributes either to an increase or decrease of the resistance or tolerance of plants to pests and diseases attack (Krauss, 2001). The nitrogen to potassium ratio plays a major role in the host-pathogen relationship in crops such as soybean, rice, barley and sesame (Last, 1962; Perrenoud, 1990; Härdter, 1997; Sweeney *et al.*, 2000; Mondal *et al.*, 2001). However, plants require 16 essential nutrient elements with macronutrients and micronutrients combined making only 4% of the total weight of a plant, but they are essential to plant's life and growth. It has been shown that plants supplied with all necessary nutrients in balanced manure are more resistant to pests and diseases (Krauss, 2001). Shah *et al.* (2003) established that the abundance of epigeal coleopteran fauna (polyphagous predators in agroecosystems) was greatest in organically managed farms as compared to conventional farms, a situation that was related to greater food resources from weeds, seeds and prey availability from the invertebrates associated with organic manures. According to Worknch and Van Bruggen (1994) and Knudsen (1995), organic matter acts on pests and diseases partly through increased soil microbial activity that leads to increased competition, parasitism and predation in the rhizophere. According to Van Bruggen *et a*l. (2007) a healthy soil is defined as a stable soil with high biological diversity, low soluble calcium and nitrate content, and disease suppressiveness. The stability of the system can be measured by its resistance and resilience to a disturbance (Van Bruggen and Semenov, 2000; Van Diepeningen *et al.*, 2006). Soil microbial populations generally fluctuate, and start to oscillate regularly in response to disturbance, such as addition of organic materials to soil. The amplitude of the waves in microbial populations (measure of resistance), their frequency, and the time needed to return to initial conditions before organic amendment (measure of resilience) may be used as indicators for soil health (Van Bruggen and Semenov, 2000). Organically managed soils commonly have a higher diversity of bacteria, mycorrhizal fungi, nematodes, earthworms, insects and arthropods than conventionally managed soils (Mader *et al*., 2002). Soils with higher biological diversity, such as natural or organically managed agricultural soils are frequently more suppressive to soil–borne diseases than conventionally managed agricultural soils (Van Bruggen and Termorshuizen, 2003; Hiddink *et al*., 2005).

Fertilizers application to enrich soil increases not only increases the nitrogen content of crops but also plant infestation by the insects (Tingey and Singh, 1980). Soil fertility is said to change plant nutritional quality especially nitrogen and water. The nitrogen content of phytophagous insects is several times higher than that of plants, and because food is the only source of water and nitrogen for most insects, feeding on plants with good accumulation of nitrogen and water is obligatory for herbivorous insects (Scriber, 1977). Slansky and Scriber (1985) stated that pest's infestation decline with decrease in plant nitrogen. Increasing the nitrogen content in plants through fertilizer application to enrich soil has been found to increase the plant attack by pests (Manolache *et al.,* 1976; Scriber and Feeny, 1979; Martins *et al*., 1980; Tingey and Singh, 1980; Dwomoh *et al*., 2008). Under Kenyan situation, conventional compound fertilizers such as N.P.K. 17:17:17 and N.P.K. 22:6:12 are mainly used in coffee farming to improve soil nitrogen, phosphorous and potassium (macronutrients) content. The N.P.K. 17:17:17 has equal percentage content of these macronutrients while the N.P.K. 22:6:12 is an improved compound with readily available small quantities of secondary macronutrients [Ca (3%), Mg (2%) and S (1.5%)] and micronutrients [B (0.3%), and Zn (0.3%)]. However, study on recycled coffee wastes as replacement of inorganic fertilizers in coffee production have showed that composted coffee pulp has the potential to partially substitute inorganic fertilizers in sustainable coffee production (Chemura *et al*., 2008).

Management of coffee insect pests using insecticides alone contributes about 40% of the total cost of coffee production in Kenya (Roe and Nyoro, 1986). This high production cost is mostly beyond the reach of smallholders. To alleviate the high productions cost constraints, Coffee Research Station, Kenya, developed an Arabica hybrid (Ruiru 11), a coffee variety which is resistant to both Coffee Berry Disease and Coffee Leaf Rust (Van Vossen and Walyaro, 1980).

According to Roe and Nyoro (1986), Kenya had 4,000 hectares planted with Ruiru 11 by 1986 and this was estimated to have cut down the total cost of production by 26%.

In order to control environmental problems, and any other constraints associated with use of pesticides to manage crop pests, Integrated Pest Management (IPM) approach is recommended. According to Food and Agriculture Organization (FAO) International code of conduct on the distribution and use of pesticides (Article 2), "*IPM is a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economically unacceptable damage or loss*". In integrated systems, growers are advised to integrate control of target pests with non-target ones without negative effects on the other (Afia, 2002). Implementation of integrated management has been very successful on several production systems. For instance, in United States of America (U.S.A) a strain of the predacious mite, *A. fallacis,* resistant to azimphosmethyl, biologically controls the red spider mites whereas the insecticide, azimphosmethyl, controls the key apple pests (Codling moth and apple maggot) (Croft, 1982)). In Cape Provinces, South Africa, a carbaryl resistant strain of the predacious mite, *A. addoensis*, controls thrips and other small insects on citrus, while the insecticide carbaryl controls Mediterranean fruit fly (El-Banhawy, 1997). In Egyptian citrus production, three IPM strategies have successfully been implemented according to locality and climate where the common predacious mite, *A. swirskii* was the major natural enemy in these strategies (El-Banhawy *et al.*- In press).

A coffee tree adequately supplied with nitrogen show rapid growth, ramification of the fruit bearing branches and abundant formation of bright green leaves (Malavolta *et al.*, 1962; Muller, 1966). Hubert (1959) described the effects of nutrition to plant resistance to diseases and insect pests. Excess nitrogenous manuring predisposes the plant to attack by some pests whereas lack of available phosphate and potash induces a decline in resistance (Hubert, 1959). Nevertheless, increased supply of potash or phosphate makes the plant more resistant to fungal and insect pests attack (Hurbert, 1959). Sseruwagi *et al.* (2003) found that N.P.K. fertilizer application significantly favours the incidence of Cassava Mosaic Virus disease on cassava cultivars as well as the adult whitefly populations per shoot. Bi *et al.* (2001) also found that adult and immature whiteflies increased in numbers with increasing amounts of applied nitrogen. According to Bentz *et al.*, (1996), parasitism of the white fly, *Bemisia argentifolii* Bellows and Perring by the parasitoid, *Encarsia formosa* Gahan was higher on plants treated with Calcium nitrate than those treated with Ammonium nitrate or on control. They further stated that *E. formosa* probably gets influenced by the nutritional suitability of the host to continue to oviposit, feed or disperse. More *E. formosa* were found to occur on fertilized Poinsettia (a species of flowering plant indigenous to Mexico), *Euphobia pulcherrima* Willd. ex Klotzsch than on non-fertilized plants. But Tawfik (2001) found that Potassium and Calcium nutrition are the key factors that improve potato production in drip- irrigated sandy soils. The management practice that combines early planting, close spacing and minimum insecticide application (spraying once at budding, flowering and podding stages) effectively reduces pest infestations in cowpea (Karungi *et al.*, 1999). A review by Verkerk *et al.* (1998) outlined that crop-pest-natural enemy manipulation contributes to the improvements in the control of insect pests.

This study developed and evaluated coffee pest management strategies that integrates plant nutrition, selective insecticides and an enhanced predacious mites population levels that can be used to manage insect pests in coffee.

2.6 Statement of the problem

Overreliance on residual insecticides to manage insect pests has resulted in many environmental and human health problems. Poor plant health compromises crop yield and quality while possible temporal and spatial changes in the distribution of pests may affect choice of insecticides used by farmers.

Current study investigates the viability of a three-pronged coffee farm management strategy that combines use of selective insecticides, conservation of biocontrol agents and improved plant health.

2.7 Justification

The losses caused by CBB infestation among other pests on coffee yield and quality is enormous (US$ 0.5 billion /annually). In order to safeguard the yield and quality, farmers mainly apply insecticides as control measures. Their use causes environmental pollution, ecological imbalance leading to insect pest resurgence and final produce contamination (Abasa, 1983). Thus the existing control methods against CBB have several problems associated with them hence the need to develop a better CBB management system.

2.8 Research Hypotheses

1. Common insect pests of coffee occur in Kenya but their distribution along coffee agroecozones varies.
2. Several species of predacious mites inhabit coffee plants in Kenya and their distribution to different coffee agroecozones varies.
3. Some common predacious mites locally existing in Kenya are resistant to Chlorpyrifos which is mostly applied in coffee to control primary insect pests.
4. Balanced coffee nutrition coupled with use of selective insecticides (Chlorpyrifos and Spinosad) and biological control agents (e.g. predacious mites) enhances the yield and quality of coffee.

The Chlorpyrifos has conventionally become selective as natural enemies such as predacious mites have developed resistance towards it. The Spinosad is regarded as selective because unlike the Chlorpyrifos is not harmful to predacious mites but effectively controls the primary pest(s).

2.9 Objectives

2.9.1 General objective

The general objective was to determine the distribution of both insect pests and predacious mites of coffee in Kenya, and to develop and evaluate the potential of integrating the latter with selective insecticides and plant nutrition in management of coffee insect pests. The Coffee Berry Borer being the primary target pest with thrips as the non-target ones.

2.9.2 Specific Objectives

1. To determine the common insect pests of coffee in Kenya and their distribution along coffee agroecozones.
2. To establish the predacious mites species inhabiting coffee plants in Kenya and their distribution along coffee agroecozones.
3. To evaluate the sensitivity of most common predacious mites to Chlorpyrifos (Dursban 480EC) from coffee farms in Kenya.
4. To evaluate the integration of plant nutrition, selective insecticides and predacious mites for the management of coffee insect pests

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Field survey for coffee insect pests and their distribution in major coffee growing areas

3.1.1 Coffee growing districts / areas surveyed

To determine the distribution of coffee insect pests, a survey was carried out in six of the eight coffee growing provinces of Kenya, namely; Coast, Eastern, Central, Rift Valley, Western and Nyanza. Coffee farmers/farms from thirteen major coffee growing districts (Taita, Machakos, Makueni, Embu, Meru Central, Kiambu, Muranga, Kirinyaga, Nyeri, Nakuru, Bungoma, Trans-Nzoia and Kisii) within these provinces (Table 1) were interviewed, with the UM-subzones (UM1, UM2, and UM3) taken into consideration in the random selection of farmers/farms. Meru Central, Embu, Kirinyaga, Nyeri, Muranga and Thika had all the three agroecological zones each (UM1, UM2 and UM3). Machakos, Nakuru, Trans Nzoia, Bungoma and Kisii had two each (UM1 and UM2) whereas Taita Taveta and Makueni had only one each (UM2). The coffee growing districts surveyed per province were selected based on mean national coffee production where 82% of the Kenyan coffee comes from the provinces found in East of the Rift Valley (Figure 1).

3.1.2 The sampling design

A sample size of N=120 (where N was the number of farms) was allocated to the six provinces in a proportionate stratified sampling design with $n=N.p_i$, where p_i was the proportion of coffee produced in each province. The allocated sample sizes for each province were distributed randomly among the subzones present in the selected districts. A total of 36, 52 and 32 farms/farmers were sampled or interviewed in UM1, UM2 and UM3, respectively (Figure 2). In each UM-subzone, four farms were selected for the survey of pests (Table 1). The coffee farms sampled were geo-referenced and their location is shown in Figure 3. Following the principle of disproportionate, most of the sampled farms (70%) were located in eastern and central provinces, which are the main coffee-growing regions in Kenya (Figure 3).

Table 1: Distribution of the sampled farms in the coffee-growing districts surveyed and their respective agro-ecological zones

Coffee district	Agroecozone	No of farms sampled / surveyed in each province					
		Coast	Eastern	Central	Rift Valley	Western	Nyanza
Taita Taveta	UM2	4					
Makueni	UM2		4				
Machakos	UM2,UM3		8				
Meru Central	UM1, UM2, UM3		12				
Embu	UM1, UM2, UM3		12				
Thika	UM1, UM2, UM3			12			
Muranga	UM1, UM2, UM3			12			
Nyeri	UM1, UM2, UM3			12			
Kirinyaga	UM1, UM2, UM3			12			
Nakuru	UM1, UM2				8		
Trans Nzoia	UM1, UM2				8		
Bungoma	UM2, UM3					8	
Kisii	UM1, UM2						8
TOTAL		4	36	48	16	8	8

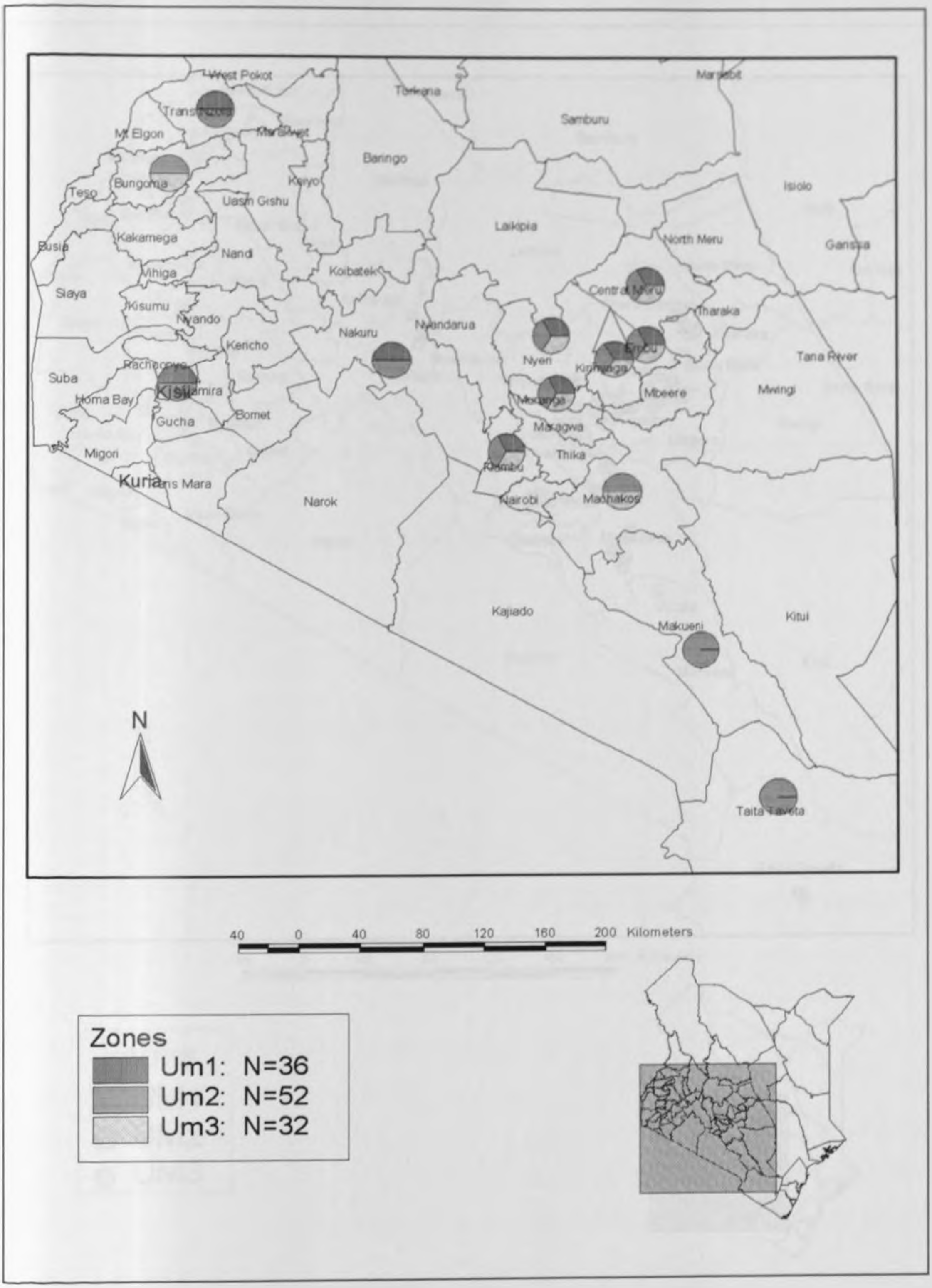

Figure 2: Distribution of coffee growing agroecozones in Kenya
Source: Regional Centre for Mapping

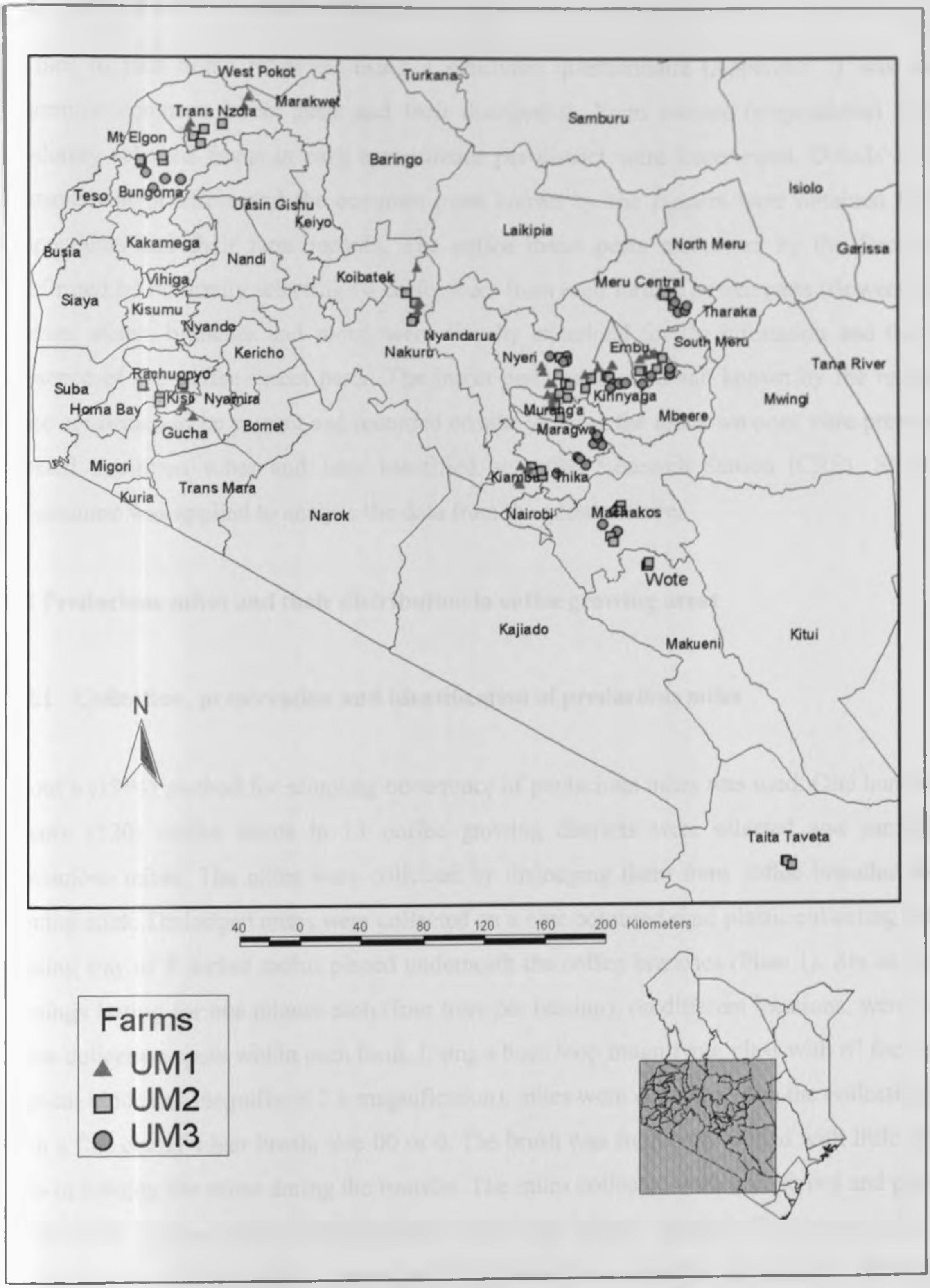

Figure 3: Distribution of coffee farms surveyed in various parts of Kenya
Source: Regional Centre for Mapping

3.1.3 Distribution of coffee insect pests

A face to face home interview using a structured questionnaire (Appendix 1) was used to determine common insect pests and their distribution. Farm owners (respondents) from the randomly selected farms in each agroecozone per district were interviewed. Details of coffee management practices and the common pests known by the farmers were obtained from the respondents and their farm records. The coffee insect pests mentioned by the farmer were confirmed by randomly selecting 10 coffee trees from each farm. The tree parts (flowers, leaves, berries, stems, branches and roots) were visually examined for the infestation and the actual presence of the coffee insect pests. The insect pests mentioned and known by the respondent were confirmed to be present and recorded on site, whereas the unknown ones were preserved in labeled specimen tubes and later identified at coffee Research Station (CRS). SPSS 11.5 programme was applied to analyze the data from the questionnaire.

3.2 Predacious mites and their distribution in coffee growing areas

3.2.1 Collection, preservation and identification of predacious mites

Grout's (1994) method for sampling occurrence of predacious mites was used. One hundred and twenty (120) coffee farms in 13 coffee growing districts were selected and sampled for predacious mites. The mites were collected by dislodging them from coffee branches using a beating stick. Dislodged mites were collected on a blue coloured rigid plastic collecting board or beating tray of 8 inches radius placed underneath the coffee branches (Plate 1). Six to ten light beatings lasting for one minute each (four trees per beating), on different locations, were used as mites collection spots within each farm. Using a head loop magnifying glass with 6" focal length (optical binocular magnifier x 2.6 magnification), mites were collected from the collecting board with a fine camel's hair brush, size 00 or 0. The brush was frequently wetted with little water to help in holding the mites during the transfer. The mites collected were transferred and preserved or stored in labeled small vials/specimen tubes with 70-80% alcohol. To prevent mites from drying out incase the alcohol evaporated 5% glycerol was added to the alcohol. During mites collection, information such as locality, date of collection, collector, host plant, geographical

Plate 1. Collection of predacious mites on a beating tray

position and altitude were recorded for each sampling site. Geographical position of each farm was recorded using a Global Positioning System (GPS) (Magellan systems, PS 2000).

3.2.2 Mounting and identification of mites

Predacious mites were initially prepared for identification by clearing or macerating the specimens. The specimen tubes with mites were initially emptied leaving the dead mites inside. Using a dropper, the mites were put in a spot tile containing a mixture of lactic acid and glycerol (one to two drops). The mites were left for 48 hours at room temperature to clear. Hoyer's medium (mounting medium) made from mixing distilled water 25ml, Gum arabic 15g, Chloral hydrate 100g and Glycerine 10ml in that sequence, was used for mounting the mites. During mounting, a very small drop of Hoyer's medium was placed on the glass slide and spread out to a fairly thin layer. The mite (one per slide) was placed in the Hoyer's medium by using a minute insect pin.

Before placing a cover slip or glass, the slide was dried in an oven at 40^0C for up to 3 hours for the Hoyer's to set. A fresh drop of Hoyer's medium was finally placed on top of the set mite followed by gently lowering a cover glass over it. The mounted mites were put in an oven at about 40^0C for seven days until the specimens fully cleared and dried. The dried specimens were finally removed from the oven and identification carried out according to Ueckermann and Loots (1988), and Chant and McMurtry (2006; 2005a; 2004a; 2003 and 1994). SPSS 11.5 programme and Canonical analysis were used to analyze the data.

3.3 Toxicological assessment of Chlorpyrifos (Dursban® 480EC) against *Euseius kenyae* (Swirski and Ragusa)

The common predacious mites on coffee, *E. kenyae* (Plate 2) was assessed for its sensitivity against Chlorpyrifos 480EC (o,o-diethyl o-(3,5,6-trichloro-2-pyridinyl) ester), the most commonly applied insecticide (at rate of 0.75 ml per litre of water) by farmers to control several key coffee insect pests. Concentrations of 1.5, 0.75, 0.375 and 0.1875 ml per litre of water equivalent to 200, 100, 50, and 25% field rates, were used as toxicants with pure distilled water included as control.

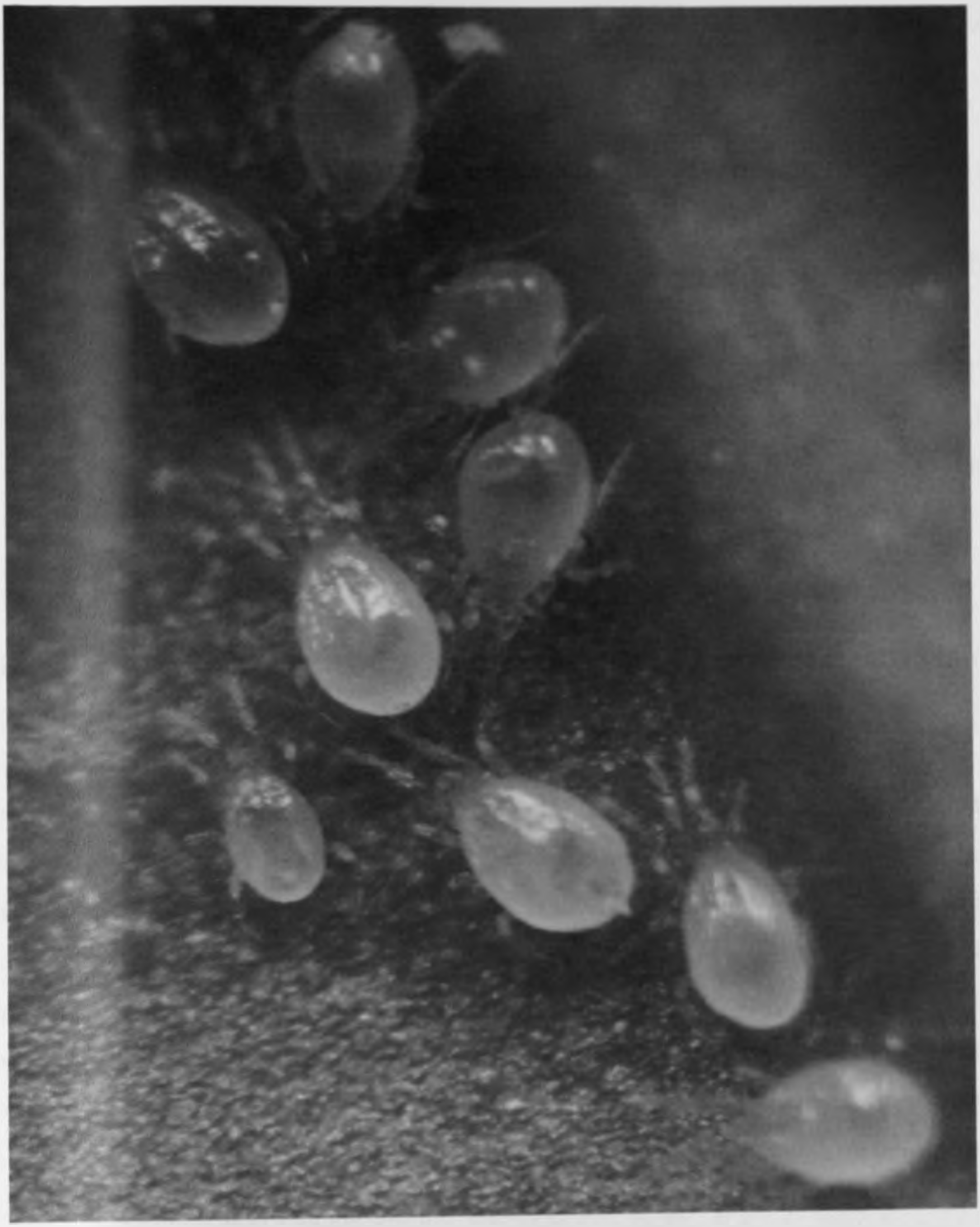

Plate 2. Colony of *Euseius kenyae* (Swirski and Ragusa) on coffee leaf

Among the 120 coffee farms where predacious mites were surveyed, fourteen (14) farms were selected from east of Rift Valley for mites collection and subsequent laboratory mass rearing. The farms were selected on the basis of:

1) History of Chlorpyrifos (Dursban 480EC) use to control some of the key insect pests of coffee for the last five or more years
2) History of no Chlorpyrifos (Dursban 480EC) or any other insecticide use against coffee insect pests within the last five or more years
3) History of using either Fenithrothion (Sumithion 500EC) (Dimethyl 3-methyl-4-nitrphenyl phosphorothioate), Omethoate (Folimat 500EC) (Dimethyl S-(N-methylcarbomonylmethyl) phosphorothioate) or their combination in controlling primary coffee insect pests and
4) The presence of *E. kenyae*

3.3.1 Field collection and laboratory mass rearing of *Euseuis kenyae* (Swirski and Ragusa)

The *E. kenyae* were mass reared in the laboratory to provide enough numbers for the bioassay on sensitivity to chlorpyrifos. Young coffee seedlings aged between six and eight months and potted in polyethylene bags (size 5" x 9" gauge 200) with perforations to allow water drainage and aeration were used to carry and transport the mites to the laboratory (Plate 3a). Using beating trays, mites were dislodged from the coffee trees and carefully transferred to the leaves of coffee seedlings using a fine camel hair brush. Fifty to a hundred mites per coffee farm were obtained. Both the underside and upper side of the leaves for each coffee seedling were then carefully dusted with coffee pollen grains as a food source for the collected mites. The seedlings were labeled with the collection site, date and the farm owner. Each labeled seedling was placed in a plastic bucket of size 14" x 14.5" and filled quarter way with synthetic sand granules (size particles of 0.3 x 0.3mm) (Plate 3b). The granules provided stable anchorage for seedlings during transportation to the laboratory.

Coffee seedlings containing the predacious mites from the field were carefully removed from the buckets on arrival at the CRF laboratory. The seedlings were each transferred into labeled small size plastic bucket of size 9"x 9" with holes at the bottom and filled with well fertilized soils to rovide the environment suitable for growth of the seedlings. Seedlings from each collection site ·ere placed in separate rearing rooms in the laboratory where fresh coffee pollen grains were usted after every three days to feed the mites. The mites were given a period of two to three ıonths to multiply and establish themselves. The rearing was carried out under normal ıboratory conditions with mean temperature and relative humidity of 27± 2^0C and 75%, espectively.

.3.2 Harvesting of predacious mites for toxicological tests

After the collected mites had multiplied and established themselves in the laboratory, fresh olonies approximately of the same age from each of the collection sites were raised for oxicological assessment. Eggs estimating two hundred (200) from the reared colonies for each ite were harvested and transferred to fresh coffee seedlings with the aid of camel's hair brush. Four seedlings each having 50 eggs were used as the rearing units. The eggs were incubated ınder laboratory conditions for a period of two weeks. The newly hatched mites were collected ınd used for the toxicological study at the age of two weeks. The females being the biased sex in *E. kenyae* were used for the study. The harvested females were placed in a plate of 6" diameter ınd internally surrounded with a thin layer of wet cotton wool, were put in a refrigerator at 4^0C for several minutes (10-15 minutes). This treatment reduced the mobility of the mites to allow hem to be transferred to the Petri dishes with leaf discs (2cm in diameter) treated with 1.5, 0.75,).375 and 0.1875ml of Chlorpyrifos per litre of water as concentrations.

3.3.3 Bioassaying of Chlorpyrifos (Dursban ® 480EC) against *Euseuis kenyae* (Swirski and Ragusa)

Four batches of 20 mites from the same population and age were exposed to various concentrations of Chlorpyrifos (1.5, 0.75, 0.375 and 0.1875 ml per litre of water equivalent to 200, 100, 50, and 25% field rates) and distilled water as the control. Petri dishes with cotton wool soaked in water were prepared as the arena for bioassay. Young fresh coffee leaves from a farm with no history of insecticides use were plucked and leaf discs of 2cm in diameter cut.

a

b

Plate 3. Coffee seedlings used to carry predacious mites from the field (a), and a single seedling in a bucket with artificial sand granules (b)

The discs were immersed separately in the different concentrations of Chlorpyrifos or distilled water for ten seconds. The discs were then placed in different clean Petri dishes to dry. Each of the dried leaf discs was placed upside down in the Petri dish. A strip of cotton wool was put around the edges of the disc to prevent the mites from escaping. This was replicated four times for each concentration. Pollen grains were dusted on each of the discs as a source of food for the mites. On every disc, 20 female mites were placed using a fine hair brush. The mites were exposed to the five treatments for duration of 48 hours after which mortality was recorded from each disc. This bioassay was repeated twice. Mortality counts were corrected according to Abbott's formula (1925) and plotted on a log-dosage probit paper according to Finny (1952).

3.4 Comparison between different integrated pest management strategies on coffee insect pests

An experiment on different integrated systems for pest control was carried out at Coffee Research Station (CRS), Ruiru for three successive years. CRS is situated in the main coffee growing agroecozone (UM2). The station is located at an altitude of 1608m on eastern slopes of Aberdare ranges, 27km North of Nairobi city (1.06^0 South, 36.45^0 East). The mean annual rainfall is 1058mm, bimodally distributed with main rainy season being March- May (Long Rains) and November- December (Short rains). The soil at the Coffee Research Station is humic and euric nitosol (Kikuyu Red Loam). Generally, this soil is dark reddish brown to dusky red, very deep (1.5-2.0m), friable and free draining with acid humic topsoil. It is of volcanic origin and is formed *in situ* by the decomposition and leaching of tertiary trachytic lava and tuff deposits. It has high clay content, often of 60-80%, high holding water capacity, good porosity and drainage. This soil type is slightly very acidic.

3.4.1 Experimental site

The experiment was laid out at CRS in a main coffee block with mature trees of Arabica coffee hybrid, Ruiru 11 known to be resistant to two main coffee diseases: Coffee Berry Disease and Leaf Rust. Prior to this, soil sampling was carried out and analysed to determine the PH level. The trees had a planting of close spacing of 2M x 2M giving a total of 2500 trees per hectare. Agronomic practices such as pruning, liming, handling and weeding were carried out as recommended during the trial period. A block of 1500 coffee trees of Ruiru 11 was carved out from the main block for the experiment.

3.4.2 Experimental design and treatments

The selected and carved coffee block was sub-divided into three equal medium size sub-blocks each with about 500 trees. The first sub-block was fertilized using compound fertilizer (N.P.K. 17:17:17), the second was organically fertilized using a composted manure (made from a mixture of boma and poultry manures, coffee pulps and banana chippings and trace elements) while the third sub-block received improved N.P.K (22:6:12) (Figure 4). In all the sub-blocks, Gypsum (Lime/calcium source) was applied at a nominal rate of 300g /tree annually according to results of soil analysis so as to improve Calcium level that was found inadequate in soils where trial was laid. Calcium Ammonium Nitrate (CAN: 26:0:0) was applied as a supplement in the sub-blocks treated with inorganic compound fertilizers as recommended by CRF (Table 2).

Three different plots with 16 trees each were randomly distributed in the sub-blocks. In each sub-block selective insecticides; Spinosad (Tracer) (a naturally derived compound, which is a mixture of spinosyns A and D - a novel class of macrocyclic lactones produced by the soil actinomycete, *Saccharopolyspora spinosa* (Mertz and Yao)) and Chlorpyrifos (Dursban 480EC) were applied as the treatments with untreated plot as control. Using a Complete Randomized Block Design, each treatment was replicated four times in each sub-block. Two rows of coffee trees were left between the sub-blocks, plots and the periphery as guard rows. Adjacent to the fertilized coffee sub- blocks, an equivalent sub-block were used as the control (neither fertilizers nor insecticides were applied).

3.4.3 Compost manure preparations

A mixture of cattle (20 tonnes) and poultry (2 tonnes) manures, coffee pulp (5 tonnes) and banana chippings (3 tonnes) in different proportions were used to make the compost (Plate 4a). In the compost, small amounts of trace elements; Boron (5kg), Zinc (5kg), Magnesium (Epsom) (10kg) and lime (magmax) (60kg) were incorporated to improve and avail the micronutrients required by the plant. The compost provided 0.8: 0.2: 1.0 units of N: P: K, respectively (Table 2).

The mixtures were turned after every one week for a period of 10 weeks (Plate 4b). Temperature and pH levels were monitored on weekly basis until the two parameters stabilized (Plate 4c). This is the time compost was ready for use. The mixing was carried out on the surface of polythene paper in order to avoid loss of released macro- and micro-nutrients. The composting manure was all the time covered with polythene paper to avoid the rains and sunlight hence preventing loss of nutrients (Plate 4d).

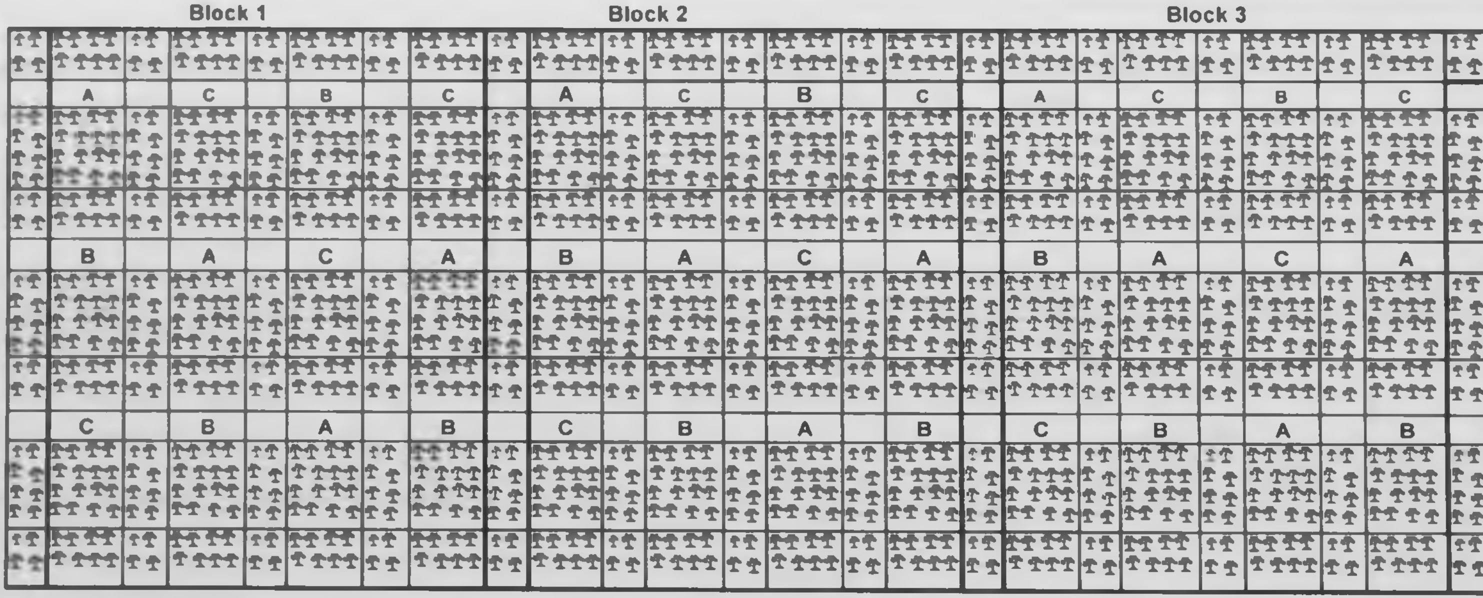

Figure 4 Soil fertilization regimes experimental design in a coffee farm at Coffee Research Station from 2006-2008

NB: **Blocks;** 1: N.P.K 17:17:17
2: Organic Compost
3: N.P.K 22:6:12

Plots; A: Untreated
B: Chlorpyrifos
C: Spinosad

Table 2: Soil fertilization regimes used in different coffee experimental plots at Coffee Research Station (2006-2008)

Fertilization/ treatment	Nutrient supply source	Rate (g,Kg)		Element nutrient supply (g/tree)			Application period or month	No of Applications
		g/tree	Kg/ha	N	P_2O_5	K_2O		
Conventional	**N.P.K.: 17:17:17**	250	332.5	42.5	42.5	42.5	Oct/Nov	1
	- CAN: 26:0:0	150	199.5	39	0	0	Apri ,May	2
	- Lime/Calcium source	150	199.5	-	-	-	Aug , Jan	2
Modified/ Improved	**N.P.K. 22:6:12**	250	332.5	55	15	30	Oct/Nov	1
	- CAN: 26:0:0	125	166.3	32.5	0	0	Apri , May	2
	- Lime/Calcium source	150	199.5	-	-	-	Aug , Jan	2
Organic	**Compost manure** (Farmyard manure, Poultry manure, Coffee pulp andBanana chippings)	14000	18620	120.5	33.04	135.52	Aug/Sept	1
	- Lime/Calcium source	150	199.5				Aug, Jan	2

NB: (1) N.P.K.: 22.6.12: Improved compound fertilizer with readily available small quantities of secondary macronutrients [Ca (3%), Mg (2%) and S (1.5%)] and micronutrients [B (0.3%), and Zn (0.3%)].

(2) Calcium source: Gypsum applied at a nominal rate of 300g /tree to improve Calcium level found to be inadequate in soils where trial was laid.

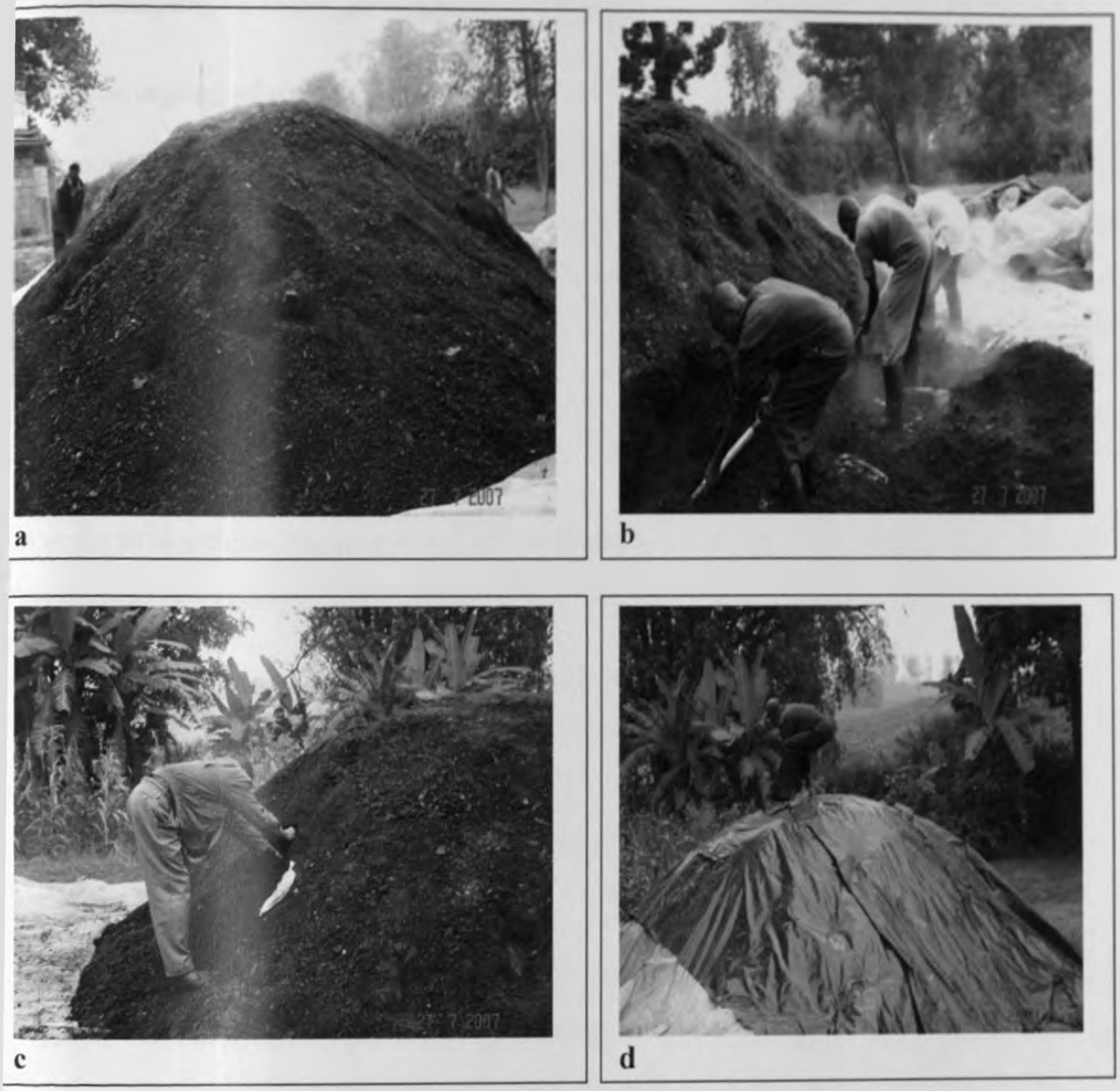

Plate 4: Compost manure (**a**) uncovered, (**b**) rotating to speed up decomposition, (**c**) temperature being recorded, and (**d**) covered with polythene paper

3.4.4 Sampling of insect pests and predacious mites

3.4.4.1 Sampling of predacious mites

Four coffee trees at the center of each plot were sampled fortnightly to monitor the population levels of predacious mites. The predacious mites were dislodged from the coffee branches in each plot using a beating stick. The beating was conducted for one minute in each plot among the four trees at the centre. The dislodged mites were collected in a collecting board, counted and recorded.

3.4.4.2 Sampling of insect pests

In order to determine the population and infestation levels of coffee insect pests, the following techniques were employed fortnightly:-

(a) Coffee Berry Borer (*Hypothenemus hampei (*Ferrari))

Randomly, one bearing primary branch from any tree in each plot was picked. The numbers of mature berries (hardened coffee berries aged over four months) were counted and their total recorded. All the berries with CBB attack were counted and the total recorded.

(b) Thrips (*Diarthrothrips coffeae* Williams)

Twenty young leaves from four trees (five leaves per tree from different directions) were randomly selected in each plot. On each leaf the number of thrips were counted and recorded. The thrips were identified at Coffee Research Station from the preserved specimens.

(c) Red spider mites (*Oligonychus coffeae* (Nietner))

The numbers of red spider mites were counted on the 20 leaves used for thrips assessment and recorded. The mites were identified at Coffee Research Station from the preserved specimens

(d) Green scales (GS) (*Coccus alpinus* De Lotto)

Twenty, young leaves from four trees (five leaves per tree from five different branches representing different directions) were randomly selected in each plot. One leaf in the 4th pair/position from the tip of each branch was selected and the number of scales counted and recorded. Infestation level was computed as number of scales per leaf.

The data was analyzed by using the Analysis of Variance (ANOVA). The Least Significant Difference (LSD) was used to separate the means.

3.4.5 Assessment for yield and qualityof coffee harvested from plots under different management strategies (treatments)

Four effective or productive coffee trees at the centre of each plot were marked for yield assessment. At every cherry or coffee picking, the picked coffee was weighed and recorded, with one tenth of it taken to the factory for processing. The accumulated data for total cherry picked and processed (when hulled) at the end of each year, were used to determine the yield of clean coffee (metric tones of clean coffee) per hectare. The conversion factor of 6:1 was used in determining the yield per hectare (six kilograms of cherries gives one kilogram of clean coffee).

During each coffee season (early / late cropping), a sample of ten kilograms of cherry for quality assessment was taken and processed for each plot, particularly when the cherry ripening was optimal. Dry parchment (from early /late cropping) for each plot were mixed for hulling and grading. Parameters such as percentage grade AA and AB, weight of coffee beans and toxic residues in roasted coffee beans were used to assess the quality for each sample.

The data was analyzed by using the Analysis of Variance (ANOVA). The LSD was used to separate the means.

3.4.6 Analysis of pesticide residues in coffee beans

Pesticide residue analysis was considered as an indication of product quality. Processed coffee beans were analysed for the presence of Spinosad (Tracer) and Chlorpyrifos (Dursban 480 EC). The processed coffee beans from each treatment in a sub-block were mixed and ground to make a single sample (A total of three samples were obtained from each sub-block).

3.4.6.1 Analysis of Chlorpyrifos residues using Gas Liquid Chromatography (GLC) technique

About 500g of fully dried coffee beans from each sample was ground into a fine powder. A fraction of the sample (10g) was weighed in a sample jar and mixed with 10g of anhydrous sodium Sulphate to dehydrate the sample, after which 50 ml of acetonitrile was added and the sample blended at high speed for two minutes. The extract was filtered with suction through a Buchner funnel using GF/A Whatman filter paper, into a 200 ml volumetric flask. The sample was returned to the jar and extraction repeated two times with 50 ml of acetonitrile filtering the contents into the 200 ml volumetric flask.

The blender container was washed with 50 ml acetonitrile and the contents filtered into the same flask. The flask was filled to volume with acetonitrile. The total extract was placed in a 500 ml separating funnel for partitioning. During the first partitioning process, 50 ml of hexane was added and the contents shaken thoroughly for one minute and then allowed to stand still for the resultant layers to separate. The aqueous layer was run into a 500 ml beaker while the organic layer was dried by passing it through Sodium Sulphate. (Sodium Sulphate was retained in the funnel by a plug of glass wool). The filtrate was collected in a 500 ml rotary evaporating flask.

The partitioning process was repeated using 50 ml hexane. After the second partitioning process, the aqueous layer was run to waste while the hexane (organic layer) was run through Sodium Sulphate column into the rotary evaporator. The separator funnel was rinsed with several portions of hexane passing the washings through the sodium Sulphate and collecting all portions in one rotary evaporator.

The flask was placed on a rotary evaporator and the extract volume was reduced to near dryness (about 1 – 2 ml). Then 10 ml of acetone was added into the extract and evaporated to near dryness followed by another 10 ml of hexane which was also evaporated to near dryness. The extract was then reconstituted with 10 ml iso-octane. Samples were analysed for the presence of Chlorpyriphos using GLC method coupled with Nitrogen Phosphorous Detector (NPD) (Simpson, 1993).

.6.2 Analysis of Spinosad residues using High Pressure Liquid Chromatography (HPLC) technique

›out 500g of fully dried coffee beans for each sample was ground into a fine powder. 50g of :nded sample were extracted in acetonitrile + water (8 + 2 by volume; 100ml) for 2 min, and : contents transferred to a conical flask. Thereafter, the samples were subjected to 30 min aking on a mechanical shaker. The contents were then filtered through a Bt chner funnel and ıshed with acetonitrile + water (8 + 2 by volume). The filtrate was concentrated and partitioned th dichloromethane in a separating funnel. After phase separation, the organic layer was llected. Methanol (10 ml) and aqueous sodium hydroxide (1 ml) along with additional :hloromethane were added to the aqueous phase. The mixture was again partitioned. The oled organic phases were evaporated to dryness in a rotary vacuum evaporator at 40 °C, and : residue was finally dissolved in hexane.

ıe hexane extract was purified using a silica solid phase extraction (SPE) cartridge. The rtridge was conditioned with hexane under vacuum. The sample solution in hexane was added the silica SPE cartridge and eluted. The flask was also rinsed with hexane and eluted as above. ıe cartridge was then dried under vacuum. The flask was again rinsed with acetonitrile, and the ısate was added to the dried cartridge. The acetonitrile solution was eluted, collected and ımediately evaporated to dryness in a rotary vacuum evaporator. The residue was reconstituted methanol + acetonitrile + 20 gL¯1 aqueous ammonium acetate (1 + 1 + 1 by volume; 1mL) for ıal HPLC analysis.

ɔinosad residues were determined by HPLC equipped with a UV detector (250 nm). The ɔlumn used was C18 (250mm × 4.6mm ID). The mobile phase was acetonitrile + methanol + 20 ‿¯1 aqueous ammonium acetate (21 + 21 + 8 by volume) at a flow rate of 2.0 ml min−1. A 5ml iquot of each sample was injected each time into the HPLC system for residue analysis.

CHAPTER FOUR

4.0 RESULTS

.1 Distribution of coffee insect pests and farm management practices

The study determined the major insect pests of coffee, their distribution in coffee growing groecozones in Kenya and their management. It also established farm management practices xcercised by farmers.

The survey extensively covered all major coffee growing regions in Kenya. This survey realized complex of coffee insect pests. The pests occurred and seemed to have coevolved under various coffee varieties that have been under production for many years (1-100 years).

The coffee growers interviewed were categorized into three groups according to their farm sizes: smallholders, medium estates and large estates (plantations). Out of the 120 farmers interviewed, 76.6% (n=92) were smallholders (< 5acres), with 6.7% (n=8) and 16.7% (n=20) representing the medium (5-10 acres) and large estates (> 10 acres), respectively.

During the survey the Scots Lab (SL-28 and SL-34), the improved Hybrid cultivar Ruiru-11(R11), Kent 7 (K7) and Blue Mountain (BM) were the main commercial coffee varieties grown by the farmers, either singly or combined. The SLs and R11 were the main varieties grown in 41% and 22% of all the farms sampled, respectively. A combination of SL/R11 followed with 18% of the farms whereas the rest either purely grown or combined only represented less than 10% each.

The SLs were the most commonly preferred varieties in the three agroecozones. They were mainly grown in UM2 and UM3 where they accounted for 44.2% and 43.8% of the coffee grown, respectively. Ruiru-11 was mainly grown in UM1 and UM2 accounting for 27.8% and 23.1%, respectively, whereas K7 was mostly grown in UM2. The BM variety was only grown in UM1. Farms growing the SL/R11 combination were more in UM3 (25%) than in UM1 (16.7%) or in UM2 (15%).

The farms surveyed were grouped into ten categories depending on the age of the coffee trees. Most farms (31.7%) had old coffee trees aged 41-50 years since establishment. Only 2.6% of the farms had coffee trees aged over 61 years.

4.1.1 Farm Management Practices

Weeding, pruning, fertilization, intercropping, pesticides use, *mbuni*-stripping, irrigation and mulching were the common farm management practices used by the coffee farmers surveyed. Out of the 120 farmers interviewed, 95% (n=114) weeded their farms. Other commonly used farm management practices carried out by the farmers were: pruning (92.5%), fertilization (80%), intercropping (60.8%), pesticides use (51.7%) and *mbuni*-stripping (50%). Irrigation and mulching were uncommon and were practiced by only 10% of the farmers (Figure 5).

4.1.1.1 Farm Management Levels

The coffee farms were grouped into three categories depending on the number of farm management activities practiced. Farms where farmers practiced at least three of the farm management practices mentioned above were categorized as low managed farms whereas farms in which farmers practiced 4-5 or 6-8 of the management practices were categorized as moderate or high managed farms, respectively. Based on this criterion, most farms (66%) were under moderate management with 18.3% and 15.8% of the farms falling under high and low management, respectively.

4.1.1.2 Fertilizers Usage

The inorganic fertilizers commonly used as sources of coffee nutrition by the interviewed farmers were Nitrogen Phosphorus Potassium (N.P.K.), Calcium Ammonium Nitrate (CAN), and Di-Ammonium Phosphate (DAP) whereas the organic fertilizers were manure, coffee pulp, foliar feeds and mulching. Less than 13% of the coffee farmers applied Di-Ammonium Phosphate, coffee pulp, foliar feeds and mulching. The most commonly used fertilizer was manure (67.5%) followed by N.P.K. (52.5%) and CAN (50%) in that descending order (Figure 6a). The popularity of the various sources of coffee nutrition used by the farmers, and particularly N.P.K., CAN, manure, coffee pulp and foliar sprays varied among the agroecozones (Figure 6b). Mulching and DAP were rarely used in all the agroecozones.

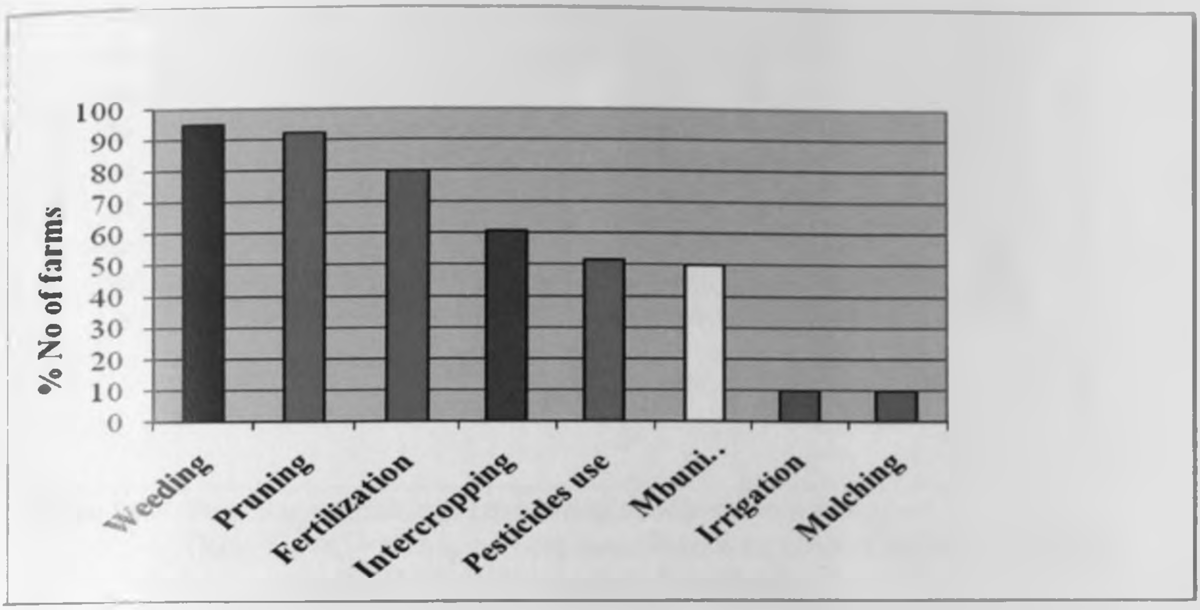

Figure 5: Farm management practices undertaken by the coffee farmers surveyed in Kenya

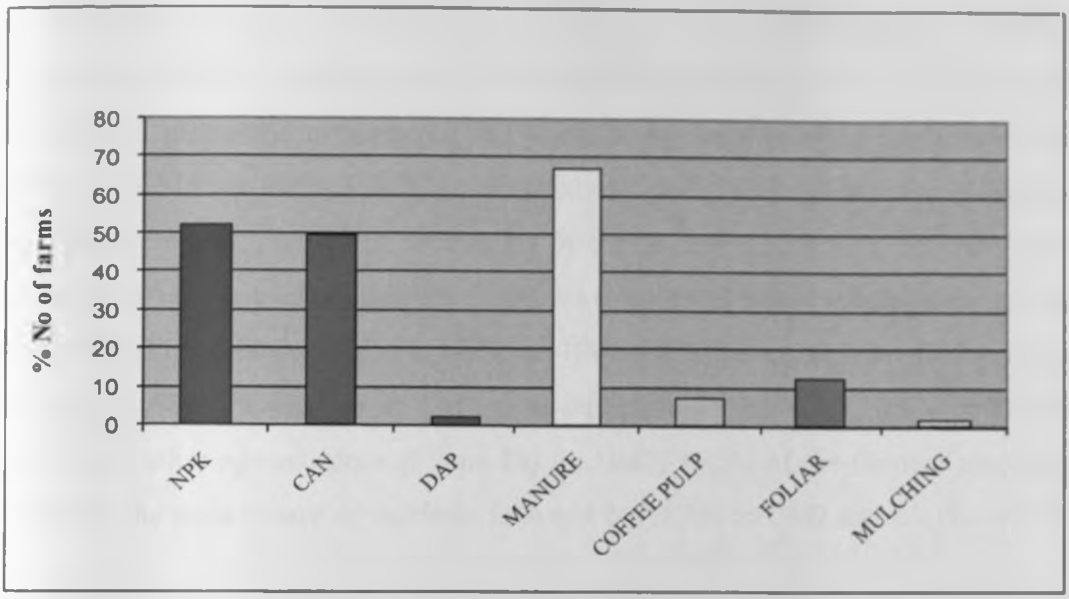

Figure 6a: Percentage number of farms using different fertilizer sources (Key: N.P.K. =Nitrogen Phosphorus Potassium, CAN=Calcium Ammonium Nitrate, DAP=Di-Ammonium Phosphate)

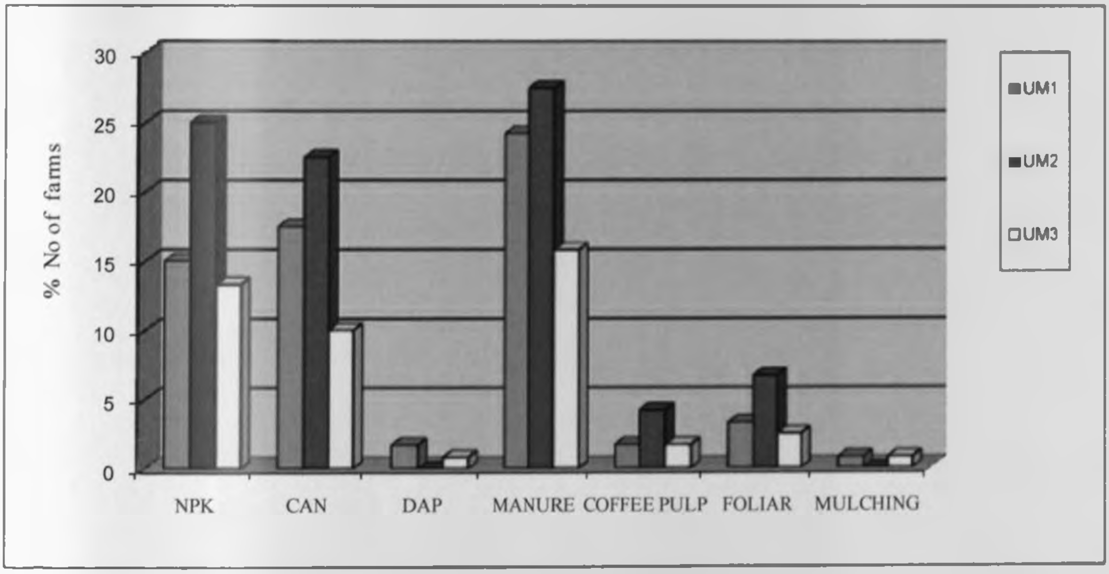

Figure 6b: Percentage number of farms using different fertilizer sources in various agroecozones

For an effective supply of essential nutrients required by coffee plants, a combination of N.P.K./CAN, N.P.K./CAN/Manure and N.P.K./CAN/Manure/foliar is recommended. However, only a small proportion of farmers (18.3% and 3.3%) were found to apply a combination of N.P.K./CAN/Manure and N.P.K./CAN, respectively, over the cropping seasons. Manure, N.P.K. and CAN were also found to be used singly by the farmers (Figure 7a). Nevertheless, 15.8% of the farms surveyed never applied any fertilizers (Neglected farms). These neglected farms were mainly found in UM2 and UM3. In UM2 and UM1 the farmers mainly applied a combination of CAN/N.P.K./Manure whereas in UM3 most farmers used the N.P.K./CAN combination more than in any other agroecozones (Figure 7b). In UM3, 15.6% of the farmers singularly applied manure as the main source of nutrients followed by 11.5% in UM2 and 11.1% in UM1 (Figure 7b).

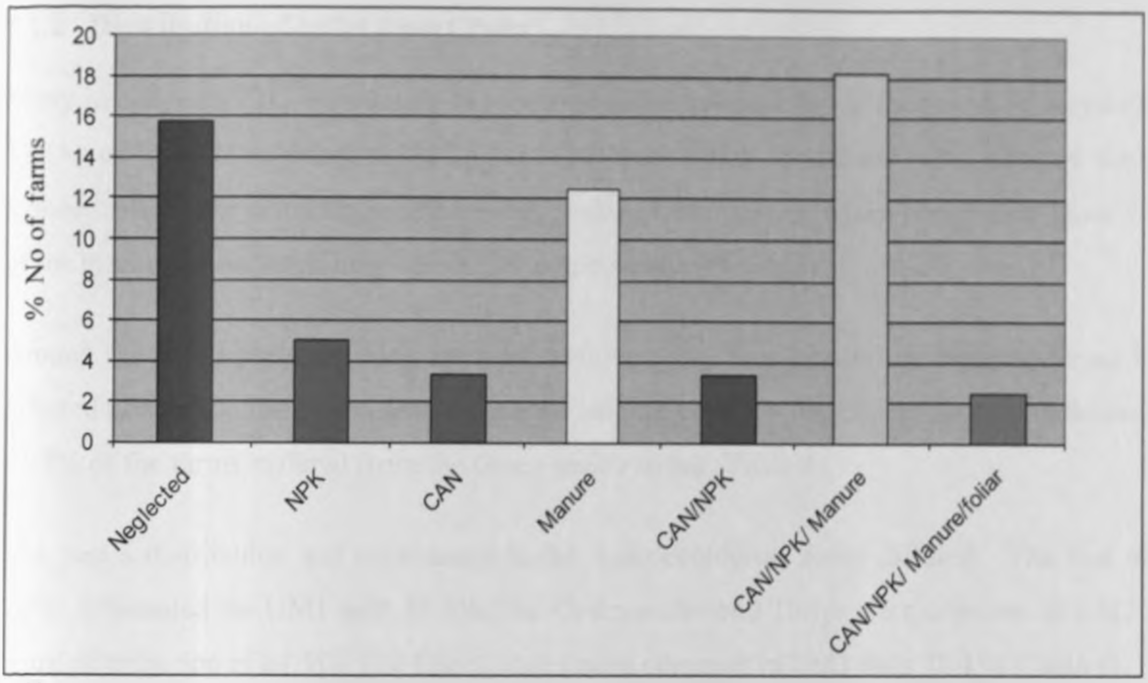

Figure 7a: Percentage of the surveyed farms neglected or using different fertilizers

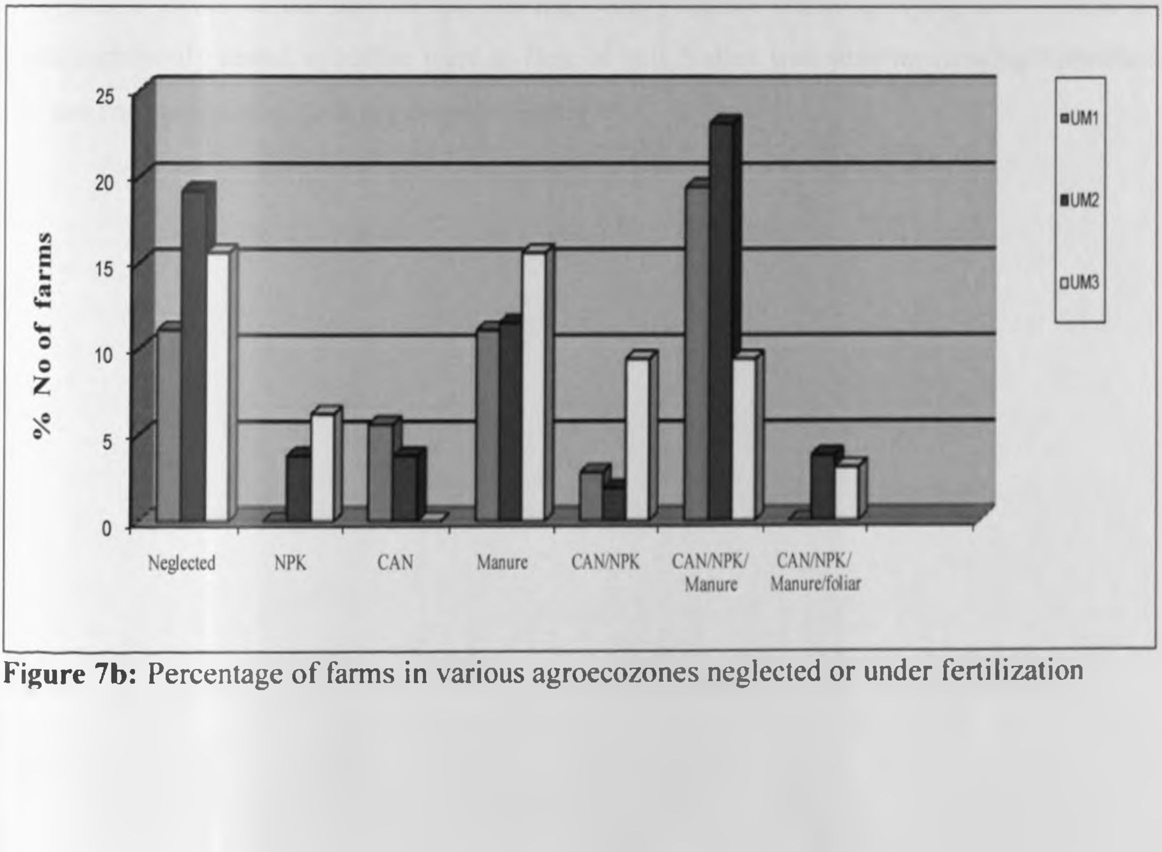

Figure 7b: Percentage of farms in various agroecozones neglected or under fertilization

4.1.2 Distribution of coffee insect Pests

Many insect pests (21) were found to constrain coffee productivity in the farms surveyed (Table 3). Out of these 21 coffee pests, 95.24 % (n=20) were widely spread and occurred in all the three agroecozones. The distribution of Fried egg scales, *Aspidiotus* sp. which constituted about 4.76% of the total pests occurred only across two agroecozones (Table 3).

Among the insect pests recorded ten were common with over 20% of the farms surveyed being infested (Table 4). The Green scales were the leading common insect pest. Results indicated that 61.7% of the farms suffered from the Green scales attack (Table 4).

The pest's distribution and dominancy in the Agro ecological zones differed. The Red spider mites dominated the UM1 with 55.6%. The Green scales and Thrips were common in UM2 with equal distribution of 61.5%. The Green scales were common in UM3 with 78.1% (Table 4).

Insect pests distributions in coffee growing areas varied. Nakuru district in Central Rift Valley had the least number of the common insects (only five). West of Rift Valley followed with at most six to seven of the insects and acarina occupying the coffee growing areas. Most insect pests commonly found in coffee were in East of Rift Valley with number ranging between nine and ten for each coffee growing district (Figure 8).

Table 3: Insect pests from the surveyed coffee farms and agroecozones

Pest	Common Name	Scientific Name	% farms attacked	Agroecozone
Insects				
	Coffee Berry Borer	*Hypothenemus hampei* (Ferrari)	25.0	UM1, UM2, UM3
	Berry Moth	*Prophantis smaragdina* (Butler)	21.7	UM1, UM2, UM3
	Thrips	*Diarthrothrips coffeae* Williams	55.8	UM1, UM2, UM3
	Capsid bugs	*Lygus coffeae* (China)	30.8	UM1, UM2, UM3
	Leaf miners	*Leucoptera* spp	33.3	UM1, UM2, UM3
	Jassids	*Coloborrhis bellicose* Distant	18.3	UM1, UM2, UM3
	Antestia	*Antestiopsis spp*	40.8	UM1, UM2, UM3
	Yellow Headed Borer	*Dirphya nigricornis* (Olivier)	28.3	UM1, UM2, UM3
	White Borer	*Anthores leuconotus* Pascoe	21.7	UM1, UM2, UM3
	Green scales	*Coccus alpinus* De Lotto	61.7	UM1, UM2, UM3
	Kenya Meallybugs	*Planococcus kenyae* (Le Pelley)	16.7	UM1, UM2, UM3
	Fruit flies	*Ceratitis capitata* (Wiedemann)	4.2	UM1, UM2, UM3
	Lace bugs	*Habrochila ghesquierei* Schouteden	11.7	UM1, UM2, UM3
	Fried egg scales	*Aspidiotus sp*	1.7	UM1, UM3
	Termites	*Odontotermes badius* Haviland	9.2	UM1, UM2, UM3
	Aphids	*Aphis coffeae* Nietner	10.0	UM1, UM2, UM3
	Stinging caterpillar	*Parasa vivida* (Walker)	5.0	UM1, UM2, UM3
	Leaf skeletonizer	*Epiplema dohertyi* (Warren)	9.2	UM1, UM2, UM3
	Systate weevils	*Systates spp*	3.3	UM1, UM2, UM3
	Giant loopers	*Ascotis selenaria reciprocaria* (Walker)	4.2	UM1, UM2, UM3
	Red spider mites	*Olygonychus coffeae* (Nietner)	48.3	UM1, UM2, UM3

Table 4: Percentage of common Insect pests in coffee growing agroecozones

Insect Pests /Acarina	**% infested**	**% attacked farms per agro-ecozone**		
		UM1	UM2	UM3
Coccus alpinus	61.7	47.2	61.5	78.1
Diarthrothrips coffeae	55.8	52.8	61.5	50.0
Olygonychus coffeae	48.3	55.6	51.9	34.4
Antestiopsis spp	40.8	33.3	40.4	50.0
Leucoptera spp	33.3	36.1	36.5	25.0
Lygus coffeae	30.8	38.9	19.2	40.6
D irphya nigricornis	28.3	22.2	36.5	21.9
Hypothenemus hampei	25.0	8.3	28.9	37.5
Prophantis smaragdina	21.7	27.8	9.6	34.4
Anthores leuconotus	21.7	2.8	23.1	40.6

Figure 8: Distribution of insect pests in coffee growing areas

4.1.2.1 Coffee insect Pests' management by use of insecticides

The farmers used thirteen insecticides to manage coffee insect pests. Approximately 42.5% of the farms surveyed applied insecticides (Table 5).

Among the insecticides recorded, four insecticides were common with over 5% of the farms using the products (Table 6). Chlorpyrifos (Dursban 480EC) was the commonly used insecticide among the farmers. Atleast 17.5% of the farmers interviewed applied Chlorpyrifos to control insect pests (Table 6).

The use of insecticides across the Agro ecological zones varied. The Fenitrothion (sumithion) was commonly used in UM1 with 19.0%. In UM2, Chlorpyrifos was the common insecticide used (23.0%). The Fenitrothion and Diazinon (Basudin) were equally common in UM3 with 13.0% each.

Insecticides use by the coffee farmers' differed across the agroecozones. They were mainly used in UM2 (44.2%) followed by UM1 and UM3 at 41.7% and 40.6%, respectively (Figure 9).

Table 5: Percentage levels of insecticides usage in coffee farms surveyed

Pesticide	Active ingredient	Trade name(s)	% No farms
Insecticides	Chlorpyrifos	Dursban	42.5
	Cabosulfan	Marshal	
	Profenofos	Selecron	
	Beta-Cyflutrin	Bulldock	
	Lambdacyhalotrin	Karate	
	Dimethoate	Folimat	
	Diazinon	Basudin	
	Fenitrothion	Sumithion	
	Malathion	Malathion	
	Fenithion	Lebaycid	
	Alphacypermetrin	Fastac	
	Pyrethroid	Decis, Pyrene,	

Table 6: Percentage use of common insecticides in coffee growing agroecozones

Insecticide	% farms	% farms per agroecozone		
		UM1	UM2	UM3
Chlorpyrifos	17.5	17	23	9.4
Fenitrothion	14.2	19	12	13
Diazinon	5.8	8.3	3.8	13
Dimethoate	5.8	5.6	7.7	3.1

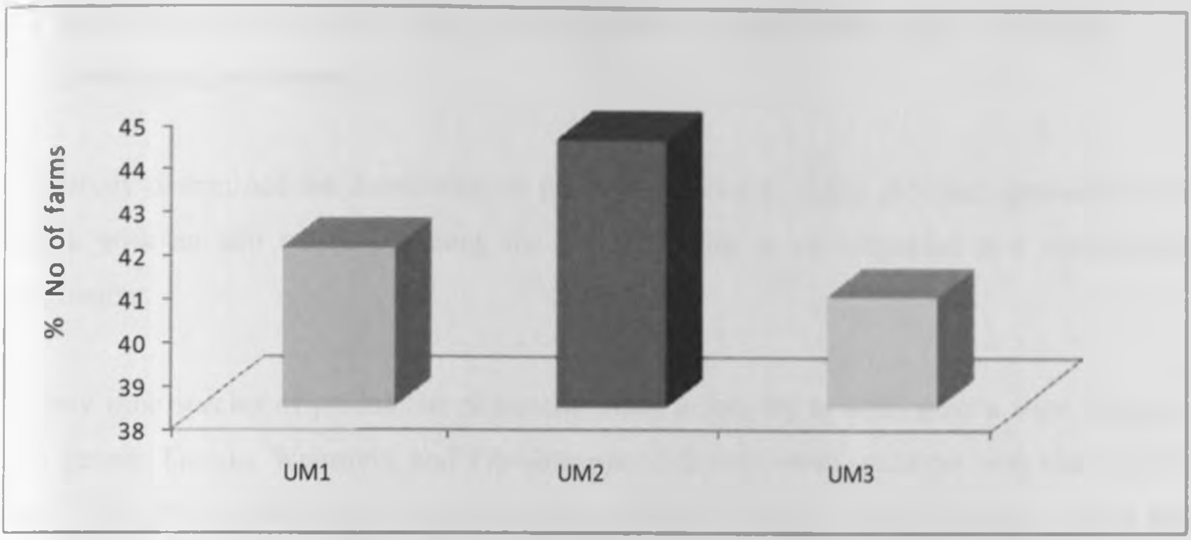

Figure 9: Percentage of coffee farmers using insecticides in different agroecozones

4.2 Occurrence and distribution of predacious mites (Acari: Phytoseiidae) in coffee growing agroecozones

This study determined the distribution of predacious mites in coffee growing agroecozones in Kenya with an aim of incorporating the potential ones in an integrated pest management programme.

Twenty nine species of predacious phytoseiid mites belonging to eight genera were recorded. The genera *Euseius* Wainstein and *Typhlodromus* Scheuten were common with nine species each. The genus *Amblyseius* Berlese had four species whereas *Ueckermannseius* Chant and McMurtry and *Typhlodromalus* Muma had two each. *Typhlodromips* Deleon, *Iphiseius* Berlese and *Phytoseius* Ribaga had one species each (Table 7). Species occurrence varied according to the genus. For instance, although an equal number of species occurred in the genera, *Euseius* and *Typhlodromus*, an average of 7.6% of the farms surveyed recorded the presence of *Euseius* spp. as compared to 1.6% of *Typhlodromus* species meaning that *Typhlodromus* species were less spread in coffee growing areas. Under the genus *Euseius*, the species *E. kenyae* was widely spread and most common. It was present in 36.7% of the farms surveyed.

Among the identified predacious phytoseeid mites, five species were common to all three coffee agroecozones. Ten other species were unique to UM2 and, another three to UM3 (Table 7). *Euseius albizziae* (Swirski and Ragusa), *E. rhusi* (Van der Merwe), *E. minutisetus* Moraes and McMurtry, *E. van denbergae* (Ueckermann and Loots) and *T. Michaeli* (Ueckermann and Loots), were found in both UM1 and UM2 whereas *E. africanus (*Evans), *Typhlodromus drymis* Ueckermann and Loots, *T. persianus* McMurtry, *and T. crassus* Van der Merwe were restricted to UM2 and UM3. Another two species, *T. magdalenae* Pritchard and Baker and *Amblyseius herbicolus* Chant were restricted to UM1 and UM3 (Table 7).

Of the 29 mite species identified, only four (*E. kenyae*, *Ueck. macrosetosus*, *E. africanus* and *E. albizziae*) were present in over 5% of the farms surveyed (Table 7 and Figure 10). The four species constituted 14% of the total predacious mites collected and they were regarded as common. The rest (86%) were less common species of predacious mites in coffee. The *E. kenyae*, the most common species, was collected in 44 of the 120 (36.7%) farms. *Ueck.*

macrosetosus was only found in 15 (12.5%) farms whereas other *Euseius* species, (*E. africanus* and *E. albizziae*) were only reported from nine and eight farms that represented 7.5% and 6.7%, respectively.

The occurence of predacious phytoseid mites varied among the coffee growing agroecozones. Among the four common species, E. *kenyae* and *E. albizziae* were more prevalent in UM1 with UM2 and UM3 followed in that order. *Euseius africanus* and *Ueck. macrosetosus* were more prevalent species in UM3 (Figure 11).

The distribution of predacious mites' species that were common varied among the sampled districts. Muranga district had *E. kenyae, E. africanus* and *Ueck. macrosetorus* as the common species of predacious mites present there. Both in Machakos and Nyeri; *E. kenyae* and *Ueck. macrosetorus*, were common predacious mite species with *E. kenyae* and *E. africanus* being common in Kirinyaga and Embu. Meru Central and Bungoma districts had *E. kenyae* and *Ueck. macrosetorus,* respectively as the common predacious mite species (Figure 12). In Makueni, Kisii and Trans-Nzoia districts, no mites were collected. The predacious mite, E. *albizziae,* one of the common species was only recorded in Nakuru district in the Rift Valley province. *Euseius van denbergae* (Ueckermann and Loots) was only recorded in Taita Taveta district though considered not common (Figure 12).

The phytoseiid species, *E. kenyae* occurred in all the agroecozones (Figures 13a, b and c). Coffee farms (47.2%) in UM1 showed the presence of this species (Figure 14a). In UM1, 12 (41.4%) species were recorded. A total of 24 (82.8%) mite species were recorded in UM2 and 14 (48.8%) in UM3 (Figures 13b and c). The mites' richness in UM2 was twice that occurring in either UM1 or UM3.

Table 7. Predacious phytoseiid mites collected and identified from 120 coffee farms in different coffee growing agro ecological zones of Kenya (2006-2008)

Species	% No farms with species present	Coffee agroecozones
Euseius kenyae (Swirski and Ragusa)	36.67	UM1,UM2, UM3
E. africanus (Evans)	7.50	UM2, UM3
E. albizziae Swirskii and Ragusa	6.67	UM1,UM2
E. lokele (Pritchard and Baker)	5.00	UM1,UM2, UM3
E. rhusi (Van der Merwe)	4.17	UM1,UM2
E. pafuriensis (Van der Merwe)	4.17	UM3
E. minutisetus Moraes and McMurtry	1.67	UM1,UM2
E. van denbergae (Ueckermann and Loots)	1.67	UM1,UM2
E. majengo El-Banhawy and Irungu	0.83	UM2
Typhlodromus drymis Ueckermann and Loots	3.33	UM2, UM3
T. persianus McMurtry	2.50	UM2, UM3
T. magdalenae Pritchard and Baker	2.50	UM1, UM3
T. crassus Van der Merwe	1.67	UM2, UM3
T. michaeli Ueckermann and Loots	1.67	UM1,UM2
T. ndibu Pritchard and Baker	0.83	UM2
T. wrenschae Ueckermann and Loots	0.83	UM2
T. rasilis Van der Merwe	0.83	UM3
T. ruiru El-Banhawy and Irungu	0.83	UM2
Amblyseius herbicolus Chant	3.33	UM1, UM3
A. largoensis (Muma)	1.67	UM2
A. swirskii Athias – Henriot	0.83	UM2
A. pundi Pritchard and Baker	0.83	UM2
Ueckermannseius macrosetosus (Van der Merwe)	12.50	UM1,UM2, UM3
Ueck. eastafrica Moraes, Zannou and Oliveira	0.83	UM2
Typhlodromalus spinosus (Meyer and Rodrigues)	1.67	UM2
Ty. olombo Pritchard andBaker	0.83	UM2
Typhlodromips shi Pritchard and Baker	3.33	UM1,UM2, UM3
Iphiseius degenerans (Berlese)	3.33	UM1,UM2, UM3
Phytoseius kaimosi El-Banhawy and Irungu	0.83	UM3

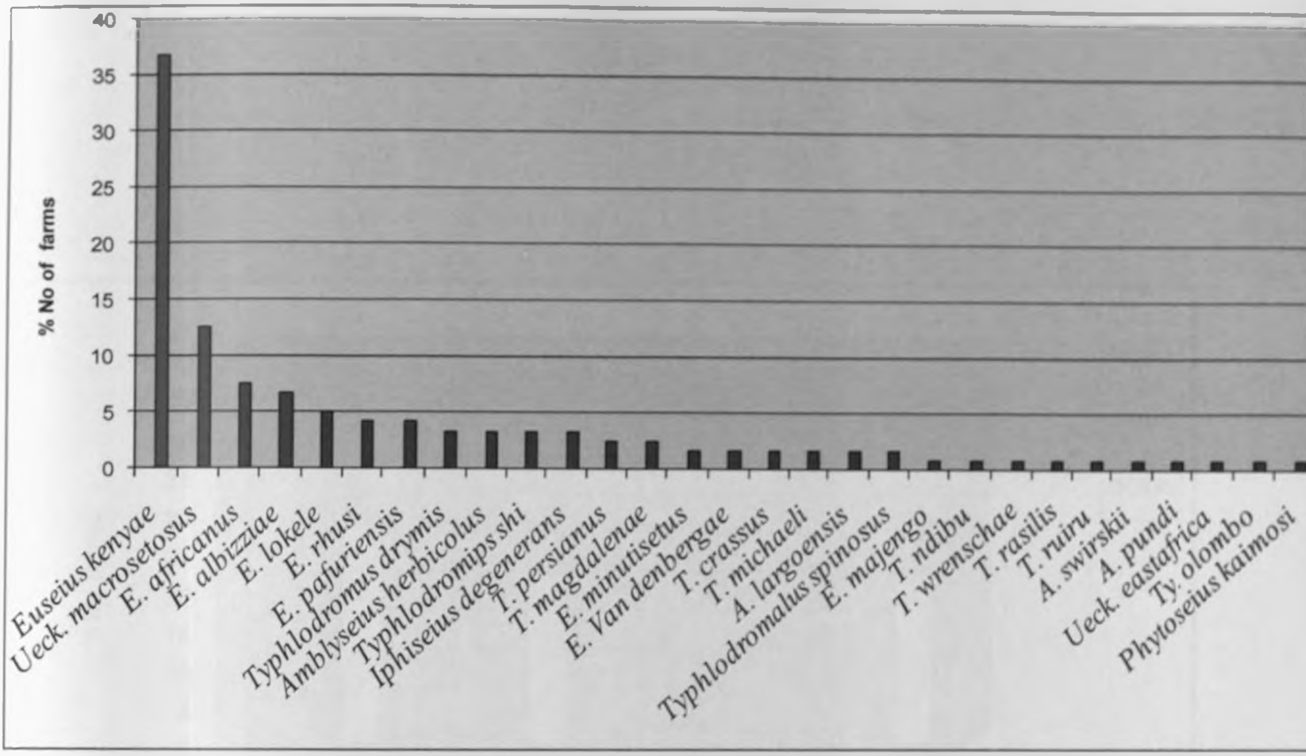

Figure 10: Percentage occurrence of predacious phytoseiid mites in the farms

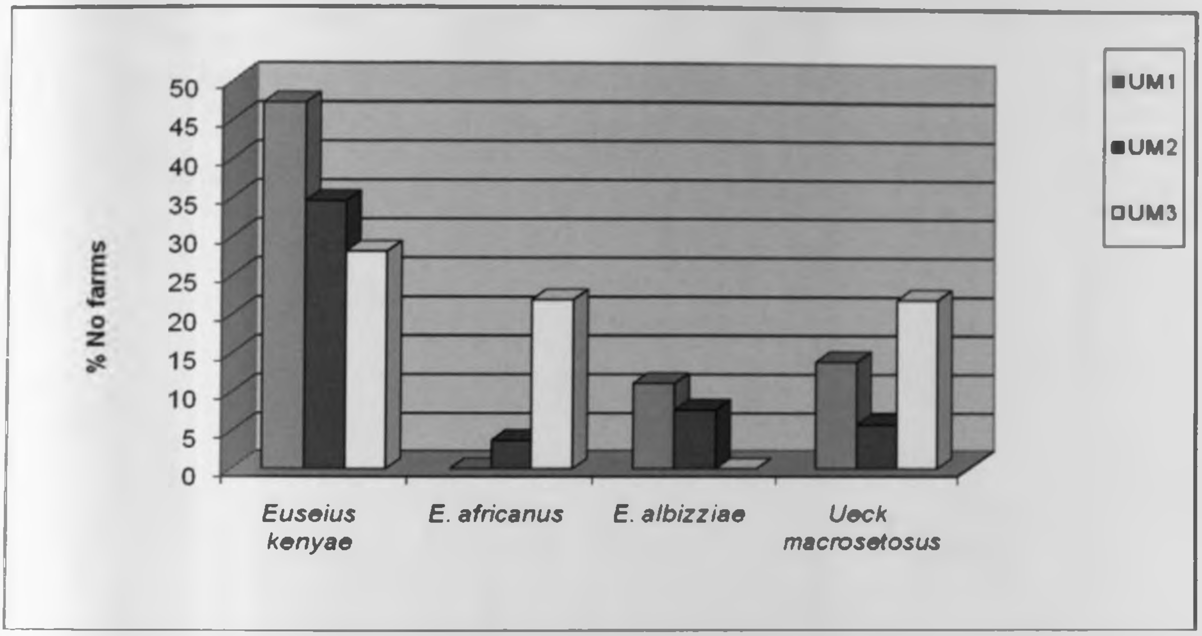

Figure 11: Percentage occurence of common species of predacious phytoseiid mites in different agroecozones

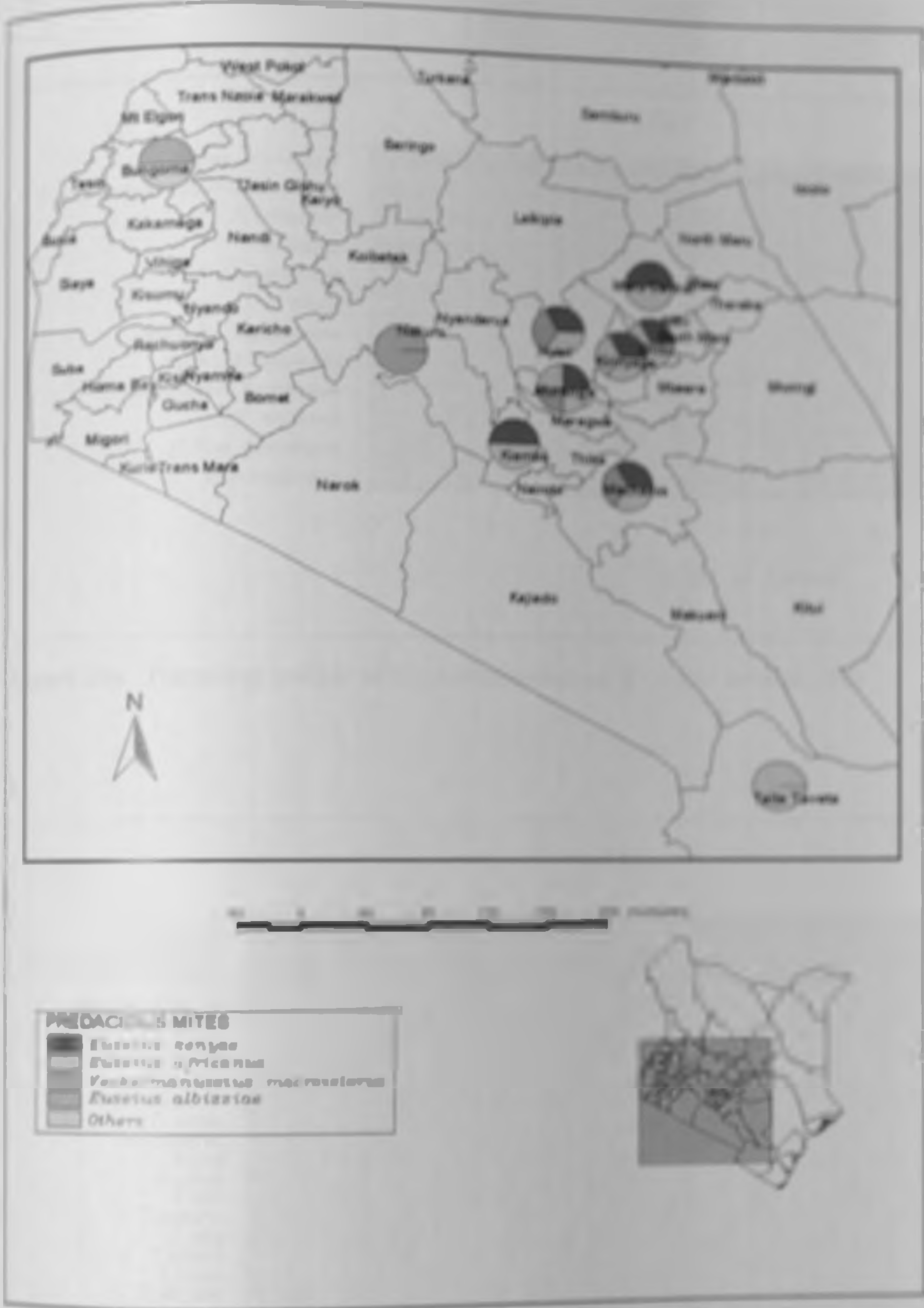

Figure 12: Distribution of coffee predacious phytoseiid mites in coffee growing areas

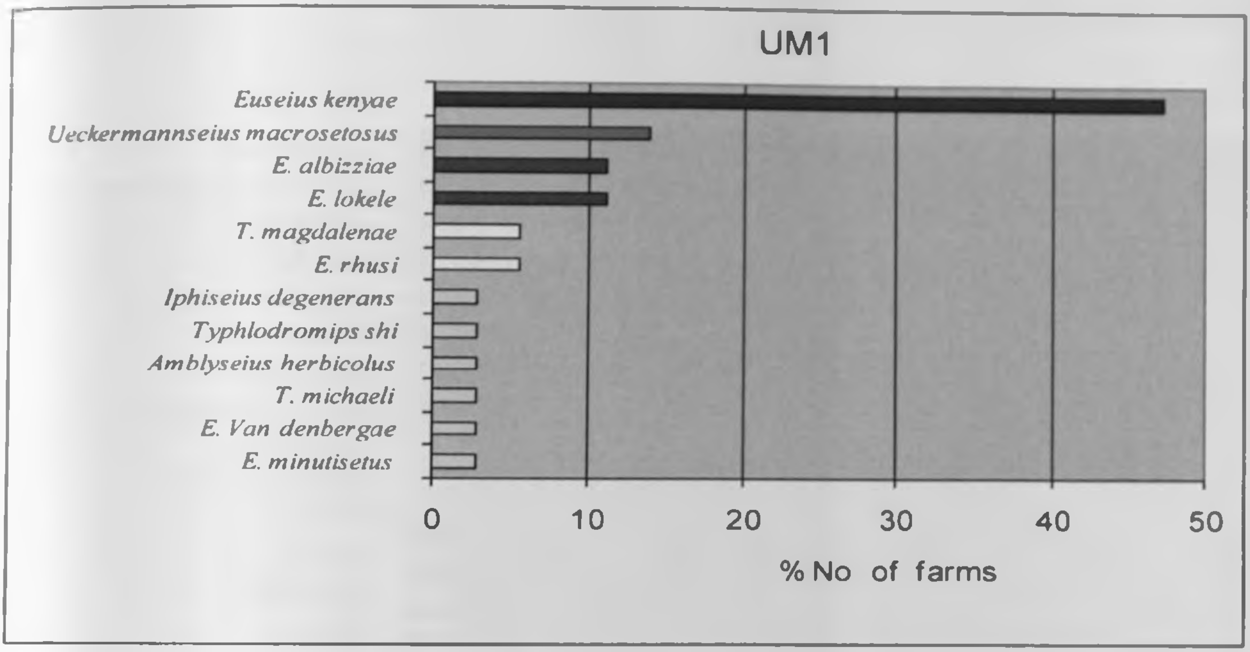

Figure 13a: Percentage number of farms with predacious phytoseiid mites in UM1

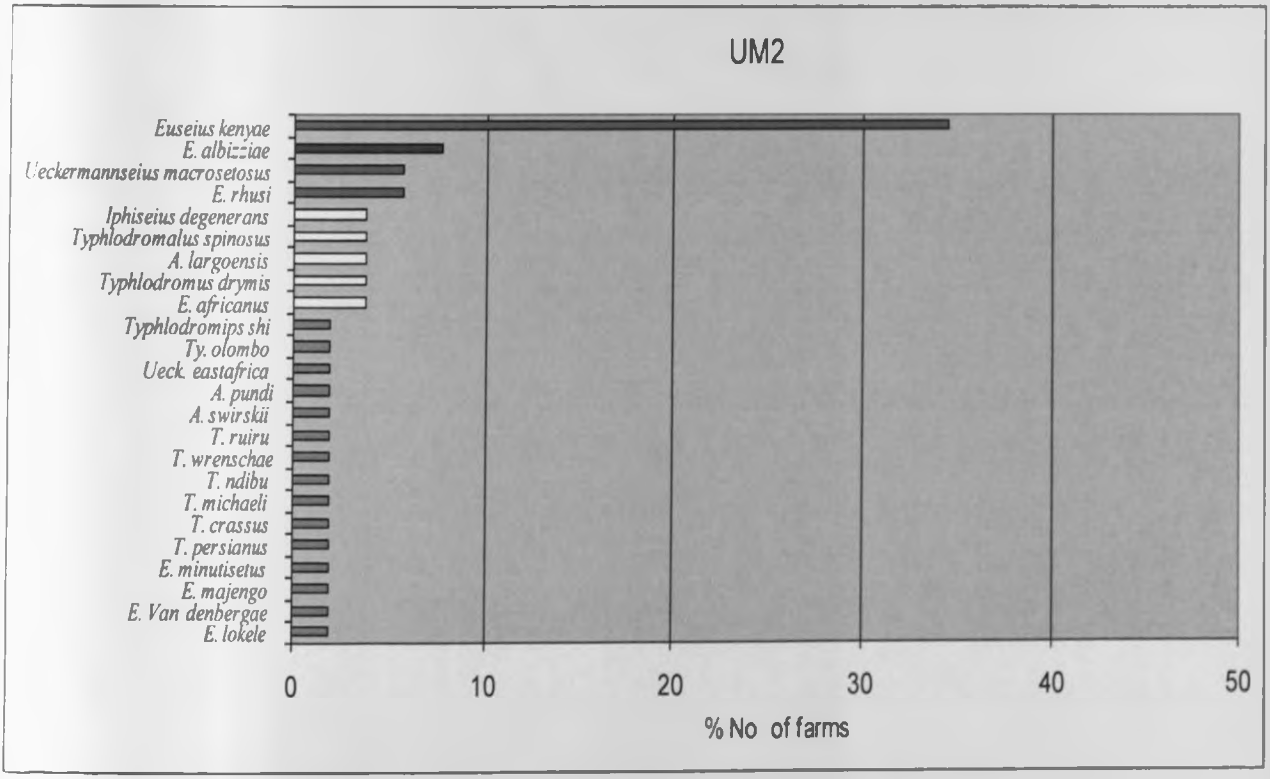

Figure 13b: Percentage number of farms with predacious phytoseiid mites in UM2

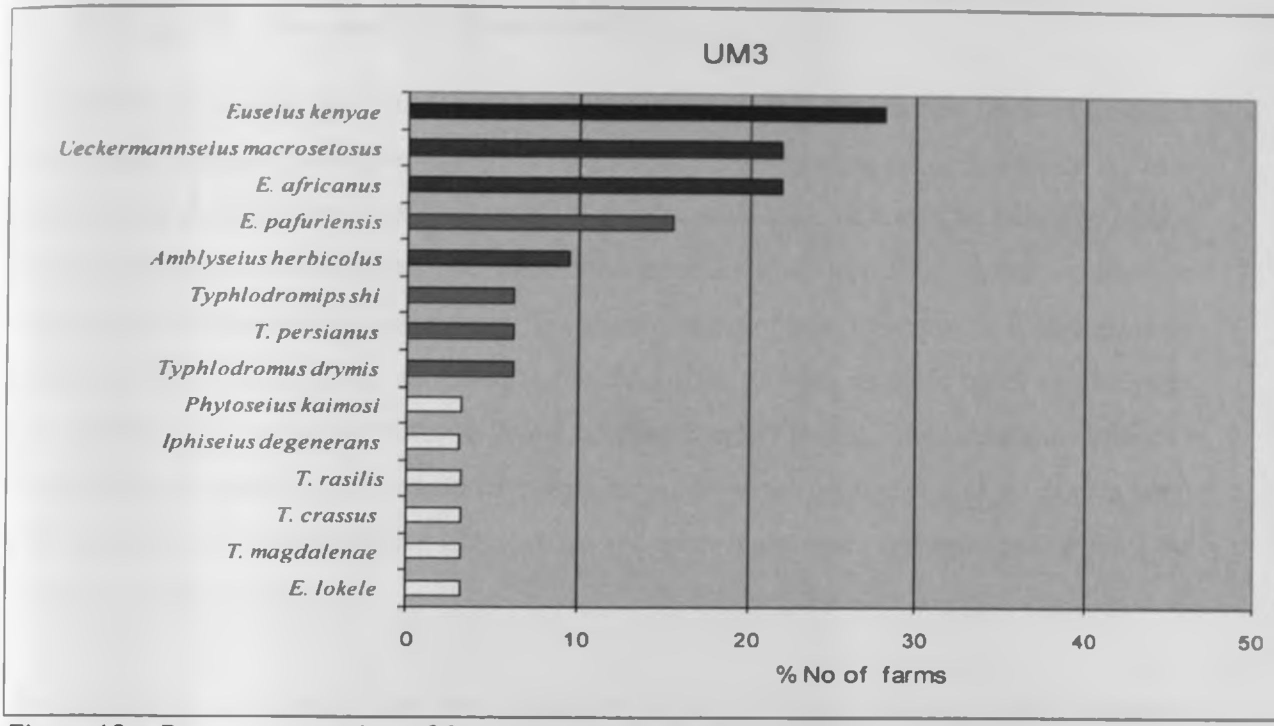

Figure 13c: Percentage number of farms with predacious phytoseiid mites in UM3

4.3 Sensitivity of *Euseius kenyae* (Swirski and Ragusa) (Acari: Phytoseiidae) to Chlorpyrifos (Dursban®) in Kenyan coffee farms

Chlorpyrifos is a widely used insecticide to control insect pests in most coffee farms in Kenya. It is used either through foliar spraying against the insect pest or banding the coffee tree at the base to keep away the attendant ants that mutually coexist with scale insects. The two approaches, differently expose both the pests and the natural enemies to Chlorpyrifos, hence variation in resistance to this chemical is anticipated. The development of any resistance to chlorpyrifos by predacious phytoseiid mites is an advantage to the coffee growers as these mites control pests such as thrips and red spider mites to below economic injury levels. To ascertain the effect of Chlorpyrifos to Predacious mites under coffee agroecosystem. populations of *E. kenyae* were collected from coffee farms where Chlorpyrifos and other insecticides had been used against the coffee insect pests (Table 8).

The populations of *E. kenyae* from the sampled coffee farms showed variation in their responses to Chlorpyrifos. The individuals of *E. kenyae* from farm C44, with young Ruiru 11 trees aged less than ten years and banding applied as a method of managing the scales, had mites which were most susceptible to Chlorpyrifos (LC_{50} = 0.044). This population was used in this study as the standard reference for susceptible strains.

Different populations of *E. kenyae* irrespective of the source differed in their susceptibility or response to Chlorpyrifos. Two different responses of *E. kenyae* occurred from coffee farms where Chlorpyrifos was used. The C1 (LC_{50} =0.653) and C4 (LC_{50} = 0.623) where Chlorpyrifos was regularly applied as foliar spray indicated that the strains of E. *kenyae* were less susceptible to Chlorpyrifos at various field rates bioassayed (Table 8). The other farms where Chlorpyrifos was either foliar sprayed or banded, the populations of E. *kenyae* were susceptible to Chlorpyrifos even at the lowest field rate. For instance C2, C12, C19 and C116 had LC50 of 0.172, 0.068, 0.102 and 0.116, respectively that were lower than 25% field rate.

The population of *E. kenyae* collected from coffee farms with no history of Chlorpyrifos use for five or more years prior to this study showed different responses to Chlorpyrifos. Some farms had populations of E. *kenyae* with high level of resistance to Chlorpyrifos at field rates ranging from 100 and 200%. For example, C7 and C119 had LC50 of 1.716 and 1.008, respectively. Their respective resistance ratios were 39.0 and 22.9 (Table 8). The population of *E. kenyae* from coffee farm (C31) under similar treatment had LC50 of 0.436 that was lower than populations from C7 and C119.

In the coffee farms where Fenitrothion, Omethoate or Fenitrothion + Omethoate were applied, the populations of *E. kenyae* were susceptible to Chlorpyrifos at various field rates bioassayed. Only populations from C25, with LC50 = 0.491 was tolerant to the field rates of Chlorpyrifos (Table 8).

Different populations of *E. kenyae* varied in their responses to Chlorpyrifos. The resistance ratios for populations from C1, C4, C7, C37, C25 and C119 were ten times more than that of the susceptible population (C44). They had LC_{50} almost equivalent to 100% (0.75ml of Chlorpyrifos in one litre of water) field rate (Table 8).

The doses of Chlorpyrifos assessed against the populations of *E. kenyae* collected from various coffee farms under different treatments were toxic or not to the mites but at different levels. The populations from C7 exposed to different concentrations of Chlorpyrifos were less susceptible to chlorpyrifos while C44 was most sensitive. The mortality increased with increase in concentrations at varying rates. For instance, the populations from C7 and C119 had gradual increase in mortality as the concentrations increased unlike in C44 where mortality was high and almost constant irrespective of variation in concentrations (Figure 14).

The *E. kenyae* populations from farms either exposed to Chlorpyrifos or not for the last five years, was more resistance to the concentrations tested when compared to the most susceptible (C44) and almost equivalent to that of most resistance populations (C7) (Figure 15). The coffee farms treated with Fenithrothion, Omethoate or Fenitrothion + Omethoate had most of *E. kenyae* populations resistant to Chlorpyrifos concentrations tested. The population of C72 exposed to the same products showed susceptibility to Chlorpyrifos (Figure 16).

The cumulative mean percentage mortalities from various doses of Chlorpyrifos on different populations of *E. kenyae* were statistically significant from each other [F=33.72, df = (3, 262), n=280, P<0.05] (Table 9). The mean mortality rate from mite population obtained from C7 was significantly lower than in all the other coffee farms except C119 [F=33.72, df = (3, 262), n=280, P<0.05]. The C44 population had the highest mean % mortality that was statistically significant [F=33.72, df = (3, 262), n=280, P< 0.05] from that of C1, C2, C4, C7, C25, C31, C37, C50 and C119 (Table 9).

Table 8: Response of different populations of *Euseius kenyae* (Swirski and Ragusa) from coffee farms in Kenya to Chlorpyrifos (Dursban ® 480EC)

Treatment	Population source	Location/Agroecozone	LC_{50} ± S.E	Slope	Resistance ratio
Chlorpyrifos *	C1	Kiambu UM2	0.653±0.194	0.653	14.84
Chlorpyrifos **	C2	,, ,,	0.172±0.206	2. 055	3.91
Chlorpyrifos *	C4	,, ,,	0.623±0.151	0. 311	14.16
Chlorpyrifos **	C12	,, UM1	0.068±0.206	2.028	1.54
Chlorpyrifos *	C19	Muranga UM2	0.102±0.278	3.040	2.32
Chlorpyrifos *	C116	Nyeri UM2	0.166±0.221	2. 351	3.77
No Chlorpyrifos	C7	Kiambu UM3	1.716±0.194	-0.550	39.00
,,	C31	Meru UM2	0.436±0.207	1.446	9.91
,,	C37	Embu UM1	0.684±0.201	0.624	15.54
,,	C119	Nyeri UM3	1.008±0.182	-0.009	22.91
Fenitrothion / Omethoate *	C25	Meru UM1	0.491±0.191	1.071	11.16
,,	C50	Kirinyaga UM2	0.224±0.210	2.089	5.09
,,	C72	Machakos UM2	0.088±0.412	4.163	2.00
Chlorpyrifos**	C44	Embu UM2	0.044±0.339	3.472	-

Key: *Foliar spraying; ** Banding; CI=Rukera farm; C2= Mburu farm; C4= Gitonga farm; C7= Mongalia estate; C12= Kibubuti Estate; C19= Gichore farm; C25= Kithuu farm; C31= Kirai farm; C37= Ndwiga farm; C44=Kariuki farm; C50= Kamau farm; C72= Kitavi farm; C116=Mbuthia farm; C119=Muringato estate

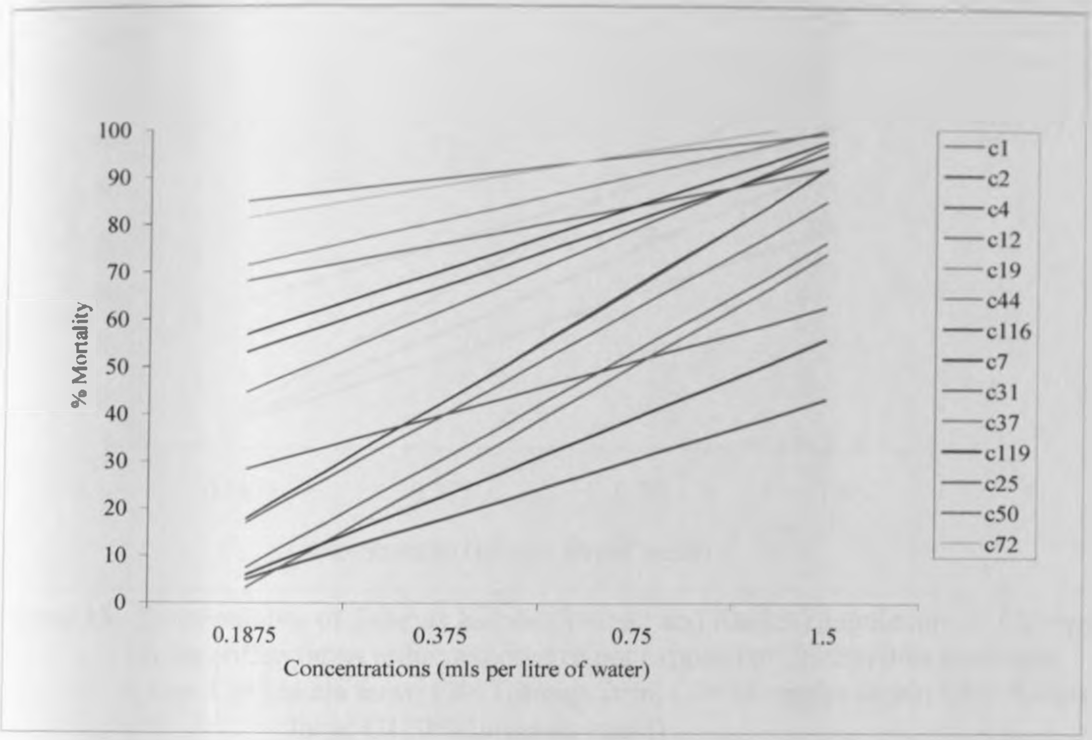

Figure 14: Susceptibility of *Euseuis kenyae* (Swirski and Ragusa) populations to Chlorpyrifos from coffee farms under different insecticide(s) treatments

(Key: CI=Rukera farm; C2= Mburu farm; C4= Gitonga farm; C7= Mongalia estate; C12= Kibubuti Estate; C19= Gichore farm; C25= Kithuu farm; C31= Kirai farm; C37= Ndwiga farm; C44=Kariuki farm; C50= Kamau farm; C72= Kitavi farm; C116=Mbuthia farm; C119=Muringato estate)

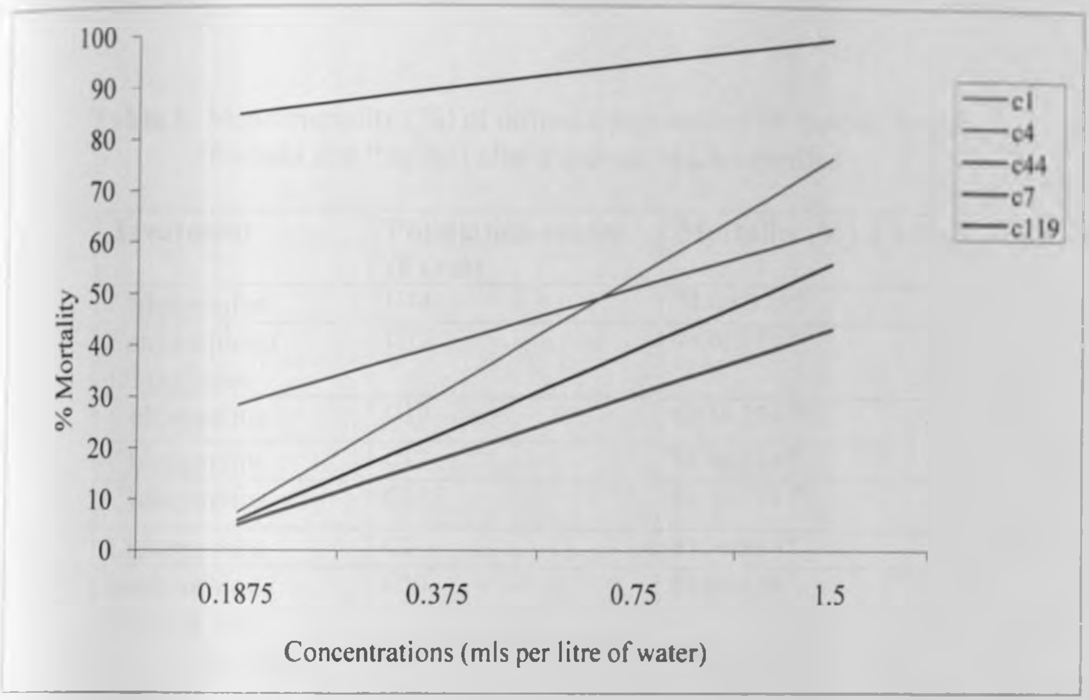

Figure 15: Susceptibility of *Euseuis kenyae* (Swirski and Ragusa) populations to Chlorpyrifos from coffee farms either exposed or not exposed to Chlorpyrifos treatment (*Key*: CI=Rukera farm; C4= Gitonga farm; C7= Mongalia estate; C44=Kariuki farm; C119=Muringato estate)

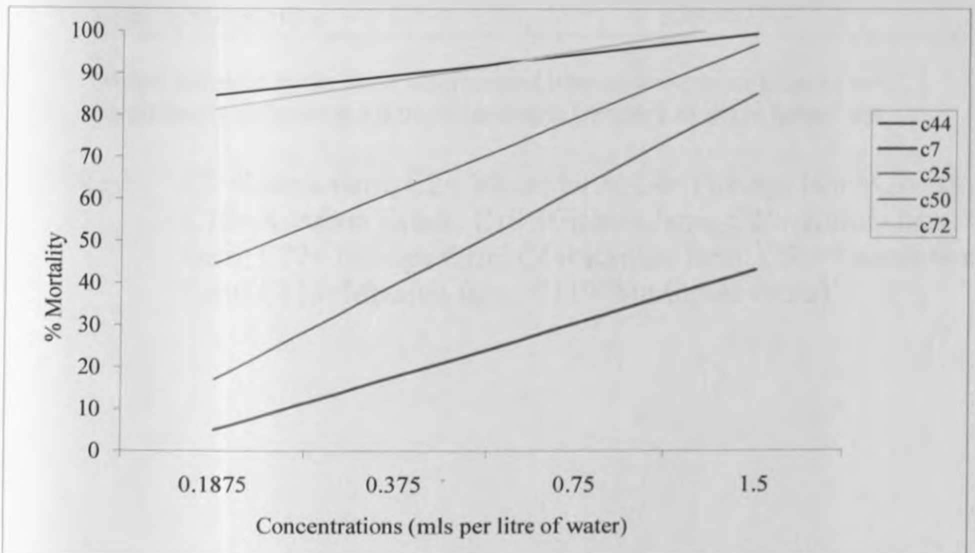

Figure 16: Susceptibility of *Euseuis kenyae* (Swirski and Ragusa) populations to Chlorpyrifos from coffee farms exposed to Fenitrothion or Dimethoate treatments (Key: C7= Mongalia estate; C25= Kithuu farm; C44=Kariuki farm; C50= Kamau farm; C72= Kitavi farm)

Table 9: Mean mortality (%) of different populations of *Euseuis kenyae* (Swirski and Ragusa) after exposure to Chlorpyrifos

Treatment	Population source (Farm)	Mortality (%) ± S.D
Chlorpyrifos	C44	74.0 ± 37.8 [a]
Fenitrothion / Dimethoate	C72	74.0± 37.5 [a]
Chlorpyrifos	C19	69.8± 35.4 [ab]
Chlorpyrifos	C12	65.8± 32.6 [ab]
Chlorpyrifos	C116	62.3± 35.1 [ab]
Chlorpyrifos	C2	61.3± 32.4 [b]
Fenitrothion / Dimethoate	C50	58.8± 33.0 [b]
No Chlorpyrifos	C31	45.3± 33.5 [c]
Fenitrothion / Dimethoate	C25	42.3± 31.2 [c]
Chlorpyrifos	C4	38.8± 24.4 [cd]
Chlorpyrifos	C1	36.0± 33.8 [cd]
No Chlorpyrifos	C37	35.0± 29.3 [cd]
No Chlorpyrifos	C119	29.0± 21.4 [de]
No Chlorpyrifos	C7	21.3± 17.3 [e]

Means followed by the same superscripted letter(s) down the column are not significantly different ($p > 0.05$) according to Duncan's Multiple Range Test

(Key: Cl=Rukera farm; C2= Mburu farm; C4= Gitonga farm; C7= Mongalia estate; C12= Kibubuti Estate; C19= Gichore farm; C25= Kithuu farm; C31= Kirai farm; C37= Ndwiga farm; C44=Kariuki farm; C50= Kamau farm; C72= Kitavi farm; C116=Mbuthia farm; C119=Muringato estate)

4.4 Integration of different soil fertilization regimes, chemical control and predacious mites as strategies for management of coffee insect pests

Field experiment was laid out at Coffee Research Station, under a coffee block planted with Ruiru 11 coffee trees. Three compound fertilizers; two inorganic and one organic were ground applied. The inorganic fertilizers were supplemented with CAN at various rates as recommended by Coffee Research Foundation. The Gypsum as source of lime was applied in the coffee block according to the soil tests in order to keep the soil PH at the recommended level suitable for coffee production. Two chemical compounds; Chlorpyrifos and Spinosad were sprayed against the Coffee Berry Borer. The effect of integrating these components under coffee farming on predacious mites' population, Coffee Berry Borer and thrips infestations were assessed. The final coffee yield and quality was also detremined

4.4.1 Population trends of the predacious mites, *Euseius kenyae* (Swirski and Ragusa) and coffee insect pests under different soil fertilization regimes and chemical control in a coffee farm at Coffee Research Station from 2006 to 2008.

Following application of Chlorpyrifos and Spinosad against the Coffee Berry Borer during the period 2006-2008 (two applications per year in June/July), the population of predacious mites, *E. kenyae* under coffee block fertilized with N.P.K. 17:17:17 remained low in the first five months (August – December 2006) before flactuating in the first six months of 2007, with peaks in January and May and a depression in March 2007 (Figure 17a). In 2007, insecticides application was done when the population was low (< 2 mites / sampling) but the population remained low for only a month before flactuating again with peaks in September and November and a depression in October 2007. The population remained low from December 2007 up to April 2008 when it started to rise again. Although application of the insecticides in June/ July 2008 was done at peak population, it resulted in only a transient (one month) population reduction with the population of the mites peaking at an even higher level in August before it started to oscillate again (Figure 17a). Similar population trends occurred in all the other coffee blocks under the different fertilization regimes but with subtle differences in the abundance of the mites (Figures 17b and c). For example in all the blocks, the population was always low in plots sprayed with Chlorpyrifos than in those under Spinosad or the control. These population trends suggest a progressively increasing tolerance or resistance of *E. kenyae* to the insecticides applied. Similar trend of population of *E. kenyae* in the connrol plot were observed.

The Coffee Berry Borer (CBB) infestations under coffee block with N.P.K. 17:17:17 applied as nutrient source remained low during the first five months from August – December 2006 following the application of Chlorpyrifos and Spinosad in June/July 2006 (Figure 18a). In January 2007, the infestation increased rapidly and flactuated from February – May 2007, with peaks in February and April and depressions in March and May 2007. In 2007, Chlorpyrifos and Spinosad were applied when the infestation was high (12.3%), but it remained almost the same level for four months (August – November 2007) before peaking in December 2007. During the year 2008, a similar trend as occurred in year 2007 was experienced despite the application of Chlorpyrifos and Spinosad when the infestation was rather low. In all the other coffee blocks treated with organic compost and N.P.K. 22:6:12, similar infestation trends occurred though with varied Coffee Berry Borer infestation levels (Figures 18b and c). These infestation trends showed relatively equal effect of Chlorpyrifos and Spinosad in controlling the Coffee Berry Borer despite the peaks that occurred in February, April and December in each year. The controlled plots irrespective of the fertilizer applied, had similar infestation trends as to where either Chlorpyrifos or Spinosad was used.

Coffee thrips, *Diarthrothrips coffeae* under coffee block applied with N.P.K. 17:17:17 as the inorganic fertilizer had low population (< 0.03 thrips per leaf) of *D.coffeae* for two months (August – September 2006) following the spraying of Chlorpyrifos and Spinosad in June/ July 2006 (Figure 19a). This progressively increased from October – December 2006. Between January – May 2007, the population trend of *D. coffeae* fluctuated with peaks occurring in February and April and depressions in March and May 2007. Following application of Chlorpyrifos and Spinosad in June/July 2007, the thrips population decreased for one month. In August 2007, the *D. coffeae* population peaked especially from the controlled plots. This was experienced for one month before it depressed in September 2007 and remained moderately low (< 0.04 thrips per leaf) for three months (October- December 2007). In January 2008, the thrips population trend depressed. This was later followed by oscillation for four months (February –

May 2008) with peaks in February and April and depressions in March and May 2008. Following the application of Chlorpyrifos and Spinosad in June/July 2008, the thrips population decreased during that period but peaked in August and depressed in September after which the population trend remained at the same level. Similar population trends occurred in coffee blocks treated with organic compost and N.P.K. 22:6:12 (Figures 19b and c). The effect of spraying maintained low population of thrips. But despite this, the thrips population trends under either treated or untreated coffee plots behaved the same meaning that other control measures were containing the likely upsurge of the thrips under coffee agro ecosystems.

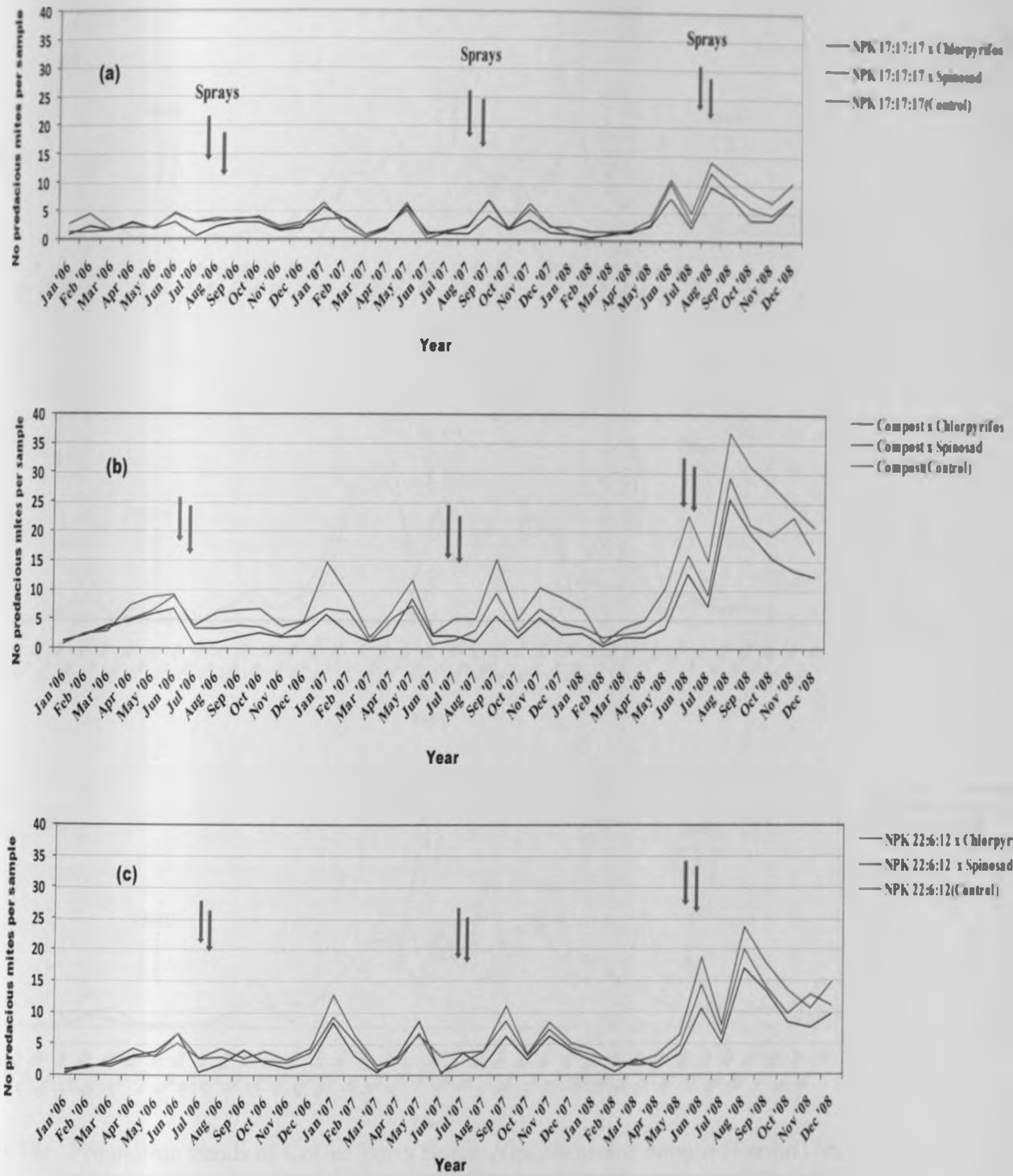

Figure 17: Population trends of *Euseius kenyae* (Swirski and Ragusa) on coffee under: **(a)** N.P.K. 17:17:17, **(b)** Compost manure and **(c)** N.P.K. 22:12:6 fertilizer following application of Chlorpyrifos or Spinosad

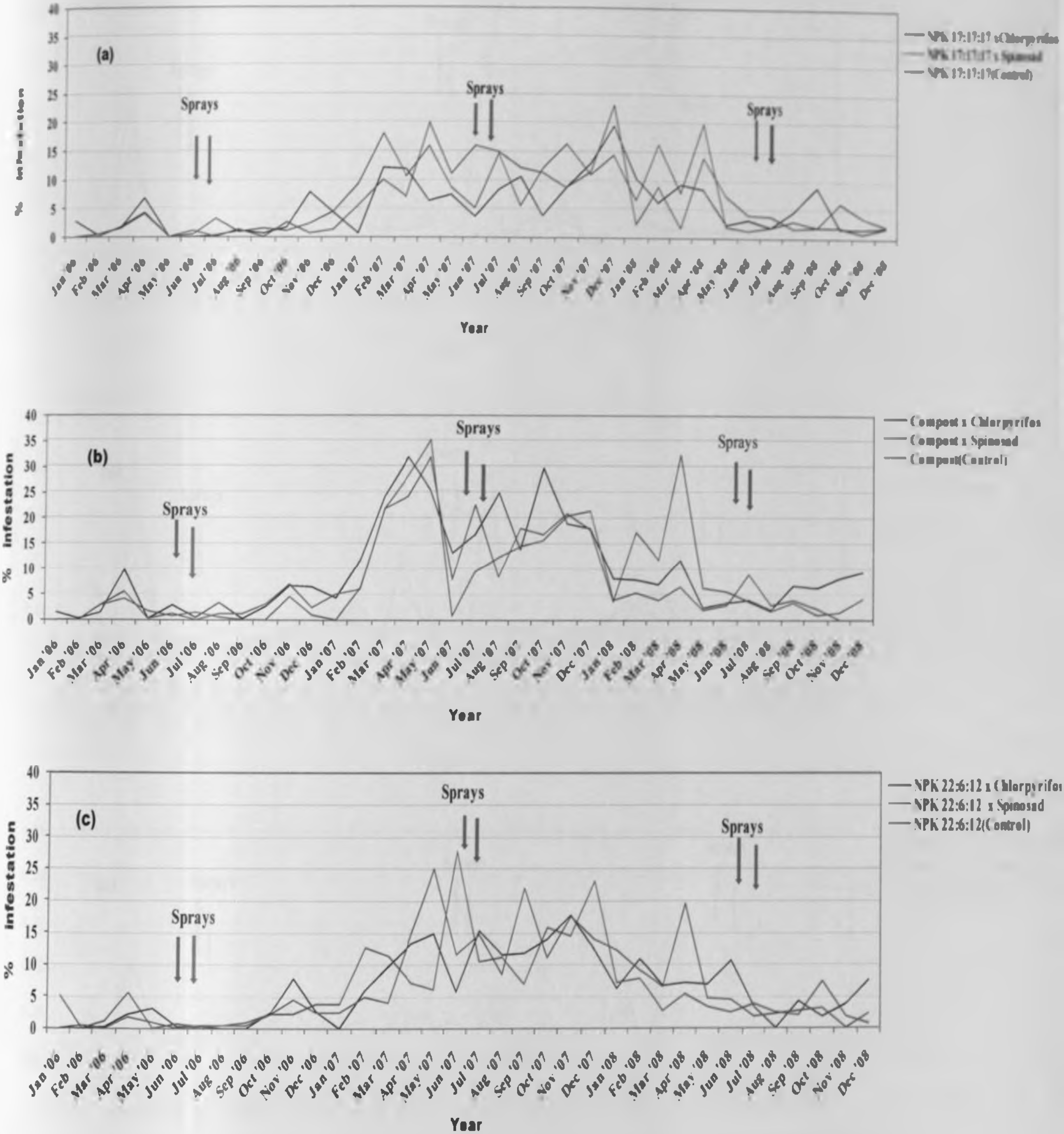

Figure 18: Population trends of Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) on coffee under: **(a)** N.P.K. 17:17:17, **(b)** Compost manure and **(c)** N.P.K. 22:12:6 fertilizer following application of Chlorpyrifos or Spinosad

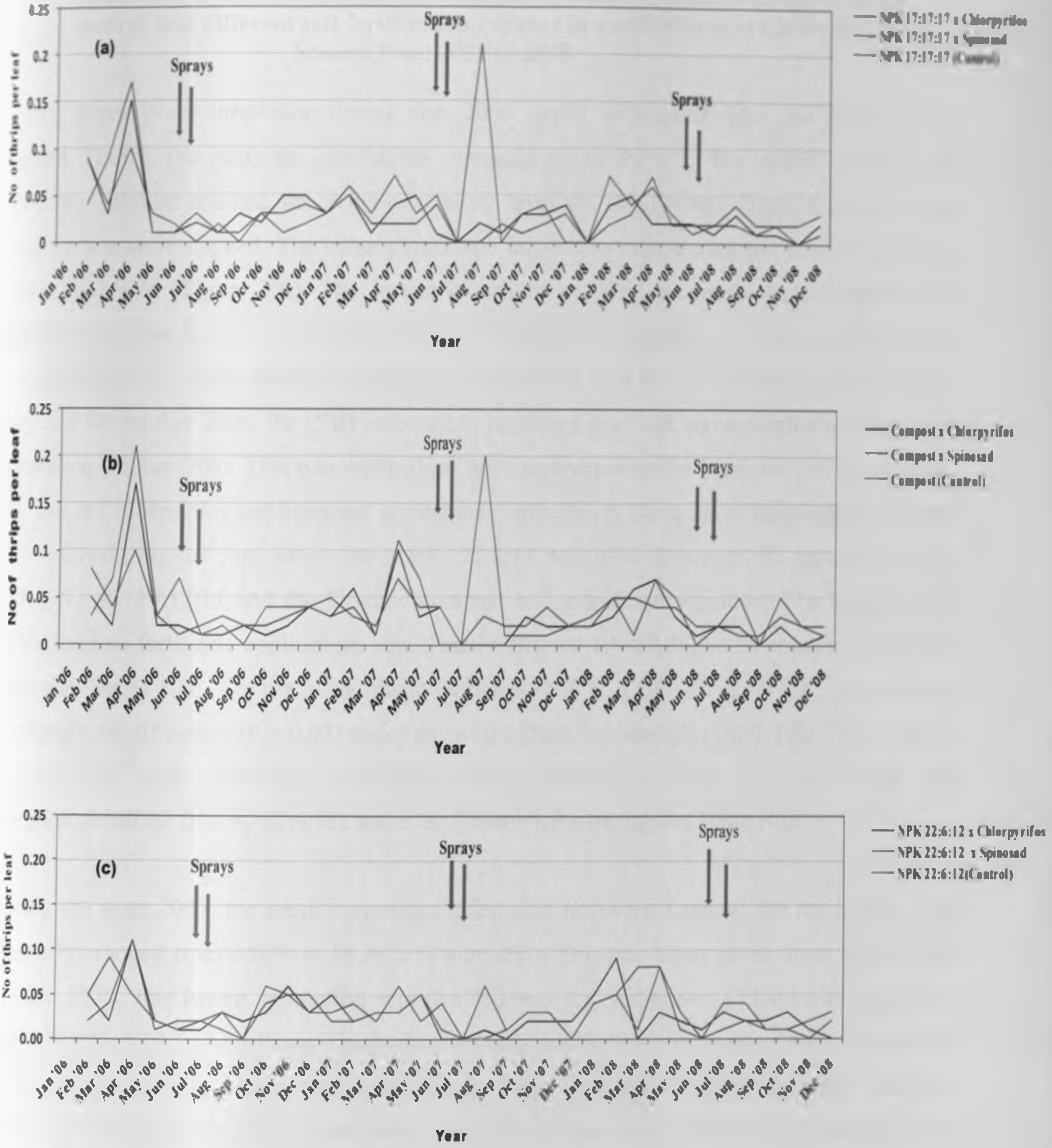

Figure 19: Population trends of *Diarthrothrips coffeae* Williams on coffee under: **(a)** N.P.K. 17:17:17, **(b)** Compost manure and **(c)** N.P.K. 22:12:6 fertilizer following application of Chlorpyrifos or Spinosad

4.4.2 Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) infestation under chemical control and different soil fertilization regimes in a coffee farm at Coffee Research Station from 2006 to 2008

Coffee Berry Borer infestation during year 2006 varied with insecticides and the fertilizers applied. During the year, the infestations remained below 10%. In the month of April, the infestation almost attained the economic injury level (> 10%) where Organic compost and Chlorpyrifos were applied. The mean percentage infestation rates during the year ranged from 1.04% to 2.97% (Figure 20a). The lowest infestation (1.04%) occurred where Spinosad was applied under the N.P.K. 17:17:17 fertilizer. The highest infestation (2.97%) occurred where Chlorpyrifos was applied under the Organic Compost (N.P.K. 0.8:0.2:1.0) (Figure 20a). Between May and September 2006, the CBB infestations remained low with some months recording 0% infestation (Figure 20a). This was when there were no mature coffee berries for CBB to infest. The use of Chlorpyrifos and Spinosad against the Coffee Berry Borer never significantly differed ($P > 0.05$) during the year where the N.P.K. 22:6:12 was used. However, the two insecticides under N.P.K. 17:17:17 and the Organic compost had significant variation. The Chlorpyrifos under the two fertilizers application, significantly differed ($P < 0.05$) when compared with the Spinosad (Table 10a). The use of inorganic fertilizers (N.P.K. 17:17:17 and N.P.K. 22:6:12) had no significant difference ($P > 0.05$) under any of the chemical controls (Table 10b). The Organic compost had mean percentage infestation rate significantly different ($P < 0.05$) from the inorganic fertilizer (N.P.K. 22:6:12) under the Chlorpyrifos treatment (Table 10b).

During the year 2007, the mean percentage infestation rate varied among the treatments. The infestation ranged from 8.80% to 19.39% (Figure 20b). This was about seven times higher than in year 2006. The lowest infestation rate (8.80%) was realized where Chlorpyrifos was used under N.P.K. 17:17:17 fertilizer. The highest infestation (19.39%) occurred where Chlorpyrifos was applied under the Organic compost (Figure 20b). The mean infestations during the year except for N.P.K. 17:17:17 combined with Chlorpyrifos was above 10% i.e the infestations were therefore above the economical injury levels. During this period, the CBB infestation was present over 12 months. This encouraged increased infestation because there were mature coffee berries that suffered CBB attack throughout the cropping seasons since the CBB life cycle could not be broken in between (Figure 20b). The application of Chlorpyrifos and Spinosad under

N.P.K. 17:17:17 had significant variations. The Chlorpyrifos had mean percentage infestation rate significantly different ($P < 0.05$) to Spinosad (Table 10a). There was no statistical difference ($P > 0.05$) between the chemical treatments under both the N.P.K. 22:6:12 and the Organic compost (Table 10a). The CBB infestations rate varied under the various fertilizers application. The Organic compost under the Chlorpyrifos and control treatments had significantly higher mean percentage infestation rates than the inorganic fertilizer N.P.K. 17:17:17 at $P < 0.05$. The inorganic fertilizers were not significantly different ($P > 0.05$) from each other under any chemical treatments (Table 10b).

In year 2008, the CBB infestation was moderate. The mean infestations were below the economical injury levels despite the fertilization regimes and insecticides applied (Figure 21c). The infestation ranged between 3.5% and 7.6% (Figure 20c). The lowest infestation occurred where Spinosad was applied under the Organic compost while the highest infestation was realized where only Organic compost was applied without any chemical treatments (Figure 20c).The highest infestation of over 30% occurred in April 2008 under organic compost control plot (Figure 20c). This concided with the peak period when coffee berries matures and become susceptible to CBB attack. The infestations at certain period of the year were almost 0%. The chemical treatments under the various regimes of fertilizers application had no significant effect ($P > 0.05$) on CBB infestation (Tables 10a and b).

Over the three years period the chemical treatments had no significant difference ($P < 0.05$) on CBB infestation (Table 10a). However, the fertilizers under Chlorpyrifos treatment had significant difference ($P < 0.05$) during the same period (Table 10b). The Organic compost when used together with Chlorpyrifos had significantly higher mean percentage infestation than either of the inorgainic fertilizers (Table 10b).

Chemical applications under various regimes of fertilizers were not significantly different from each other against CBB infestation unlike the fertilizers (Appendix 2a). The infestation rate significantly differed ($P < 0.05$) among the years (Appendix 2a) with heavy infestation occurring during year 2007.

Year 1 (2006)

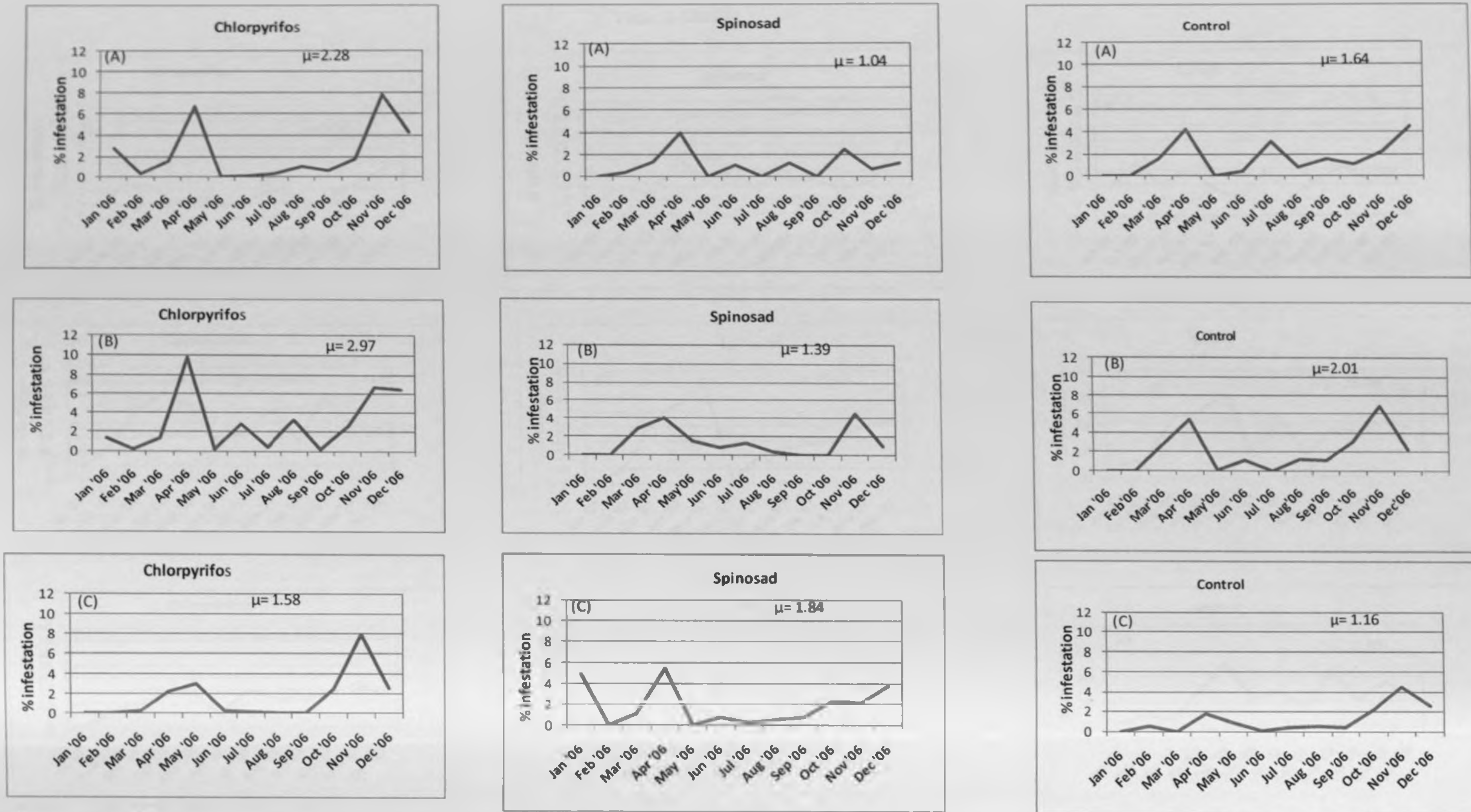

Figure 20a: The infestation level of Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) under treatment of Chlorpyrifos and Spinosad and different soil fertilization regimes in 2006. [**(A):** N.P.K. 17:17:17 fertilizer; **(B):** Organic compost (N.P.K. 8: 0.2: 1.0); **(C):** N.P.K. 22:6:12 fertilizer]

Year 2 (2007)

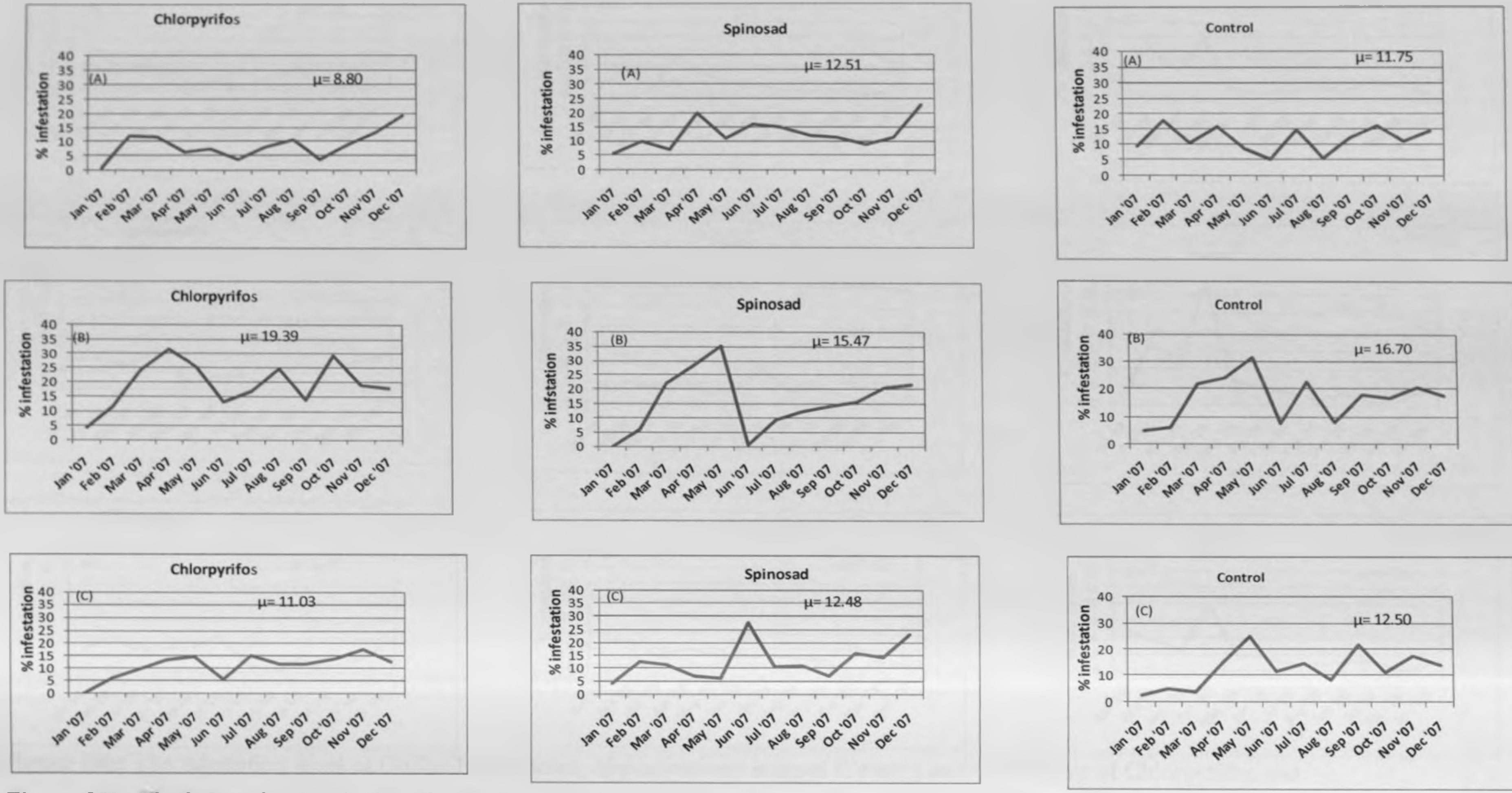

Figure 20b: The infestation level of Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) under treatment of Chlorpyrifos and Spinosad and different soil fertilization regimes in 2007. [**(A):** N.P.K. 17:17:17 fertilizer; **(B):** Organic compost (N.P.K. 0.8: 0.2: 1.0); **(C):** N.P.K. 22:6:12 fertilizer]

Year 3 (2008)

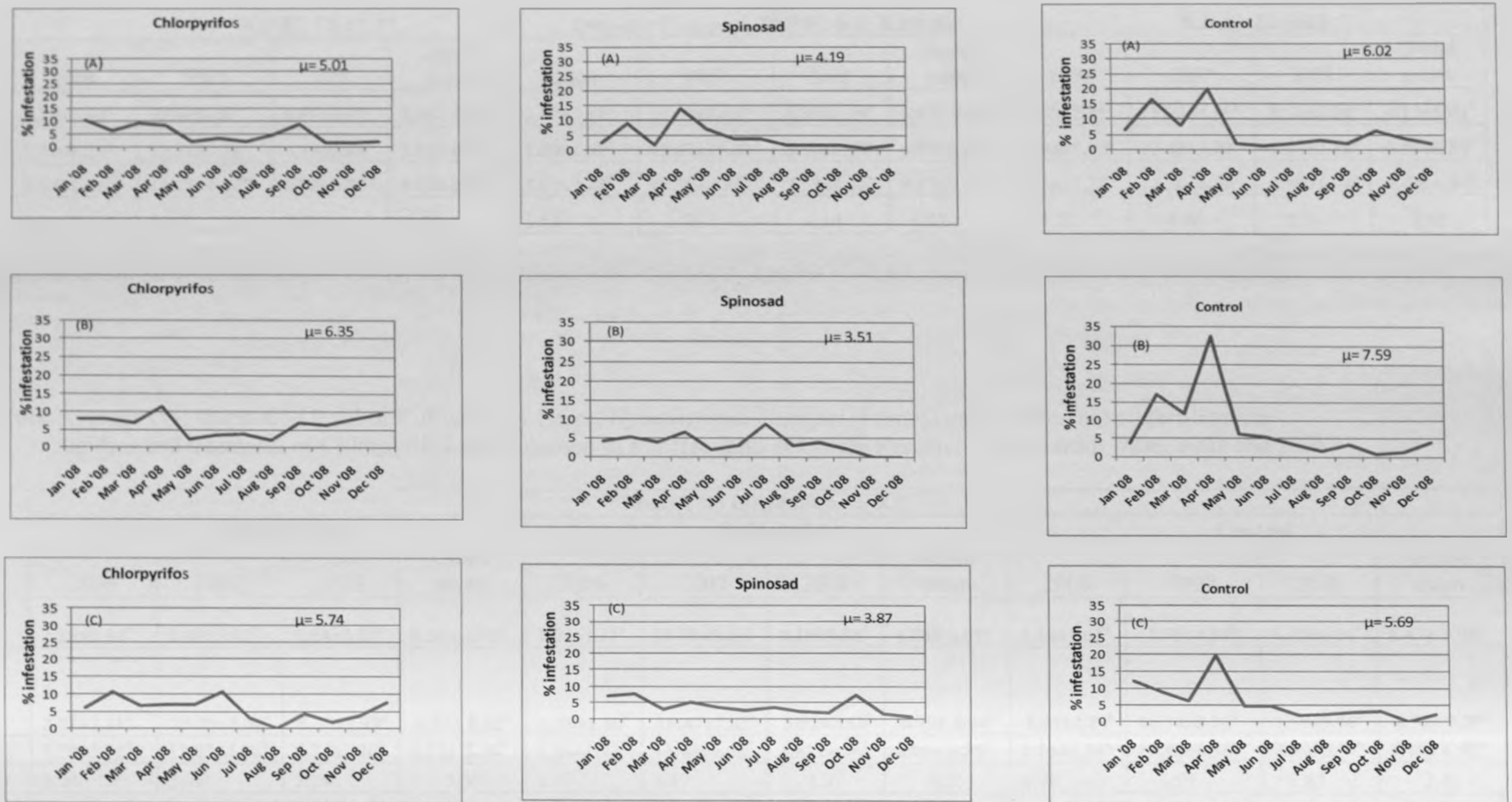

Figure 20c: The infestation level of Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) under treatment of Chlorpyrifos and Spinosad and different soil fertilization regimes in 2008. [**(A):** N.P.K. 17:17:17 fertilizer; **(B):** Organic compost (N.P.K. 0.8: 0.2: 1.0); **(C):** N.P.K. 22:6:12 fertilizer]

Table 10a: Average (%) infestation level of Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) under Chlorpyrifos and Spinosad and different soil fertilization regimes in a coffee farm at Coffee Research Station from 2006, 2007 and 2008

Treatment	Mean (%) infestation ± S.D											
	N.P.K. 17:17:17				Organic Compost (N.P.K. 0.8: 0.2:1.0)				N.P.K. 22:6:12			
	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean
Chlorpyrifos	2.28 ± 2.64^{a}	8.80 ± 5.06^{b}	5.01 ± 3.37^{a}	5.36 ± 4.60^{a}	2.97 ± 3.11^{a}	19.39 ± 8.06^{a}	6.35 ± 2.98^{a}	9.57 ± 8.82^{a}	1.58 ± 2.31^{a}	11.03 ± 4.96^{a}	5.74 ± 3.26^{a}	6.12 ± 5.03^{a}
Spinosad	1.04 ± 1.21^{b}	12.51 ± 5.11^{a}	4.19 ± 3.88^{a}	5.92 ± 6.12^{a}	1.39 ± 1.61^{b}	15.47 ± 10.67^{a}	3.51 ± 2.53^{a}	6.79 ± 8.84^{a}	1.84 ± 1.93^{a}	12.48 ± 7.02^{a}	3.87 ± 2.36^{a}	6.06 ± 6.34^{a}
Control	1.64 ± 1.61^{ab}	11.75 ± 4.16^{ab}	6.02 ± 6.06^{a}	6.47 ± 5.95^{a}	2.01 ± 2.24^{ab}	16.70 ± 8.26^{a}	7.59 ± 9.06^{a}	8.77 ± 9.30^{a}	1.16 ± 1.36^{a}	12.50 ± 6.98^{a}	5.69 ± 5.54^{a}	6.45 ± 6.94^{a}
LSD (0.05)	1.2	3.4	2.79	2.58	1.52	3.95	4.14	4.07	1.22	4.96	2.74	3.00

Means followed by the same superscripted letter(s) down the column are not significantly different ($p > 0.05$) according to Duncan's Multiple Range Test

Table 10b: Average (%) infestation level of Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) under different soil fertilization regimes and treatment of Chlorpyrifos and Spinosad in a coffee farm at Coffee Research Station from 2006, 2007 and 2008

Fertilizer	Mean (%) infestation ± S.D											
	Chlorpyrifos				Spinosad				Control			
	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean
N.P.K. 17:17:17	2.28 ± 2.64^{ab}	8.80 ± 5.06^{b}	5.04 ± 3.37^{a}	5.36 ± 4.60^{b}	1.04 ± 1.21^{a}	12.51 ± 5.11^{a}	4.19 ± 3.88^{a}	6.78 ± 6.89^{a}	1.64 ± 1.61^{a}	11.75 ± 4.16^{b}	6.02 ± 6.06^{a}	6.47 ± 5.95^{a}
Organic Compost (N.P.K. 0.8: 0.2:1.0)	2.97 ± 3.11^{a}	19.39 ± 8.06^{a}	6.35 ± 2.98^{a}	9.57 ± 8.82^{a}	1.39 ± 1.60^{a}	15.47 ± 7.02^{a}	3.51 ± 2.53^{a}	6.79 ± 8.84^{a}	2.01 ± 2.24^{a}	16.70 ± 8.26^{a}	7.59 ± 9.06^{a}	8.77 ± 9.30^{a}
N.P.K. 22:6:12	1.58 ± 2.32^{b}	11.03 ± 4.96^{b}	5.74 ± 3.26^{a}	6.12 ± 5.30^{b}	1.84 ± 1.93^{a}	12.48 ± 7.02^{a}	3.87 ± 2.36^{a}	6.06 ± 6.35^{a}	1.16 ± 1.36^{a}	12.50 ± 6.98^{ab}	5.69 ± 5.54^{a}	6.45 ± 6.92^{a}
LSD (0.05)	1.24	3.96	2.29	3.06	1.09	6.49	1.97	4.36	0.99	4.59	2.67	3.43

Means followed by the same superscripted letter(s) down the column are not significantly different ($p > 0.05$) according to Duncan's Multiple Range Test

4.4.3 Interactions of predacious mite, *Euseius kenyae* (Swirski and Ragusa) and thrips, *Diarthrothrips coffeae* Williams populations under different soil fertilization regimes and chemical control in a coffee farm at Coffee Research Station from 2006 to 2008

During the year 2006, both the *E.kenyae* and *D. coffeae* population varied. The *D. coffeae* peaked in April leading to increased population of *E.kenyae* where either the Chlorpyrifos or Spinosad was applied under different fertilizer regimes (Figure 21a).The increased population of *E.kenyae* from April managed to maintain the thrips population to a low level throughout the rest of the season (less than one thrip per leaf). The population of thrips during the year 2006 remained below the established economic injury levels (below one-two thrips per leaf). Over the same period the population of *E. kenyae* negatively correlated with the population of *D. coffeae* (Table 11). During the same year the population of predacious mites increased while that of *D.coffeae* decreased simultaneously and vice versa. The population of *D.coffeae* during the month of September was Zero under any fertilizer regimes and insecticides treatments but that of *E. kenyae* remained high (Figure 21a). Despite the absence of *D.coffeae*, the E. *kenyae* was able to sustain high population levels.

In the year 2007, the population of *D. coffeae* in the month of July had attained zero thrips per leaf irrespective of Chlorpyrifos or Spinosad application under different fertilizer regimes (Figure 21b). The population of E. *kenyae* remained above zero mites per sample during the same month. The population of predatory mites remained high throughout the year. Unlike in year 2006, the Spinosad and control under both the organic compost and N.P.K. 17:17:17, and the control under N.P.K. 22:6:12, the populations of predatory mites and the thrips were positively correlated (Figure 21b, Table 11).

The thrips and predatory mites' populations during the year 2008 varied (Figure 21c). In the first six months, the population of *D. coffeae* remained high while that of *E. kenyae* was low (Figure 21c). This changed from June when the thrips population decreased and in some cases recording zero while that of predacious mites upsurged. From the month of July the population of *E. kenyae* remained high while that of *D. coffeae* attained low levels (Figure 21c). During the year, the population of *E. kenyae* negatively correlated with that of *D. coffeae* irrespective of Chlorpyrifos and Spinosad application under different fertilizer regimes (Figure 21c, Table 11).

Over the three years period on average, the population of thrips was below one thrip per leaf (Table 12). The grand mean for the three year period indicated that Chlorpyrifos and Spinosad application under various fertilizer regimes had no significant effect on thrips population ($P > 0.05$) (Table 12). The fertilizers likewise under Chlorpyrifos and Spinosad applications had no significant effect ($P > 0.05$) on thrips population (Table 13). On average the number of thrips per leaf never exceeded 0.04 (Tables 12 and 13). The combination of insecticides and fertilizers treatment had no significant effect on thrips population at $P > 0.05$ (Appendix 2b).

The use of Chlorpyrifos and Spinosad had significant effect ($P < 0.05$) on predacious mite population. Spinosad where applied under various fertilizer regimes, had significantly ($P < 0.05$) higher mean number of predacious mite per sample than under Chlorpyrifos (Table 14). The control under any fertilizer regime was not significantly different from either the Spinosad or the Chlorpyrifos treated coffee blocks on predacious mite population (Table 14). The use of fertilizers affected the population of predacious mite. The coffee plots under Organic compost had significantly ($P < 0.05$) higher population of predacious mites than N.P.K. 17:17:17 (Table 15). However, the population of predacious mites under N.P.K. 22:6:12 was not significantly different ($P > 0.05$) from that under Organic compost. The populations of predacious mite under N.P.K.17:17:17 and N.P.K. 22:6:12 were not statistically different ($P < 0.05$) from each other. Where Chlorpyrifos was used under various fertilizer regimes, the population of predacious mites was significantly ($P < 0.05$) higher under organic compost than under N.P.K. 17:17:17. There was no significant difference ($P > 0.05$) in population of predacious mites where Chlorpyrifos was applied under inorganic fertilizers (Table 15). Higher number of predacious mite was observed in coffee block treated with Organic compost and Spinosad (Tables 14 and 15). The interaction of insecticides and fertilizers had significant effect on predator's population at $P < 0.05$ (Appendix 2c).

Year 1 (2006)

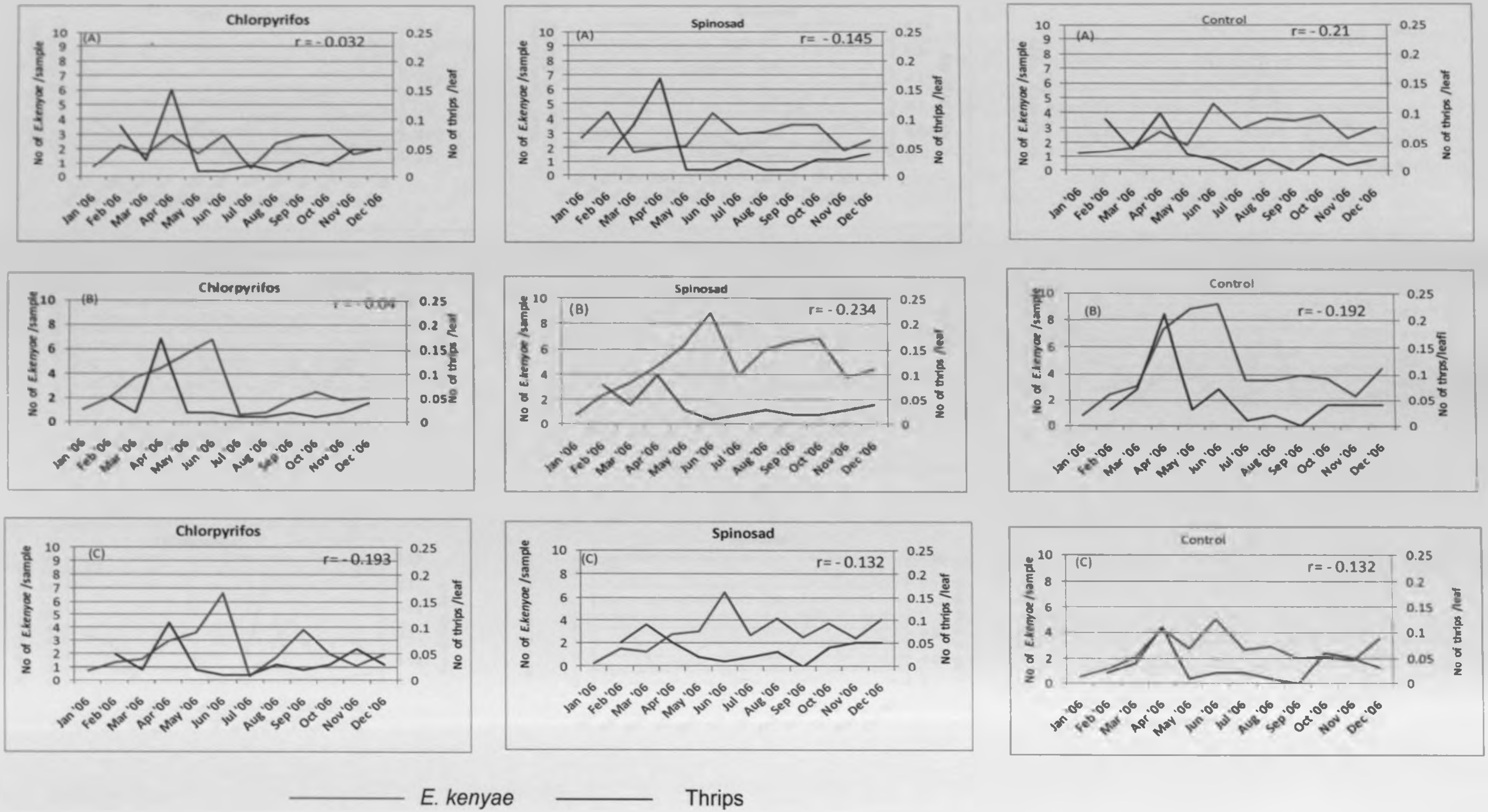

Figure 21a: Number of *Euseius kenyae* (Swirski and Ragusa) and thrips, *Diarthrothrips coffeae* Williams from coffee trees under chemicals (Chlorpyrifos and Spinosad) and different soil fertilization regimes in 2006. [**(A):** N.P.K. 17:17:17 fertilizer; **(B):** Organic compost (N.P.K. 0.8: 0.2: 1.0); **(C):** N.P.K. 22:6:12 fertilizer]

Year 2 (2007)

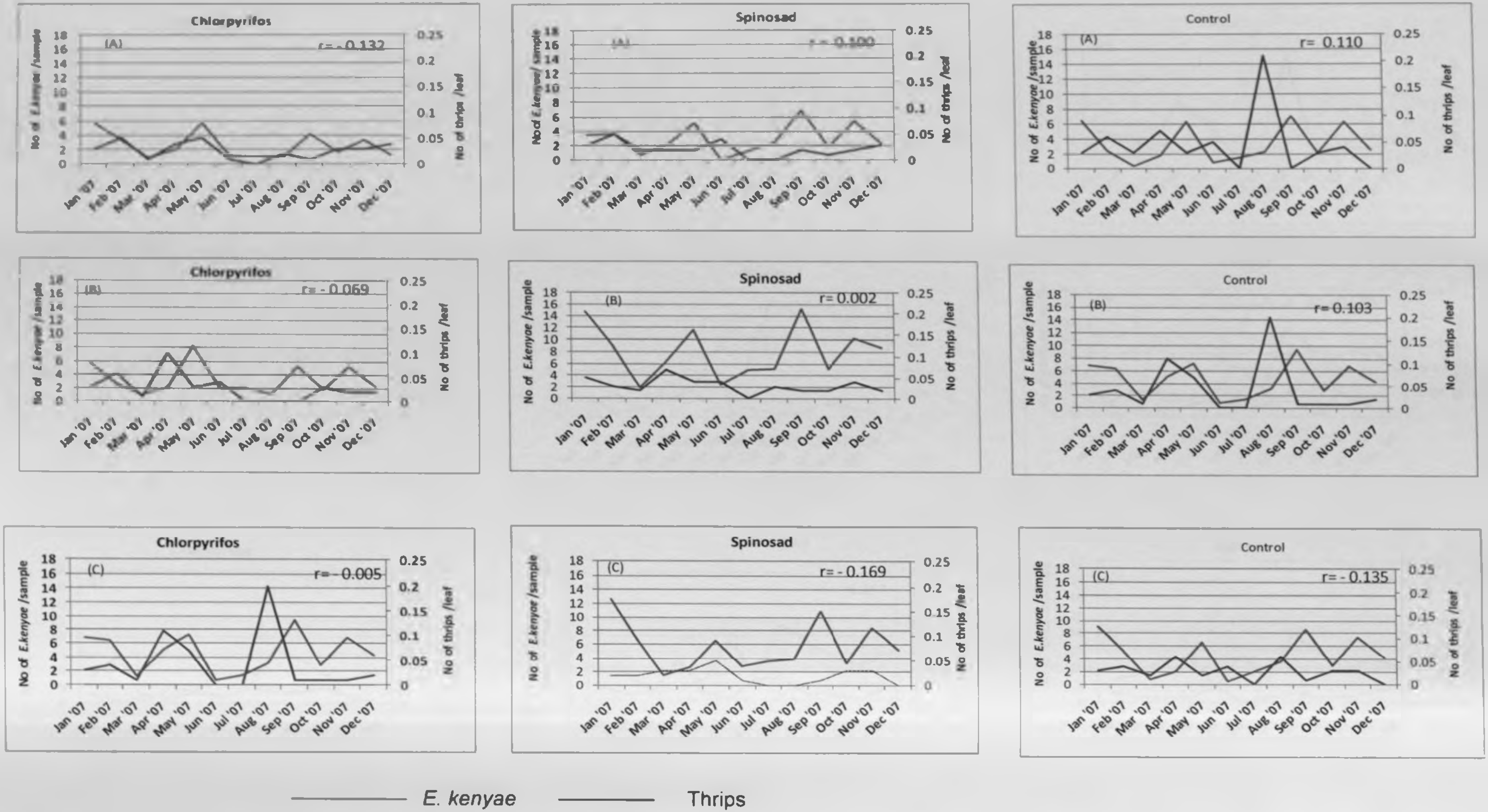

Figure 21b: Number of *Euseius kenyae* (Swirski and Ragusa) and thrips, *Diarthrothrips coffeae* Williams from coffee trees under chemicals (Chlorpyrifos and Spinosad) and different soil fertilization regimes in 2007.[**(A):** N.P.K. 17:17:17 fertilizer; **(B):** Organic compost (N.P.K. 0.8: 0.2: 1.0); **(C):** N.P.K. 22:6:12 fertilizer]

Year 3 (2008)

Figure 21c. Number of *Euseius kenyae* (Swirski and Ragusa) and thrips. *Diarthrothrips coffeae* Williams from coffee trees under chemicals (Chlorpyrifos and Spinosad) and different soil fertilization regimes in 2008.[**(A)**:N.P.K. 17:17:17 fertilizer; **(B)**: Organic compost (N.P.K. 0.8: 0.2: 1.0); **(C)**: N.P.K.22:6:12 fertilizer

Table 11: The relationships between the populations of *Euseius kenyae* (Swirski and Ragusa) and *Diarthrothrips coffeae* Williams when sprayed with Chlorpyrifos and Spinosad under different soil fertilization regimes in a coffee farm at Coffee Research Station from 2006, 2007 and 2008

Fertilization regime	Insecticide	2006			2007			2008		
		r	D.f	Slope	r	D.f	Slope	r	D.f	Slope
N.P.K. 17:17:17	Chlorpyrifos	-0.032	3	1.021	-0.132	3	1.012	-0.076	3	1.017
	Spinosad	-0.145	3	1.036	0.100	3	0.999	-0.217	3	1.028
	Control	-0.206	3	1.042	0.110	3	0.962	-0.127	3	1.016
Organic Compost (N.P.K. 0.8: 0.2: 1.0)	Chlorpyrifos	-0.040	3	1.025	-0.069	3	1.017	-0.145	3	1.031
	Spinosad	-0.234	3	1.041	0.002	3	1.013	-0.201	3	1.027
	Control	-0.192	3	1.036	0.103	3	1.000	-0.150	3	1.026
N.P.K. 22:6:12	Chlorpyrifos	-0.193	3	1.034	-0.005	3	1.012	-0.115	3	1.029
	Spinosad	-0.132	3	1.033	-0.169	3	1.032	-0.264	3	1.029
	Control	-0.132	3	1.021	0.135	3	1.021	-0.322	3	1.040

Table 12: The Grand mean number of *Diarthrothrips coffeae* Williams per leaf under treatment of Chlorpyrifos and Spinosad in a coffee farm at Coffee Research Station from 2006 to 2008

Treatment	Grand Mean No ± S.D		
	N.P.K. 17:17:17	Organic Compost (N.P.K. 0.8: 0.2:1.0)	N.P.K. 22:6:12
Chlorpyrifos	0.03 ± 0.03^{a}	0.03 ± 0.03^{a}	0.03 ± 0.02^{a}
Spinosad	0.03 ± 0.03^{a}	0.03 ± 0.03^{a}	0.03 ± 0.02^{a}
Control	0.03 ± 0.04^{a}	0.04 ± 0.05^{a}	0.03 ± 0.03^{a}
LSD (0.05)	0.01	0.02	0.01

Means followed by the same superscripted letter(s) down the column are not significantly different ($p > 0.05$) according to Duncan's Multiple Range Test

Table 13: The Grand mean number of *Diarthrothrips coffeae* Williams per leaf under different soil fertilization regimes) in a coffee farm at Coffee Research Station from 2006 to 2008

Fertilizer	Grand Mean No ± S.D		
	Chlorpyrifos	Spinosad	Control
N.P.K. 17:17:17	0.03 ± 0.03^{a}	0.03 ± 0.03^{a}	0.03 ± 0.04^{a}
Organic Compost (N.P.K. 0.8: 0.2:1.0)	0.03 ± 0.03^{a}	0.03 ± 0.02^{a}	0.04 ± 0.05^{a}
N.P.K. 22:6:12	0.03 ± 0.02^{a}	0.03 ± 0.02^{a}	0.03 ± 0.03^{a}
LSD (0.05)	0.01	0.01	0.02

Means followed by the same superscripted letter(s) down the column are not significantly different ($p > 0.05$) according to Duncan's Multiple Range Test

Table 14: The Grand mean number of *Euseius kenyae* (Swirski and Ragusa) per sample under treatment of Chlorpyrifos and Spinosad in a coffee farm at Coffee Research Station from 2006 to 2008

Treatment	Grand Mean No ± S.D		
	N.P.K. 17:17:17	Organic Compost (N.P.K. 0.8: 0.2:1.0)	N.P.K. 22:6:12
Chlorpyrifos	2.94 ± 2.25^{b}	5.25 ± 5.77^{b}	4.32 ± 3.93^{a}
Spinosad	4.13 ± 3.27^{a}	9.99 ± 8.95^{a}	6.26 ± 5.60^{a}
Control	3.67 ± 2.85^{ab}	7.17 ± 6.83^{ab}	5.12 ± 4.58^{a}
LSD (0.05)	1.19	3.21	2.05

Means followed by the same superscripted letter(s) down the column are not significantly different (p >0.05) according to Duncan's Multiple Range Test

Table 15: The Grand mean number of *Euseius kenyae* (Swirski and Ragusa) per sample under different soil fertilization regimes in a coffee farm at Coffee Research Station from 2006 to 2008

Fertilizer	Grand Mean No ± S.D		
	Chlorpyrifos	Spinosad	Control
N.P.K. 17:17:17	2.94 ± 2.25^{b}	4.13 ± 3.27^{b}	3.67 ± 2.85^{b}
Organic Compost (N.P.K. 0.8: 0.2:1.0)	5.25 ± 5.77^{a}	9.99 ± 8.95^{a}	7.17 ± 6.83^{a}
N.P.K. 22:6:12	4.32 ± 3.93^{ab}	7.17 ± 6.83^{b}	5.12 ± 4.58^{ab}
LSD (0.05)	1.89	2.79	2.20

Means followed by the same superscripted letter(s) down the column are not significantly different (p > 0.05) according to Duncan's Multiple Range Test

4.4.4 Yield and quality of coffee harvested from plots under different soil fertilization and pesticides application regimes at Coffee Research Station from 2006 to 2008

Four parameters were used to assess the yield and quality of coffee harvested for the three years period. These were; mean weight of clean coffee per hectare (Kg/ha), percentage premium coffee grades AA/AB, weight (g) per 100 coffee beans and detection of toxic residues in coffee beans (Tables 16, 17 and 18). The toxic residues on coffee beans were never detected during the three year period of this study. High coffee yields (1187.5 - 2844.3 kg/ha) were obtained during the three years of production. The use of Chlorpyrifos and Spinosad under different fertilizer regimes had no significant difference (P >0.05) on coffee yield during the year 2006, 2007 and 2008 (Table 16). There was also no significant difference for the grand mean coffee yield for the three years period [F=1.07, df = (5, 30), n=36, P > 0.05]. The coffee production per hectare varied significantly (P >0.05) among the cropping seasons (Appendix 3a). The yields ranged from 1187.5 to 2844.3 Kg/ha (Table 16).

The percentage coffee premium grades AA/AB was not significantly different at P < 0.05 from any of the insecticide treatments under the different fertilizer regimes (Table 17). There was also no significant difference for the overall premium grades AA/AB for the three years period [F=1.07, df = (5, 30), n=36, P>0.05].The premium grades AA/AB ranged from 71.1 – 89.0% (Table 17). The grades significantly varied among the production seasons/years (Appendix 3b).

The weight of coffee beans was not significantly different among the treatments at P > 0.05 (Table 18). There was also no significant difference for the grand mean weight of coffee beans for the three years period [F=1.07, df = (5, 30), n=36, P>0.05]. The weight of coffee beans had significant variation (P < 0.05) among the cropping years/seasons (Appendix 3c).

Table 16: Coffee yield (Kg/ha) under treatment of Chlorpyrifos and Spinosad and different soil fertilization regimes

Treatment	Coffee yield (Kg/ha)											
	N.P.K. 17:17:17				Organic compost (N.P.K. 0.8: 0.2:1.0)				N.P.K. 22:6:12			
	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean l	2006	2007	2008	Grand mean
Chlorpyrifos	2313.0	1383.4	2390.8	2029.0	2844.3	1609.4	1859.5	2104.4	2781.5	1203.1	1765.8	1916.9
Spinosad	2781.5	1728.4	1734.8	2081.5	2156.5	1578.1	2172.3	1969.0	2437.9	1437.5	1765.8	1880.3
Control	2641.0	1187.5	2109.5	1979.0	2109.5	1958.3	1265.8	1777.8	2641.0	1515.6	1578.3	1911.6
LSD (0.05)	618.5	456.2	766.1	596.2	1462	770.4	1006.3	619.5	816.5	565.1	626.7	577.2

Table 17: Coffee grade AA/AB (%) under treatment of Chlorpyrifos and Spinosad and different soil fertilization regimes

Treatment	% Coffee grade AA/AB											
	N.P.K. 17:17:17				Organic compost (N.P.K. 0.8: 0.2:1.0)				N.P.K. 22:6:12			
	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean
Chlorpyrifos	78.9	71.9	84.6	78.4	81.1	83.5	85.1	83.2	82.7	72.4	84.3	79.8
Spinosad	74.0	78.9	86.1	79.6	74.2	78.5	85.6	79.4	73.8	86.1	86.4	82.1
Control	80.6	78.3	87.5	82.1	81.1	83.3	88.2	84.2	71.1	81.7	89.2	80.7
LSD(0.05)	8.4	8.3	5.4	5.3	15.5	8.3	5.3	5.6	13.3	15	7.3	7.8

Table 18: Weight (g) of coffee beans under treatment of Chlorpyrifos and Spinosad and different soil fertilization regimes

Treatment	Weight (g)/ 100 coffee beans											
	N.P.K. 17:17:17				Organic compost (N.P.K. 0.8: 0.2:1.0)				N.P.K. 22:6:12			
	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean	2006	2007	2008	Grand mean
Chlorpyrifos	19.8	19.8	15.2	18.3	19.3	20.0	15.5	18.3	19.3	19.8	14.6	17.9
Spinosad	18.7	20.2	15.2	18.0	18.4	18.2	15.8	17.5	17.8	19.3	14.9	17.3
Control	18.3	20.3	14.7	17.8	20.1	20.0	15.3	18.5	17.3	18.8	14.6	16.9
LSD(0.05)	3.4	0.7	2.1	2.2	1.7	1.8	1.8	1.9	3.4	1.6	2	2.1

CHAPTER FIVE

5.0 DISCUSSION, CONLUSIONS AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Insect pests of coffee and their distribution in major coffee growing agroecozones

The mean coffee production per tree differs between the smallhoher (2.8kg/tree/year) and estate (5-6kg/tree/year) coffee farmers. There are a number of reasons to this variation such as coffee varities grown, pests attack and their management, farm management practices among others. The main commercial coffee varieties grown both by the smallholders and estates included the SLs, R11, K7 and BM. The SLs although susceptible to the two major coffee diseases; CBD and CLR , when compared to R11 which is resistant to the two diseases, the SLs remained the most commonly grown varieties by most of the farmers (41%). The reasons why this was the scenario was not fully established but farmers indicated that the R11 is rather inferior when compared with SLs in terms of quality, berry weight, anchorage and is also highly affected during dry spell. As a result of these uncertainties, a number of farmers grow a combination of SLs and R11 although some farmers (22%) grow R11 on its own.

The R11 though a variety suitable for growing in all the agroecozones because of its resistance to CBD and CLR was mainly found to be grown in UM1 and UM2 than in UM3. Its limitation for growing in UM3 may be due to low rainfalls and high temperatures that are experienced there. The UM1 and UM2 with high rainfall and low temperatures could be favourable factors for this variety. The K7 and BM were the common varieties grown in low (UM3) and high (UM1) altitude areas. This is because the K7 and BM are less infected by CLR and CBD, respectively thus making them more suitable for the two agroecozones. Growing the combination of R11/SLs was prevalent in UM3. This indicates that the coffee farmers from this agroecozone prefer the two varieties and in particular the SLs. In low altitude with high incidences of CLR, combination of the two varieties is an advantage in minimizing the probable crop loss because of this disease hence expected high returns by the coffee growers.

For high coffee yield and quality to be sustained, farmers require tocarry out good agricultural practices. Cultural practices for instance Pruning, fertilization, intercropping (leading to shading), buni stripping and mulching, are some common factors that contribute in management of several pests of coffee. These practices as found to be carried out by the farmers could, therefore, be associated with farmer's knowledge on how to manage some of the major pests of coffee. Cultural practices in managing coffee pests have been supported by many researchers (Wheatly, 1963, 1964; Le Pelley, 1968; Anonymous, 1975; Anonymous, 1975; Mugo and Ndoiru, 1997; Vega *et al.*, 2006; Mugo, 1994, 2008). Along side use of cultural practices, pesticides use by the farmers at 51.7% was realized as another major activity practiced to manage most of the coffee pests. It is well known that coffee farmers depend heavily on pesticides to control coffee pests despite this being associated with upsurgence of new pests as a result of elimination of their associated biological control agents. The pesticide use and its side effects have been discussed previously by other scientists (Anonymous, 1975; Van der Vossen and Walyaro, 1980; Masaba, 1991; Masaba and Waller, 1992; Mugo and Ndoiru, 1997).

During this survey it was evident that a small proportion of the farmers representing only 18.3% practiced high coffee management levels with almost an equivalent proportion of 15.8% carrying out low management practices. An estimated 65.9% of the farmers were found to practice moderate management levels. However, both low and moderate management levels accounting for 81.7% may be considered as one of the factors that could have caused a decline in annual national coffee production from 130,000 to 50,000 metric tones of clean coffee. The difference that can be attributed to declined coffee management practices. To address this, national strategies need to be put in place to change all those farms that are under low and moderate management levels to the category of high managed ones.

All plants require essential nutrients for life and growth. Plants supplied with all necessary nutrients in balanced organic or synthetic fertilizer are less susceptible or tolerant to pests and diseases as stated by Krauss (2001). Most of coffee farms in Kenya are found in UM2, which is the main coffee growing agroecozone. However, to maximize on production, proper feeding of this crop is a major requirement. Farmers growing coffee in UM2 were found to utilize mostly all sources of plant nutrients that mainly included inorganic and organic fertilizers. This was followed by UM1 and UM3 in that order. The collect use of fertilizers in UM2 can be attributed to coffee being the main source of income in this agroecozone irrespective of other upcoming enterprises such as dairy farming, horticulture, floriculture and apiculture.

In the last two decades, national coffee production has been on the decline with several coffee farmers neglecting their farms. An estimated 15.8% of the farms surveyed were neglected or none of the farms had fertilizer application. This was so in UM2 and UM3, an indication that other enterprises are becoming major sources of income to the farmers in these agroecozones. For supply of balanced nutrients required by coffee, a combination of either N.P.K./CAN or N.P.K./CAN/Manure or N.P.K./CAN/Manure/foliar sprays is recommended to be applied. However, only 24.1% of the farmers managed this recommendation. Another 20.8% of the farmers applied Manure, N.P.K. and CAN on their own as sources of nutrients to coffee. Under the two systems of fertilizers application, it was observed that most of the farmers applied less quantity per tree than recommended. Though under dose of fertilizer application was common with most of the farmers, the situation was aggravated further by 15.8% of the farmers neglecting or not applying any fertilizers to their farms. It was therefore evident that with this kind of complex scenario, coffee cherry produced per tree was likely to decrease thus leading to the currently observed decline in coffee production in Kenya.

Neglected farms were mainly found in UM2 and UM3, with UM2 known to be the main coffee growing zone. Though cases of neglected farms occurred in UM2, it was realized that farmers in this zone applied a combination of CAN/N.P.K./Manure, which is the recommendation for better coffee productivity. It is therefore possible that coffee production in this zone can be increased and number of neglected farms reduced if cost of fertilizers can be lowered as farmers regarded this as a major constraining factor in coffee production.

It was evident from the survey that coffee hosts a number of insect pests. Twenty one (21) of them were realized, an indication that insects are major problems in coffee farming, although not all are key pests. In Kenya according to Mugo (1994) as many as 36 insect pests attack this crop. However, ten insect pests namely *A. leuconotus*, *Antestiopsis spp*, *C. alpinus*, *D. coffeae*, *D. nigricornis*, *H. hampei*, *L. coffeae*, *Leucoptera spp*, *O. coffeae* and *P. smaragdina* were considered by farmers as most common. They were widely spread and occurred in all the coffee growing agroecozones. Thus their effect on coffee production is across all the coffee growing regions hence effective pest management practices need to be put in place.

It was observed that with changes in climate or global warming different pests were suited to different agroecozones. For instance *O. coffeae*, *D. coffeae* and *C. alpinus* dominated the UM1, UM2 and UM3, respectively meaning that these pests prefer different climatical conditions more than the others.

The distributions of coffee insect pests in coffee growing districts varied widely. Districts in West of Rift Valley, unlike those in East of Rift Valley had low pest pressure. The variation in distribution of these pests in different coffee growing districts can be due to the age and history of where coffee farming started in Kenya, the natural topographical barriers, heavy usage of pesticides, rainfall and temperature patterns, coffee farming systems and conserved biocontrol agents.

The coffee pests' complex established in this study requires effective and sustainable pest management strategies. Despite use of cultural practices by some coffee farmers to control the pests, most of them applied various pesticides. About 13 insecticides were used to control insects. With many insect pests infesting coffee, Chlorpyrifos with broad spectrum was found to be commonly used insecticide the farmers.

The farmers in the three agroecozones were found to commonly and equally use insecticides, an indication that insect pests are a major constraint in coffee production in all the agroecozones.. Combination of more than one pesticide though noted was mainly common in UM2 where the farmers felt that there were more pests than in any other zone.

Coffee farming as established in this study is compounded by numerous constraints and appropriate remedies require to be designed. The trend whereby Ruiru 11 is only grown by 22% of the farmers as compared to 41% growing the SLs if reversed will contribute significantly towards increased coffee productivity as Ruiru11 is resistant to both the Coffee Berry Disease and Coffee Leaf Rust. Rehabilitation of neglected farms with low and moderately managed farms improved towards high management level will subsequently enhance the national coffee production per unit area. Effective use of nutrient supply sources (organic or inorganic fertilizers) by the coffee growers remains a key factor to be addressed. Many farmers as realized only applied one type of fertilizer as nutrients' sources, a situation not likely to achieve high coffee productivity because some essential elements may be lacking in the soil for the coffee plants.

5.1.2 Predacious mites and their distribution in coffee growing areas

Several natural enemies of coffee insect pests have been identified and reported (Le Pelley, 1968; Waikwa and Mathenge, 1977; Kinuthia and Mwangi, 1986; Anonymous, 1991). However, identified predacious phytoseiid mites from coffee growing countries are rare. Only limited information of such mites inhabiting coffee is reported from Australia, Brazil, Costa Rica, Hawaii and Java (Penzig and Chiabrera, 1903; Pemperton and Turner 1989; O'Dowd, 1994; Matos *et al.*, 2004, 2006; Mineira *et al.*, 2006a, b; Vega *et al.*, 2007; Pallini *et al.*, 2008).

According to the findings during the present study, five phytoseiids occupied all the three coffee growing agroecozones an indication of their greater ecological adaptation. It was also found that *Typhlodromus* species were several but were less spread in coffee growing areas probably because of low adaptation leve. McMurtry *et al.*, (1970) stated that factors such as biotic and abiotic affect the population and behaviour of phytoseiid mites. The wide adaptation of the predacious phytoseiid mites in the coffee growing agroecozones as established provides high possibilities of secondary coffee insect pests being checked and contained below their economic injury levels.

The presence and occurrence of predacious mites depend on several factors such as agrochemical applications, availability of prey, prevailing competition and plant conditions. The species richness in coffee growing agroecozones occurred in UM2 (24 species). However, this zone was found to heavily use insecticides to manage the coffee insect pests. As expected and according to McMurtry *et al*., (1970), where the pesticides are greatly applied the population of predacious mites is expected to be reduced. The finding during this study differs with that of McMurtry *et al*., (1970). In coffee farming, insecticides are heavily used to contain the wide number of pests associated with this crop. Subsequently as a result of this, the predacious phytoseiid mites inhabiting coffee are likely to have evolved and developed some resistance that has enabled them to exist in UM2. On the other hand, it is known that majority of phytoseiid mites feed on a wide range of prey that includes red spider mites, gall and rust mites and small other insects. The UM2 being the main coffee growing agroecozone and inhabited by several insect pests, could provide diversified food sources for coffee predacious phytoseiid mites hence their richness in this zone.

Under coffee farming systems in Kenya, the numerous predacious phytoseiid mites realized indicate the existing potential of biocontrol agents that can be conserved, enhanced and used as component of integrated insect pest management programme. This will in the process, create a healthy coffee farming environment where insecticides will be used less. In order to realize the full potential of the most common predacious mites established in this study, investigations on host preference and the effect of some insecticides used in coffee against these phytoseiids require to be conducted as part of a strategy in designing effective pest management approach.

5.1.3 Sensitivity of predacious mites to Chlorpyrifos (Dursban 480EC)

Past studies have indicated that as a result of regular use of insecticides, species of predacious phytoseiid mites could develop resistance to insecticides (El- Banhawy *et al*., 2000). Such resistance has been detected from phytoseiid mites such as *Neoseiulus fallacis* (German), *Metaseiulus occidentalis* (Nesbitt), *Phytoseiulus persimilis* A. - H., *Amblyseius cydnodactylon* Shehata and Zaher (Motoyama *et al*., 1970; Croft and Meyer, 1973; Roush and Hoy, 1981; El- Banhawy *et al.*, 2000).

The present investigations indicated that under coffee agro-ecosystems, resistance occurred among different populations of the common predacious phytoseiid mites. *E. kenyae* after their exposure to the insecticide, Chlorpyrifos which is commonly used to control primary insect pests of coffee such as the Coffee Berry Borer. Normally Chlorpyrifos is used in management of coffee insect pests either through foliar spraying or banding the coffee stems at the base. Foliar spraying tends to expose the insect pests and the biological control agents such as predacious mites more to Chlorpyrifos residues, thus causing high chances of resistance to develop through selective breeding from resistant survivors. However, the population of predacious mites from C44 in this case when bioassayed against Chlorpyrifos was found to be more sensitive or less resistant to the product than from any other farm. The observation made during the predacious mite's collection in C44 showed that there was no foliar spraying in the farm. Instead banding was the major and common practice as the farm experienced frequent infestation by the Green scales.

Although the coffee farms C7 and C119 had not used Chlorpyrifos for over five years prior to this study, the farms were neglected with no weeding, fertilizer application, pruning or spraying of any insecticides being carried out. Despite this, the two farms were large coffee plantations meaning that in the past, coffee was intensively farmed with the possibility of the two farms heavily applying Chlorpyrifos or other organophosphorous to manage various primary coffee insect pests. It is, therefore possible that the resistance established from the populations collected from these farms probably had developed by then and still exists to date. On the other hand it was observed that C7 despite being neglected, there were a lot of horticultural activities in the surrounding area with pineapples and French beans intensively produced for both internal and external markets The observations made during collection of predacious mites in C7 indicated that there was heavy use of pesticides (to produce French beans) and particularly the organophosphates that contaminated the surrounding area leading to *E. kenyae* developing resistance against Chlorpyrifos. In C119, horticultural enterprise was also the main activity that seemed to have substituted coffee farming hence creating a similar situation as observed in C7.

It was evident from this study that populations of *E. kenyae* with resistance or low susceptibility to Chlorpyrifos exist under coffee agro-ecosystems. This can therefore lead to selection of predacious phytoseiid mite strains resistant to Chlorpyrifos. According to Schulten *et al.*(1976) and Golorkina and Akssyutova (1990), modern integrated pest management on crops such as fruit trees and apples, employs use of resistant strains of predacious mites. The present strains of *E. kenyae* with resistance to Chlorpyrifos can effectively be employed in a biocontrol strategy to manage secondary coffee insect pests while Chlorpyrifos still manage the primary pests with less effect on biocontrol agents such as *E. kenyae*. At present no incidence of resistance has been reported on priamry insect pests such as *H. hampei* against Chlorpyrifos application thus making the resistant strains of *E. kenyae* suitable for use in an integrated pest management of coffee in Kenya.

5.1.4 Integrating plant nutrition, selective insecticides and predacious mites in managing coffee insect pests

Biological control is one of the options towards ecologically viable solutions in pest management. Predacious mites, control small insects such as thrips and contain them below economic injury levels. Field experiment was conducted to investigate the effect of Chlorpyrifos and Spinosad under different fertilizer regimes on Coffee Berry Borer infestation and the effect of these on predacious mites. The predacious mite, *E. kenyae* population during the start of this study was low especially in year 2006. This increased with time despite the application of Chlorpyrifos and Spinosad against the Coffee Berry Borer. It was expected that as Chlorpyrifos and Spinosad were sprayed the population of predacious mites was rapidly to drop possibly to zero. This never happened, meaning that the mites were less susceptible to the two insecticides. Under such a situation the survival of predacious mites is an advantage as the mites will control secondary pests of coffee such as thrips and red spider mites. It is known that agricultural sprays (Pesticides) affect the natural enemies of mites and other insect pests (Barllet, 1964; Patterson, 1966). This confirmed the findings of this study. The *E.kenyae* population was significantly affected by Chlorpyrifos application against the Coffee Berry Borer. Though this was the case the predacious mites progressively developed resistant to Chlorpyrifos that led to increased number of mites with time hence control of secondary pests of coffee.

According to Finckh (2007), enhancement of often less specialized natural enemies and beneficial microorganisms through habitat management is an important approach to biological control. Mader *et al.* (2002) stated that the organically managed soils commonly have a higher diversity of bacteria, earthworms and arthropods than conventionally managed soils. The results under this study indicated that the numbers of *E. kenyae* was more under organic compost than when compared to inorganic fertilizers (N.P.K. 17:17:17 and N.P.K. 22:6:12). A confirmation that there was an improved habit hence increases in biodiversity and possibility of using fewer insecticides to control pests in coffee agroecosystem.

The Coffee Berry Borer has recently been recorded as the most prevalent pest in the world (ICO, 2009). The Coffee Berry Borer infestation peaks mainly in months of April and December. The peakings coincides with early and late crops. During April the early crop is at maturation stage that is suitable for infestation by the CBB. The second infestation that peak in December coincides with the late crop or second crop when coffee berries are vunerable to CBB attack. The increased CBB infestation in 2007 when compared with year 2006 and 2008 was mainly associated with poor agronomic practices. Failure to collect the CBB infested coffee berries that fell on the ground from the surrounding coffee blocks in 2006 acted as source of heavy infestation experienced in 2007. Also failure to strip the dry infested coffee beans left on the trees after the coffee picking also aggrevated the heavy infestation that occurred in year 2007. Overlapping in coffee cropping seasons as a result of uneven rains attributed to an increased CBB infestation experienced in both years 2007 and 2008.

The *D. coffeae* is regarded in some countries in Africa as the most damaging species of thrips (Le Pelley, 1968). During the three years of this study, the number of *D. coffeae* remained below 0.2 per leaf which was below the established economic injury levels of two thrips per leaf (Anon, 1989). The peaking of thrips population in year 2006, 2007 and 2008 indicated some variations. This was likely due to weather changes during the three years. Tthrips infestation increases when it is dry or there is prolonged drought but decreases with onset of rains probably due to favourable weather conditions that enhances the biocontrol agents such as the fungal pathogens. The use of Chlorpyrifos and Spinosad showed no distinct effect on *D. coffeae* under any regime of fertilizers meaning that they had equal effect on population of *D. coffeae*. The impact of predacious mites was the other cause, where under natural ecosystem these mites are supposed to keep the population of thrips below the economic injury levels. Though it was established that Chlorpyrifos significantly reduced the population of predacious mites when compared to Spinosad and the controlled coffee plots, it meant that the population that remained was adequate and in a position to contain the thrips to below the economic injury levels. This also showed that the strain of predacious mites that occurred in the field had to some extent a degree of resistant to Chlorpyrifos that progressively increased with continous usage of this insecticide.

The Coffee Berry Borer infestation varied from one cropping coffee season to the other. The lowest mean infestation was experienced in 2006 and the highest in 2007. This can mainly be related to the weather, CBB management levels and possibly the absence of natural enemies among other factors. Over the three years period the chemical treatments were not significantly different ($P > 0.05$) from each other against the CBB infestation. Chemical control against the CBB has limited effectiveness because of the biology and feeding behaviour of this pest. It is known that nearly the entire life cycle of CBB takes place inside the coffee cherry. For that reason, insecticides applied to control the CBB can be rarely effective against it if not timely applied. For any insecticides to be effective, it must be applied before the CBB adults get into the hardened coffee bean. According to Mugo (2006, 2008) for this to be achieved, the insecticide requires to be sprayed four to five months after the crop has flowered, the period when the coffee beans hardened and are suitable for CBB attack. With both the Chlorpyrifos and Spinosad being equally effective in controlling CBB, it is therefore possible to manage CBB using Spinosad especially where predacious mites are sensitive to Chlorpyrifos. Likewise the Chlorpyrifos can be used to control the CBB where the predacious mites are resistant to it.

Fertilizers application under Chlorpyrifos treatment had significant difference ($P < 0.05$) on CBB infestation during the study period. The Organic compost combined with Chlorpyrifos had significantly higher mean percentage CBB infestation than either of the inorganic fertilizers. Fertilizers when applied are aimed to enrich soils (Tingey and Singh, 1980). Soil fertility is said to change plant nutritional quality especially nitrogen and water. Slansky and Scriber (1985) stated that pest's infestation decline with decrease in plant nitrogen. Use of fertilizers with high nitrogen content in plants to enrich soil increases the plant attack by pests. The biochemical and physiological changes in plants occurs after fertilization that has a relationship to the activity of several piercing and sucking pests. For instance, intensive nitrogen fertilization in mineral form promotes the population of scale insects or mites. But potassium in the presence of nitrogen fertilization reduces the infestation of many insect pests (Bruning and Vebel, 1969).

Conventional compound fertilizers such as N.P.K. 17:17:17 and N.P.K. 22:6:12 are used in coffee farming in Kenya to improve soil nitrogen, phosphorous and potassium (macronutrients) content. Organic compost is also a common practice to enrich the soils under coffee. Though during this study balanced organic compost (N.P.K. 0.8:0.2:1.0) was applied in coffee, the CBB infestation was realized to be significantly higher than under inorganic fertilizers despite use of Chlorpyrifos. The insecticides application never significantly differed in management of the CBB; hence the causes of variation in CBB management under various fertilizer regimes can be related to availability of nitrogen, phosphorous and potash. The release of macronutrients depend mainly on adequate availability of the rains that help in unlocking these essential elements into the soil hence their uptake by the plant. Therefore, despite use of balanced organic compost, its failure to effectively manage the CBB as compared with inorganic fertilizers could be due to slow or inadequate release of macronutrients especially phosphorous and potash as compared to the inorganic fertilizers.

In the present study the predacious mite, *E. kenyae* population in the different treatments remained above that of the coffee thrip, *D. coffeae*. A negative correlation mainly existed between the predacious mites and the thrips. This means as the population of predacious mites increased that of *D.coffeae* decreased simultaneously and vice versa. Thus, the *E. kenyae* was considered a valuable natural enemy under coffee agro ecosystem as it controlled other minor pests such as scales, aphids and spider mites. During this study, there was no severe infestation experienced from any of these pests regardless of the treatments. On the other hand, probably the use of selective insecticides helped in creating an environment where a number of natural enemies together with *E. kenyae*, adapted themselves, increased and suppressed the populations of other minor insects. According to the findings during the present study, the organic compost had significantly ($P < 0.05$) higher population of predacious mite than N.P.K. 17:17:17. The population of predacious mite under N.P.K.17:17:17 and N.P.K. 22:6:12 were not statistically different ($P > 0.05$) from each other. The presence of significantly higher predacious mites' population under organic compost indicated a situation of an improved soil conditions or quality environment with many toxic free nutrients. Organic matter tends to improve soil physical and chemical properties, hence increase in number of microorganisms (Awad *et al.*, 1993). In this study the balance between N: P: K and the presence of other elements such as Calcium, Magnesium, Zinc, Boron and Iron in the organic compost enhanced the quality and vigorocity of the coffee trees. The encountered vigour by the coffee trees and high population of *E.kenyae*, jointly, probably reduced the damage likely to have been caused in the coffee farm by the minor pests.

The yield and quality of coffee produced during the present study showed no variation. The chemical treatments and the fertilizer regimes had no negative effects on both yield and quality. The production for the three years was free of toxic residues, an indication of high quality coffee produced for marketing and consumption.

5.2 Conclusions

This study arrived at four conclusions:

(a) Coffee farming is constrained by several insect pests (12) attack among other factors that require a well designed Integrated Pest Management strategy

(b) Kenya coffee farms harbour a number of predacious phytoseiid mites (29 species) that are beneficial in managing the secondary insect pests such as thrips and red spider mites

(c) The *Euseuis kenyae,* a common predacious mite in coffee farms has strains tolerant to chlorpyrifos hence suitable for their employment as a component in an Integrated Pest Management programme

(d) The Integration of crop nutrition, selective insecticides and predacious mites is a viable option in managing CBB and other pests of coffee

5.3 Recommendations

This study recommends three management strategies that are equally effective in controlling Coffee Berry Borer, a key pest with direct effect on quality and yield of coffee as it infests the final product. Under these strategies, conservation of *E. kenyae* is emphasized. This is where the population of *E. kenyae* will manage secondary pests such as *D. coffeae* to below economic injury levels while CBB is chemically controlled. The community of predacious mites as an example of natural enemies is always taken as an indication of quality habitat. Under such kind of habitat, the chances of a pest to cause damage to plant is minimum (Van Bruggen and Semenov, 2000).

The following strategies are therefore proposed for the control of Coffee Berry Borer on coffee:-

(a) Where *E. kenyae* has developed resistance to Chlorpyrifos, use Chlorpyrifos to control the CBB while resistant *E. kenyae* strains controls thrips, spider mites and other small insects irrespective of the recommended fertilizer regimes.This strategy will be suitable for medium and large scale coffee farms

(b) Where *E. kenyae* is sensitive to Chlorpyrifos, use Spinosad (Tracer) (not harmful to predacious mites like *E. kenyae* to control CBB while the sensitive *E. kenyae* strains control the thrips and other small secondary pests. This strategy will also be suitable for medium and large scale coffee farms

(c) Use of only organic fertilizer(s) (balanced organic compost) available at almost no cost. The option for the organic compost in such a case apart from achieving high yield and quality coffees, significantly increases the population of E. *kenyae* that controls the thrips.This strategy will be suitable for small scale coffee farms where raw materials for making the compost are available from the farm.

The results of the present study have indicated the necessity of undertaking further research work on:-

(a) The status of other species of predacious mites associated with coffee farming systems that may be resistant to Chlorpyrifos and other chemical compounds used in coffee. Especially those with potential of controlling secondary pests

(b) The genetic variation in *E. kenyae* strains with resistance to Chlorpyrifos and other associated similar chemical products

(c) The richness of microbes in the soils where organic composts are regularly applied that can be used in management of pests such as coffee nematodes and Root mealybugs

(d) The possible effect of fungicides on strains of *E. kenyae* especially where traditional coffee varieties are grown and fungicides are heavily applied to manage Coffee Berry Disease and the Leaf Rust.

REFERENCES

Abasa, R. O. (1972). Field and laboratory studies on the adult of *Ascotis selenaria*

Abasa, R.O. (1975). A review of the biological control of coffee pests in Kenya. *East Africa Agricultural and Forestry journal*, 40 (3): 292-299.

reciprocaria (Wlk.) (Lep., Geometridae) a pest of arabica coffee in Kenya. *Bull. Ent.Res.* 61:559-563.

Abasa, R. O. (1983). Management of coffee pests. pp. 162-172, *in:* A. Youdeowi and M. W. Service (eds.), Pest and vector management in the tropics with particular reference to insects, ticks, mites and snails. Longman, London and New York. 399 pp. [Zool. Rec. 1983]

Abasa, R. O., and W. M. Mathenge. (1974). Laboratory studies of the biology and food requirements of *Macrorhaphis acuta* (Hemiptera: Pentatomidae). *Entomophaga* 19: 213-218.

Abbott, W.S. (1925). A method of computing the effectiveness of an insecticide. *J. Econ.Ent.* 18, 255-257.

Acland, J.D.(1971). East African crops. Longman, London. pp. 252.

Adan, A.; Del Estal, P.;Bundia, F.; Gonzales, M. and Vinuela, E. (1996). Laboratory evaluation of the Novel naturally derived compound spinosad against *Ceratitis capitata. Pesti. Sci.* 48: 261-268.

Afia S. I. (2002). Effect of fertilization regime on the behaviour of predacious mites toward pest management in citrus orchards. PhD Thesis, Faculty of Science, Ain Shams University. 159 PP.

Altieri, M. A. and C. I. Nicholls. (1999). Biodiversity, ecosystem function and insect pest management in agricultural systems. In biodiversity in Agroecosystems (CRC Press, Bonn Raton), 69 – 84.

Andrade, O. (1966). Tractor spraying of coffee. *Kenya coffee*. 31: 372.

Anonymous., (1975). Coffee pests and their control (Smallholders series). Coffee Research Foundation. 103pp.

Anonymous.(1983). Coffee Growers Handbook. Coffee Research Foundation. 130 pp

Anonymous.(1989). Atlas of coffee pests and diseases, Coffee Research Foundation , 256pp

Anonymous. (1991). Control of coffee leaf miner. Coffee Research Foundation, Technical Circular No. 69

Anonymous. (2006). The coffee quarterly. A quarterly publication of the Kenya Coffee Traders Association. Issue No 1/2006. 13pp.

Anonymous. (2006). The coffee quarterly. A quarterly publication of the Kenya Coffee Traders Association. Issue No 3/2006. 15pp. .

Anonymous. (2007). The coffee quarterly. A quarterly publication of the Kenya Coffee Traders Association. Issue No 5/2007. 16pp

Awad,F.; Khalil, K.W and Maksound, A.M. (1993). Comparative effects of some organic manures and bentonite as soil amendments. *Agrochimica*,37, No 6.

Baker, P.S. (1999).The Coffee berry borer in Columbia. Final report of the DFID-Cencafe- CABI Bioscience IPM for coffee project (CNTR 93/1536A)

Baker, P. S. (2002). Integrated management of Coffee berry borer. Common Fund for Commodities (CFC), United States Department of Agriculture (USDA) and counterpart contributions from national programmes (ICO, CENICAFE, PROMECAFE,ANECAFE, Coffee Board of India and USDA)

Baker, P. S., Jackson, J.A.F and Murphy, S.T. (2002). Natural enemies, natural allies-how scientists and coffee farmers forged new partnerships in the war against pests and low prices, CABI commodities, **www.cabi-commodities.org**

Bardner, R. (1978). Integrated control of coffee pests. *Kenya coffee* 43: 502.

Bardner, R. and Mcharo, E.Y. (1988). Confirmation of resistance of coffee leaf miner, *Leucoptera meyricki* Ghesq. (Lepidoptera:Lyonetiidae) to organophosphate insecticide spray in Tanzania. *Tropical Pest Management*. 34: 52-54.

Bartlett, B.R. (1963). The contact toxicity of some pesticide residues to hymenopterous parasites and coccinellid predators. *J. Econ. Entomol.*, 56, 694- 698.

Bartlett, B.R. (1964). The toxicity of some pesticide residues to adult *Amblyseius hibisci*, with a compilation of the effects of pesticides upon phytoseiid mites.*J. Econ. Entomol.*, 57, 559-562.

Berthaud J. and Charrier A.(1988). Genetic resources of *Coffea*. In: Clark R J, Macrae R (eds) coffee vol 4: agronomy. Elsevier, London, pp 1-42.

Bess, H.A. (1964). Population of the leafminer *Leucoptera meyricki* and its parasites in sprayed and unsprayed coffee in Kenya. *Bull. ent. Res.* 55:59-82.

Borbon-Martinez, M.O. (1989). Bio-ecologie d'un ravageur des baies de cafeier *Hypothenemus hampei* Ferr. (Coleoptera: Scolytidae) et de ses parasitoides au Togo.PhD thesis , University of Toulouse, France.

Brun, L.O., Marcillaud, C.,Gaudichon, V. and D. M. Suckling.(1989). Endosulfan resistance to *Hypothenemus hampei* (Coleoptera, Lyonetiidae) in New Caledonia. *Journal of Economic Entomology*, 82: 1311-1316.

Bruning , D. and Vebel, E. (1969).Fertilizing and the population density of scale insects. *Agri.Vet. Chem.*10 (6): 111-113.

Bustillo, A.E., Cardenas, R., Villalba, D., Benavides, P., Orozco, J. and Posada, F.J. (1998). Manejo integrado de la broca de café *Hypothenemus hampei (*Ferrari) en Colombia. CENICAFE, Chinchina, Colombia.

Camargo, M.B.P. (2008). The impact of climate change variability on the coffee crop. Proceedings 22nd International Conference on Coffee Science 14-19 September 2008. Campinas,SP- Brazil. PP 276.

Campbell, C.A.M. (1984). The influence of overhead shade and fertilizers on the Homoptera of mature upper –Amazon Co-Coa trees in China. *Bulletin of Entomological Research*, 74 (1): 163-174.

Castagnoli, M. (1989). Biology and prospects for mass rearing of *Amblyseius cucumeris* (Oud.) (Acarina: Phytoseiidae) using *Dermatophagoides farinae* Hudges (Acarina: Pyroglyphidae) as prey. *Redia* 72, 273-279.

Chant,D.A. (1961). The effect of prey density on prey consumption and oviposition in adults of *Typhlodromus (T). occidentalis* Nesbitt (Acarina: phytoseiidae) in the laboratory. *Can. J. Zool.*, 39 (3): 311-315.

Chant,D.A. (1993). Adaptive radiation in the family phytoseiidae (Acarina: Gamasina) as reflected by adult idiosomal setation. *Internat. J. Acarol.*, 19 (3): 203-231.

Chant, D. A. and J. A. McMurtry. (1994). A review of the subfamilies Phytoseiinae and Typhlodrominae (Acari : Phytoseiidae). *Internat. J. Acarol.* 20 (4): 222 – 310.

Chant, D. A. and J. A. McMurtry. (2003). A review of the subfamily Amblyseiinae Muma (Acari : Phytoseiidae): Part II. The tribe Kampimodromini Kolodochka. *Internat. J. Acarol.* 29 (3): 179 – 224.

Chant, D. A. and J. A. McMurtry. (2004a). A review of the subfamily Amblyseiinae Muma (Acari: Phytoseiidae). The tribe Amblyseiini Wainstein: Substribe Amblyseiina n. sub-tribe. *Internat. J. Acarol.* 30 (3): 171 – 228.

Chant, D. A. and J. A. McMurtry. (2005a). A review of the subfamily Amblyseiinae Muma (Acari: Phytoseiidae). Part IV. The tribe Euseiini n tribe, subtribe Typhlodromalina n. substribe, Euseiina n., subtribe and Ricoseiina n. subtribe. *Internat. J. Acarol.* 31 (3): 187 – 224.

Chant, D. A. and J.A. Mcmurtry. (2006). A review of the subfamily *Amblyseiinae Muma* (Acari . Phytoseiidae): Part IX. An overview. *Internat. J. Acarol.* 32 (2): 125 – 152.

Chant,D.A.; Hansell, R.I.C. and Rowell, H.J. (1980). Phenetic variation between some species in the family phytoseiidae (Acarina: Gamasina). *Can. J. Zool.*, 58 (2): 184-197.

Chemura, A., Mandhlazi, R. and Mahoya,C. (2008). Recycled coffee wastes as replacements of inorganic fertilizers in coffee production. Proceedings 22nd International Conference on Coffee Science 14-19 September 2008. Campinas,SP- Brazil. PP 276.

Collyer, E. (1953). Idem.IV. The predator –mite relationship. *J. Hort. Sci.*, 28: 246-259.

Collyer, E. and Kirby, A.H. (1955). Some factors affecting the balance of phytophagous and predacious mites on apple in South- Eastern England. *J. Hort. Sci.*, 30: 97-108.

Croft, B.A. (1972). Resistant natural enemies in pest management systems. *Span.*, 159 (1): 19-22.

Croft, B.A. (1975). Tree fruit pest management .Pp. 471-507. In: "Introduction to Pest Management " Ed. R.L. Metcalf and W.H. Luckmann. Wiley Intersci., New York. 587 PP.

Croft, B.A. (1982). Arthropd resistance to insecticides: a key to pest control failures and successes in North American apple orchards. *Entomol. Exp. Appl.*, 31(1):88-110.

Croft, B.A. and Jeppson, L.R. (1970). Comparative studies on four strains of *Typhlodromus occidentalis*. II. Laboratory toxicity of ten compounds common to apple pest control. *J. Econ. Entomol.* , 63 (5): 1528-1531.

Croft, B.A. and Meyer, R.H. (1973). Carbamate and Organophosphorous resistance patterns in populations of *Amlyseius fallacies. Environ. Entomol.*, 2(4): 691-695.

Croft, B.A. and Stewart, P.G. (1973).Toxicity of one carbamate and six organophosphorus insecticides to OP- resistant strains of *Typhlodromus occidentalis* and *Amblyseius fallacis. Environ. Entomol.*, 2 (3): 486-488.

Croft, B.A. and Strickler, K.(1983). Natural enemies resistance to pesticides. Documentation, characterization, theory of application. In: G.P. Georghiou and T. Saito (Editors), Pest resistance to pesticides. Plenum Press, New York, pp.669-702.

Crowe, T.J. (1964). Coffee leafminers in Kenya (111- control measures). *Kenya coffee* 29: 343.

Damon, A. (2000). A review of the biology and control of the coffee berry borer *Hypothenemus hampei* (Coleoptera, Scolytidae). *Bulletin of Entomological Research* 90, 453-465.

Daneschwar, H. (1963). Einfluss einiger pflanzenschutzmttel auf die Raubmible *Typhlodromus pyri* Scheuten (Acari, phytoseiidae). Diss. Landwirtsch. Hochsch. Hohenheim. 74pp.

Davis,M., Dinhan, B and Williamson, S. (2001). Growing coffee with IPM. A brief for the IPM in Developing Countries Proect funded by the European Commission Environment in Developing countries. *Pest management notes* No 9.

Dean, L.A. (1939). Relationships between rainfall and coffee yields in Kona District, Hawaii, *Journal of Agricultural Research* 59, 217–222

Dwomoh, E.A., Ofofi-Frimpong, K., Afrifa,A.A. and Appiah, M.R.(2008). Effects of fertilizer on nitrogen contents of three coffee clones and berry infestation by the coffee berry borer, *Hypothenemus hampei* (Ferri) (Coleoptera: Scotylidae). *African Journal of Agricultural Research.* 3(2). pp. 111-114.

El- Badry, E.A. and El- Banhawy, E.M. (1968). The effects of pollen feeding on the predatory efficiency of *Amblyseuis gossipi* (Acarina: phytoseiidae). *Entomol. Exp. Appl.*, 11: 273- 276.

El- Banhawy, E.M. (1976). Residue toxicity of some common acaricides in Brazil to the predaciou mite, Amblyseius brazilli. *Entomophaga*, 21 (3): 303-306.

El- Banhawy, E.M. (1995). A survey of the natural enemies of phytophagous mites on citrus in South Africa. A report presented to Outspan Citrus Centre, Nelspriut, South Africa, 15 pp.

El-Banhawy, E. M. (1997). Survey of predacious mites on citrus in South Africa. Specific diversity, geographic distributions and the abundance of predacious mites. *Anz. Scad. Pflanz Umwelt*. 70: 136 – 141.

El- Banhawy, E.M., S.A.A. Amer and S.A. Saber (2000). Induction of malathion – resistant strain in the common predacious mite *Amblyseius cydnodactylon* (Acari : phytoseiidae). *Anz. Schad. Pflanz. Unwelt*. 73,22-24.

El- Banhawy, E.M.; El-Sawaf, B.M.; Osman, H.A and Afia, S.I. (1999). Effect of type of prey on the life parameters of the soil predacious mie, *Gamasiphis tylophygaous* (Mesostigmata: Ologamasidae), a predator of the citrus parasitic nematode, *Tylenchulus semipenetrans* (Tylenchida: Tylenchulidae). *Acarologia*, 40: 25-28.

El-Banhawy E.M., El-Borolossy M. A., El-Sawaf B.M. and Afia S.I. (1998a). Interaction of soil predacious mites and citrus nematodes (parasitic and saprophytic) in citrus orchard under different regime of fertilizers. The effect on the population densities and citrus yield . *Anzeiger fur schadlingskunde pflazenschutz unweltsh.* 70, 20-23.

El-Banhawy E.M., El-Borolossy M. A., El-Sawaf B.M. and Afia S.I. (1998b). Effect of organic and chemical fertilization on the distribution of predaciuous soil mites and nematodes (parasitic and saprophytic) in citrus orchard. *Egyptian Journal of Biological Control.* 71, 89-96.

FAO (Food and Agriculture Organisation of the United Nations) (2002). FAOSTAT Statistics database. Rome. UN Food and Agriculture Organisation. http://applis.fao

Ferwerda. F. P. (1976). Coffee.In. Simmonds N W (ed) Evolution of crop plants. Longman. London, pp 257-260.

Finckh, M. R. (2007). Plant protection in organic agriculture: a system approach for above- ground disease manegement. Proceedings XVI International Plant Protection Congress, 15-19 October 2007. Glasgow,Scotland, UK. 116-117

Finney, D. J. (1952). Probit analysis- A statistical treatment of the sigmoid response curve. Cambridge Univ. press.

Flaherty, D.L. and Huffaker, C. B. (1970). Biological control of pacific mites and willanete mites in San Joaquin valley vineyards. I. Role of *Metaseiulus occidentalis*. II. Influence of dispersion patterns of *Metaseiulus occidentalis*. *Hilgardia*, 40: 267-308.

Fleschner, C.A. (1958).Natural enemies of tetranychid mites on citrus and avocado in Southern California. Proc. 10th Intern. *Congr. Ent.*, Montreal (1956) 4: 627-631.

Furtado,I. (1969). Effect of copper fungicides on the occurrence of the pathogenic form of *Colletotrichum kahawae*. *Transactions of British Mycological Society*, 53 (2): 325-332.

Galvan, T.L., Koch, R.L and Hutchison, W.D. (2006). Toxicity of indoxacarb and spinosad to the multicolored Asian ladybird beetle, *Harmonia axyridis* (Coleoptera: Coccinellidae), via three routes of exposure. *Pest Management Science*. 62 (9): pp 797-804.

Garman, P. (1948). Mite species from apple trees in Connecticut. *Bull. Connecticut Agr. Expt. Sta.*, p 520.

George, P.,Fenardo,E.V., Alfredo,C., Inti,E.C. and Francisco, I. (2004). *Metaparasitylenchus hypothenemi* n.sp (Namatoda:Allantonematidae) a parasite of the Coffee Berry Borer, *Hypothenemus hampei* (Curculionidae: Scolytidae). *J. Parasitol*. 90(5). 1106-1110

Gilliatt, F.C. (1935). Some predators of the European red mite, *Paratetranychus pilosus* C. and F. in Nova Scotia. *Canadian J. Res.*, 13: 19-38.

Golovkina, L.S. and Aksyutova,L.N. (1990). Biological characteristics of the resistance forms of *Phytoseiulus persimilis* A.-H. In the gradient of a biotic factors (Acari, Parasitiformes, phytoseiidae), *Ent. Rev*. 69, 151-156.

Gordon, W. (1988). Coffee. Longman group, U.K. Ltd. 639pp

Grade, C. and Ingrassia,S. (1988). Tolerance to microencapsulated methyl parathion of phytoseiid mites of grapevines, *Amblyseius andersoni* and *Typhlodromus phialatus*. Inf. Agr., 44 (20): 91-95.

Grout, T.G. and Richards, R.I. (1994). The dietary effect of windbreak pollens on longevity and fecudity for a predacious mite Euseius addoesensis addoesensis (Acari: Phytoseeidae) found in citrus orchards in South Africa. *Bulletin of Entomological Research* 82: 317-320

Haarer, A. E. (1962). Modern coffee production. 495 pp. Leonard Hill, London.

Hairyappa, S.A. and Kurkarni, K.A. (1989). Interaction between the predatory mite, *Amblyseius ovalis* (Evans) and chilli mite, *Polyphagotarsonemus latus* (Banks). *J. Biol. Control.*, 3 (1): 31-32.

Härdter, R. (1997): Crop nutrition and plant health of rice based cropping systems in Asia. *Agro-Chemicals News in Brief*, Vol. 20, No. 4, pp. 29-39.

Hargreaves, H. (1926). Notes on the coffee berry borer(*Stephanoderis hampei*, Ferr.) in Uganda. *Uganda Bulletin of Entomological Research*16: 347-354.

Hariyappa A.S. and Kulkarni K.A.(1988). Biology and feeding efficiency of the Predatory mite, *Amblyseius longispinosus* (Evans) and chili mite, *Polyphagotarsonemus latus* (Banks). *Journal of Biological control* 2, 131-132.

Hembel ,A.A. (1934). *Prorops nasuta* Waterson no Brasil. *Arquivos do Instituto Biologico* 5, 197-212.

Herbert, H.J. (1953). Progress report on predacious mite investigation in Nova Scotia (Acarina: phytoseiidae). *Rep. Ent. Soc.* Ontario. 27-29.

Hiddink, G.A.; Bruggen, A.H.C. van; Termorshuizen, A.J.; Raaijmakers, J.M. and Semenov, A.V. (2005). Effect of organic management of soils on suppressiveness to Gaeumannomyces graminis var. tritici and its antagonist, Pseudomonas fluorescens. *European Journal of Plant Pathology. 113 (4). - p. 417 - 435.*

Holm , L.G.; Plucknett, D.L.; Pancho, J.V. and Herberger, J. P.(1977). The world's worst weeds: Distribution and biology. Honolulu: University Press of Hawaii. 609 pp.

Hoy, M.A.; Barnetta, W.W.; Reil, W.O.; Castro, D.; Cahn, D.; Hendricks, L.C.; Coviello, R. and Bentley, W.J. (1982). Large scales releases of pesticides resistant spider mite predators*Calif. Agric.*, 36 (1): 8-10.

Hoyt, S.C. (1969). Integrated chemical control of insects and biological control of mites on apple in Washington. *J. Econ.Entomol.*, 62: 74-86.

Hoyt, S.C. and Calagirone, L.E.(1971). The developing programmes of integrated control of pests of apples in Washington and peaches in California. In: Biolocal control, C.B. Huffaker, ed Plenum Press, N.Y. pp 395-421.

Huffaker, C.D., Van de Vrie, M. and McMurtry, J.A. (1969). The ecology of tetranychid mites and their natural control. *Annual Review of Entomology*. 14: pp 125-174.

ICO (2009). A seminar on the Coffee Berry Borer. International Coffee Organization, London, England, ICC 102-5.

Infante, F., J. F. Barrera, S. T. Murphy, J. Gómez, and A. Castillo. (1992). Cría y cuarentena de *Phymastichus coffea* LaSalle (Hymenoptera: Eulophidae) unparasitoide de la broca del café introducido a Mexico. XV Simposio Latinoamericano de Cafeticultura, Xalapa, Veracruz, 80 pp.

Ivens, G.W. (1989). East African weeds and their control. Oxford University Press, Nairobi.

Jaramillo, J., Borgemeister, C. and Baker, P.S. (2006). Coffee berry borer, *Hypothenemus hampei* (Coleoptera: Curculionidae): Searching for sustainable control strategies. *Bulletin of Entomological Research* 96, 223-233.

Kairu G.M (2007). Possible effects of global warming on coffee diseases in Kenya. Proceedings XVI International Plant Protection Congress, 15-19 October 2007. Glasgow,Scotland, UK. 806-807.

Karanja, A.M. (1996). Highlights on coffee production, cost of production and milling in Kenya. *Kenya coffee* 61: 721

Karungi, J., Nampala, M., Adipala, E., Kyamanywa, S. O., and Latigo, M.(1999). Population dynamics of selected cowpea insect pests as influenced by different management in Eastern Uganda. *African Crop Science Journal*. 7 (4). 487-495.

Kinuthia, M.W. (1986). The natural enemies of Icerya Patterson (Newst) in a coffee estate. *Kenya coffee* 38: 327

Kinuthia, M.W. and Mwangi , R.W. (1986). Studies on the biology of *Icerya pattersoni* (Homo. Margoro) a coffee pest in Kenya. Msc dissertation. Nairobi university.

Knudsen, I.M.B.; Debosz K Hockenhull J Jensen DF and Elmholt S 1995. Suppressiveness of organically and conventionally managed soils towards brown foot rot of barley. *Applied Soil Ecology* 12, 61-7.

Kotecha, S., (2002). 'Coffee in Africa: Impacts and Issues of Low Price Crisis'. Discussion Paper prepared for the Inter African Coffee Organization Ministerial Conference in Equatorial Guinea. Malabo, September, 2002

Krauss, A.D.M. (2001). Potassium and abiotic stress. In: International Potash Institute (ed) *Potassium in Argentina's Agricultural Systems*. Buenos Aires, pp 1–6

Last, F.T. (1962). Analysis of the Effects of *Erysiphe graminis* DC. on the Growth of Barley. *Ann Bot* 26: 279-289.

Le Pelley, R.H. (1968). Pests of coffee. Longmans Green and Co, London,UK.

Le Pelley, R.H. (1973). Coffee insects. *Annual Review of Entomology* 18, 121-142.

Mader, P., FlieBbach, A., Dubois, D., Gunst, L., Fried, P. and Niggli, U. (2002). Soil F ertility and Biodiversity in Organic Farming. *Science 296, 1694-1697*.

Malavolta,E., Haag,H.F., Mello,F.A.F. and Sobro, M.O.C. (1962).On the mineral nutrition of some tropical crops, International Potash Institute .Berne, pp 1-55

Manion, M., G. Dicum., N. Luttinger., G. Richards., J.J.Harder and T. Walker.(1999). The scale and trends of coffee production impacts on global Biodiversity. Paper prepared by industrial Economics .Inc. for the center for Applied Biodiversity , Conservation International, Washington D.C. October 15. 60 pp. Draft

Manolache, C., Pasol, P., Nicolaresur, N., Naum, A. and Schmidt, E. (1976). Role of some cultural measures in the control of of wheat crops in reddish brown forest soil. *Problene de protectia planteler*. 2(4): pp. 363-379.

Martins, J.P., Pinoceiro, B. and love, J.A. (1980). Nitrogen and infestation by the stalk borer in irrigated rice. *Pesquisa Agropecuaria Brasilliera*. 13(3): pp. 23-25

Masaba, D.M. (1991). The role of saprophytic surface microflora in the development of coffee berry disease (*Colletotrichum kahawae)* in Kenya. Phd thesis. University of Reading

Masaba, D.M. (1993). Effectiveness of new fungicides against coffee berry disease (*Colletrotrichum coffeanum*) in Kenya. *Kenya coffee* 58: 678

Masaba D.M.and Waller J.M., 1992. Coffee berry disease: the current status. In: Bailey JA, Jeger MJ (eds), *Colletotrichum*: Biology, pathology and control, pp 237-249.Wallingford UK: CAB International.

Massee, A.M. (1954). The pests of fruits and hops. Crosby Lockwood and Sons, Ltd., London.

Matos,C.H.C., A. Pallini, F.F. Chaves, and C. Galbiati.(2004).Domaticias do cafeeiro beneficiam o acaro predator *Iphiseiodes zuluagai* Denmark and Muma (Acari: Phytoseiidae)? *Neotrop. Entomol.*33: pp57-63

Matos, C.H.C., A. Pallini, F.F. Chaves, J.H. Schoereder and A. Jassen.((2006). Do domatia mediate mutualistic interactions between coffee plants and predatory mites? *Entomol.Exper.Appl.* 18: pp185-192.

McEwan, R.B. and B.Allgood (2001). Nicaraguan Coffee. The sustainable crop . Unpuplished paper.

McMurtry, J.A. and Scriven, G.T. (1966). The influence of pollen and prey density on the number of prey consumed by *Amblyseius hibisci* (Acarina: Phytoseiidae). Ann. *Entomol.Soc.Amer.*, 59(1):147-149.

McMurtry,J.A.; Huffaker. C.B. and van de Vrie, M. (1970). Ecology of tetranychid mites and their natural enemies : A review. I. Tetranychid enemies: their biological characters and the impact of spray practices. *Hilgardia*, 40: 331-390.

Michori P.K., 1993. Nitrogen budget under coffee. PhD Thesis, Reading. 334 pp.

Mineiro,J.L.de C., M.E.Sato, A.Raga, V.Athur, K.G.Cangani and F.V.Barbosa.(2006a). Diversidade de acaros (Arachnida: Acari) em cinco cultivares de duas especies de cafeeiros (*Coffea spp.*) em Garca, Estado de Sao Paulo. *Arq.Inst.Biolo.*, SaoPaulo, 73: pp333-341.

Mineiro,J.L.de C., M.E.Sato, A. Raga, V. Athur, G.J.de Moraes, F. de O.Sarreta and A.Carrijo.(2006b). Diversidade de acaros (Arachnida: Acari) em *Coffea urabica* L.Cv.Mundo Nova, nos municipios de jeriquara e Garca, Estado de Sao Paulo. *Biota Neotrop.* 6: pp1-15

Mondal, S.S., Pramanik, C.K. and Das, J. (2001). Effect of nitrogen and potassium on oil yield, nutrient uptake and soil fertility in soybean (*Glycine max*) – sesame (*Sesamum indicum*) intercropping system. *Indian J. Agric. Sci.* 71: 44-46.

Motoyama, N.; Rock, G.C. and Dauterman, W.C. (1970). Organophosphorus resistance in an apple orchard population of *Typhlodromus (Amblyseius) fallacies. J. Econ. Entomol.*, 63 (5): 1439-1442.

Mouen, B.J.A., Bieysse,D., Cilas,C. and Notteghem,T.L.(2008). Effect of temperature and rainfall v variation on coffee berry disease (*Colletotrichum kahawae*). Proceedings 22nd International Conference on Coffee Science 14-19 September 2008. Campinas,SP- Brazil. PP 276.

Mugo, H. M. (1994). Coffee insect pests attacking flowers and berries in Kenya. A review *Kenya coffee*. 59 (691): 1777-1783.

Mugo, H.M (1996). Biological control of Green and Fried egg scales in coffee by ladybird beetles. *Kenya coffee*. 61 (720): 2313-2317.

Mugo.H.M. (2006). Effective application of chemical strategy against Coffee berry borer, *Hypothenemus hampei*, infestation in Kenya. Paper presented during International conference on coffee science, Montepellier, France. 11th – 15th September 2006.

Mugo, H.M (2008). The coffee berry borer (*hypothenemus hampei*) distrbution and the effect of coffee management practices in Kenya. Proceedings 22nd International Conference on Coffee Science 14-19 September 2008. Campinas,SP- Brazil. PP 276.

Mugo,H.M. and Ndoiru, S.K. (1997). Use of *Telenomus (Asolcus) seychellensis* (Hymenoptera: Sceliodae) in biological control of Antestia bugs, *Antestiopsis spp* (Hemiptera: Pentatomidae) in coffee. *Kenya coffee*. 62 (728): pp 2455-2459.

Muller,L. E. (1966). Coffee nutrition. In Temperate to Tropical Fruit Nutrition.(Ed. N. F. C hilders). 2nd Edition ,Somerset press Inc., Someville, New Jersey (USA) , PP685-776.

Murphy S. T and Rangi, D.K. (1991): The use of African wasp, *Prorops nasuta* for the control of the coffee berry borer, *Hypothenemus hampei* in Mexico and Ecuador: The introduction programme. *Insect Sc.Appl.* (ICIPE). 12 (1-2-3). 27-34.

Murphy S. T., Donnel D. J., Mang'ayo F.L., Cross A and Evans H.G. (1986): First Report of the Coffee Berry Borer Project. Unpublished Report CABI Institute of Biological control. 23pp.

Murphy S. T., Donnel D. J., Mang'ayo F.L., Cross A and Evans H.G. (1989): Second Report of the Coffee Berry Borer Project. Unpublished Report CABI Institute of Biological control. 23pp

Murphy,S.T. and Moore,D. (1990). Biological control of Coffee berry borer, *Hypothenemus hampei (*Ferrari) (Coleoptera: Scolytidae): Previous programmes and possibilities for the future. Biological News and Information 11, 107-117.

Mwang'ombe, A.W. (1994). Tolerance in isolates of *Colletotrichum coffeanum* to Prochloraz-Mn in Kenya. *Journal of Phytopathology*. 140: 114-122.

Nakamura, T., T. Taniguchi and E. Maeda. (1992). Leaf anatomy of Coffea Arabica L. with reference to domatia. Jpn. *J. Crop Sci.* 61: 642-650.

Ndungi, A. W. (1994).New natural enemies of coffee berry moth. *Prophantis smaragdina* (Butler) in Kenya. *Kenya coffee* 59: 688

Nesbitt, H.H.J. (1951). A taxonomic study of the phytoseiidae (Family Laelaptidae) predaceous upon Tetranychidae of economic importance. *Zool. Verb.*, 12: 1-16.

Nutman, F. J. (1933a). The root system of *Coffea arabica*. I. Root systems in typical soils of British East Africa. Empire *Journal of Experimental Agriculture* 1:271-284.

Nutman, F. J. (1933b). The root system of *Coffea arabica* L. Part II. The effect of some soil conditions in modifying the 'normal' root system. Empire *Journal of Experimental Agriculture* 1:285-296.

O'Dowd, D.J.(1994).Mite association with the leaf domatia of coffee *(Coffea Arabica)* in north Queensland, Australia . *Bull.Entomol. Res.* 84: PP361-366.

Oerke, E.C., Dehne, H.W., Schohnbeck, F. and Weber, A. (1995). Crop production and crop protection: Estimated losses in major food and cash crops. Amsterdam, Elsevier (quoted in IFPRI Discussion paper 25, 1998).

Okioga,D.M. (1976). Occurrence of strains of *Colletotrichum coffeanum* resistant to methyl benzimidazol-2-ylcarbamate (carbendazim) and chemically similar compounds. *Annals of Applied Biology*. 84: 21-30.

Omondi,C.O. and Gichuru, E.K.(2006). Development of a strategy for a durable management of the resistance to Coffee Berry Disease in Africa. Coffee Research Foundation (CRF) final report for the period November 2001 to October 2006.pp 49

Osorio, N.(2002. The global coffee crisis : a threat to sustainable development. ICO, London .

Pallini, A., Marchetti, M. M., Ferla,N.J. and Matioli, A. L.(2008). Mites associated with coffee plants in Minas Gerais, Brazil. Proceedings 22nd International Conference on Coffee Science 14-19 September 2008. Campinas,SP- Brazil. PP 276.

Parrott, P.T.; Hodgkiss, H.E and Schoene, W.J. (1906). The Eriophyidae part 1. The apple and pear mites. New York Agr. *Exp. Sta. Bull*., 283: 302-303.

Patterson, N.A. (1966). The influence of spray programmes on the fauna of apple orchards in Nova Scotia. XVI. The long-term effect of mild pesticides on pests and predators. *J.Econ. Entomol*., 59: 1430-1435.

Pemberton, R.W. and C.E.Turner. (1989). Occurrence of predatory and fungivorous mites in leaf domatia. *Amer. J. Bo*t. 76: pp105-112.

Penzig, O. and C. Chiabrera. (1903). Contributo alla conoscenza delle piante acarofile. *Malphigia*. 17: 429-487.

Pereira, H. C.; Jones, P. A. (1954). A tillage study in Kenya Coffee. Part I: the effects of tillage practices on coffee yields. *Emp. J. Exp. Agric*. 22: 231-240.

Perrenoud, S. (1990). Potassium and plant health. IPI Research Topics No. 3, 2nd rev. edition. Basel/Switzerland.

Phiri, N.A., Karanja, D. and Kimani, M. (2007). Integrated management practices for the control of important crop diseases in developing countries. Proceedings XVI International Plant Protection Congress, 15-19 October 2007. Glasgow,Scotland, UK. 734-735.

Ralph, J and Helmut, S (1983). Farm management handbook of Kenya. Natural conditions and farm management information, Vol. II B/C.

Rasmy, A.H. (1971). Relation between predacious and phytophagous mies on citrus. *Zeit.fur.Angew.Entomol.*, 67: 6-9.

Readshow, J. L. (1975). The Ecology of tetranychid mites in Australian orchards. *J. Appl. Ecol.*, 12: 473-495.

Ristich, S.S. (1956). Toxicity of pesticides to *Typhlodromus fallacies. J. Econ.Entomol.*, 49(4): 511-515.

Roe, J. D and Nyoro, J.K (1986). Economic implications of introducing the new hybrid variety of Arabica coffee. *Kenya Coffee* 51 (599), 219-244.

Roush,R.T. and M.A.Hoy,(1981. Laboratory glass house and field studies of artificial selected carbaryl resistance in *Metaseiulus occidentalis. J. Econ. Entomol.* 74: 142-147.

Salama, H.S.; EL-Sherif, A.F. and Magahed, M. (1985). Soil nutrients affecting the population density of *Parlatoria zizyphus* (Lucas) and *Icerya purchase* Mask (Homoptera: Coccoidae) on citrus seedlings. *Zeit. Ang. Ent.*, 99(5): 471-476.

Sandness, J.N. and McMurtry, J.A. (1970). Functional response of three species of phytoseiidae (Acarina) to prey density. *Can. Entomol.*, 102 (6): 692-704.

Schoeman,P.S.(1994). Aspekte van die bio-ekologie van die witkoffiestamboorder *Monochamus leuconotus* (Pascoe) (Coleoptera: Cerambycidae). MSc.Thesis, PU vir CHE

Schulten, G. G. M., Van de Klashort, G., and Russel, V. M. (1976). Resistance of *Phytoseiulus persimilis* A.-H. (Acari: phytoseiidae) to some insecticides. *Z. Ang. Entom.* 80, 337-341.

Scriber, J.M. (1977). Limiting effects of low leaf water content on nitrogen utilization, energy budget, and larval growth of *Hyalopora cecropia* (Lepidoptera: Saturniidae). *Oecologia* 28: pp. 269-287.

Scriber, J.M and Feeny, P.P. (1979).The growth of herbivorous caterpillars in relation to degree of feeding specialization and growth form of food plant. *Ecol* 60: pp. 829-850.

Shah, P. A. , Brooks, D. R., Ashby, J. E., Perry, J. N. and Wolwod, I. P. (2003). Diversity and abundance of the coleopteran fauna from organic and conventional management systems in Southern England. *Agric. Forest. Ent.* 5(1) 51 – 60.

Sharon. D. (2004). Stopping the Coffee Berry Borer from boring into profits. Agricultural Research. http://findarticles.com/p/articles/mi-m3741/is-11-52/ai-n707291/

Simpson, B.W. (1993).Organophosphate residues in plant materials. *PPQ- Pesticide residue chemistry method manual.* Agricultural chemistry method No PPQ-02. pp 1-8.

Slansky, F. Jr and Scriber, J.M. (1985). Food consumption and utilization. 87- 164. In: G.A. Kerkuit and L.I.Gilbert (eds.), Comprehensive insect physiology, biochemistry and pharmacology. Pergamon,Oxford.

Sseruwagi, P. O., Nape, G. W., Osiru, D. S. O., and Thresh, J M., (2003). Influence of N.P.K. fertilizer on populations of the whitefly Vector and incidence of Cassava Mosaic virus disease. *African Crop Science Journal.* 11(3). 171-179.

Sweeney, D.W., Granade, G.V., Eversmeyer, M.G. and Whitney, D.A. (2000). Phosphorus, potassium, chloride, and fungicide effects on wheat yield and leaf rust severity. *J. Plant Nutr.* 23:9, 1267-1281.

Swift,F.C. (1968). Population densities of the European red mite and the predaciou mite, *Typhlodromus (A.) fallacies* on apple foliage following treatment with various insecticides. *J. Econ.Entomol.*, 61(6): 1489-1491.

Tabashnik, B.E. (1986). Evolution of pesticide resistance in predator - prey system. *Bull. Entomol.Soc.Am.*, 32 : 156-161.

Tawfik, A.A., (2001). Potassium and Calcium nutrition improves potato production in drip irrigated sandy soil. *African Crop Science Journal.* 9(1). 147-155.

Ticheler, J. (1961). Etude analytique de lepidemiologie du scolyte de grains de café *Stephanoderis hampei* Ferr. en Cote d'Ivoire. Mededelingen Landbouwhogeschool Wageningen 61, 1-49.

Tingey, W. M. and Singh, S.R. (1980). Envir. factors influencing the magnitude and expression of resistance., In F.G. Maxwell and P. R. Jennings (Eds.) Breeding plants resistance to insects. J. Wiley, New York. Pp. 89-113.

Ueckermann, E. A. and Loots , G.C (1988). The African species of the subgenera *Anthoseius* Deleon and *Amblyseius* Berlesc (Acari: Phytoseiidae) . Entomol. Man. Dep. Agric. Water supply. *Res. S. Atn.* , 73: 1-168.

Van Bruggen, A.H.C. and Termorshuizen, A.J.(2003). Integrated approaches to root disease management in organic farming systems. *Australasian Plant Pathology* 32: 141-156.

Van Bruggen, A.H.C.and Semenov, A.M. (2000). In search of biological indicators for soil health and disease suppression. *Forestry.* 15: 13-24.

Van Bruggen, A.H.C., Block, W.J.and Semenov, A. M. (2007). Promoting plant health through organic systems: soil health and root disease suppression. Proceedings XVI International Plant Protection Congress, 15-19 October 2007. Glasgow,Scotland, UK. 118-119

Van de Vrie, M. (1962). The influence of spray chemicals on predatory and phytophygaous mites on apple trees in laboratory and field trials in Netherlands. *Entomophaga.* 7(3): 253-250.

Van der Vossen, H.A.M. and Walyaro, D.J.(1980). Breeding for resistance to coffee berry disease in *Coffea Arabica* L. Inheritance of the resistance. E*uphytica*. 29:777-791.

Van Diepeningen, A .D., de Vos O. J., Korthals, G. W. and van Bruggen . A. H .C.(2006). Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. *Applied Soil Ecology* **31**:120–135.

Vega, F. E.(2004). Coffee berry borer Hypothenemus hampei (Ferrari) (Coleoptera: Scolytidae). In: Capinera, J.L. (Ed), Encyclopedia oof Entomology, Vol.1. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 575-576.

Vega, F. E., Posada, F.and Infante, F. (2006). Coffee insects, ecology, and control. In D. Pimentel (Ed.), *Encyclopedia of Pest Management*, Dekker, published online.

Vega, F.E., Ochoa, R., Astorga, C. and Walter,D.E.(2007). Mites (Arachnida: Acari) inhabiting coffee domatia: A short review and recent findings from Costa Rica. *Internat.J.Acarol.*33(4): pp291-295

Verkek, R.H.J., Leather, S.R., and Wright, D.J.,(1998). The potential for manipulating crop-pest-natural enemy interactions for improved insect management. *Bulletin of Entomological Research* . 88(50).493-501.

Waikwa, J.M and Mathenge, M.W (1977).Field studies on the effects of *Bacillus thuringiensis* Berlines on larvae of the Giant looper and the side effects on leaf miner parasites. *Kenya coffee*. 42 (492) 95-101

Wallis, J.A.N. (1963). Water use bu irrigated Arabica coffee in Kenya. *Journal of Agricultural Science*, 60: 381-388

Walter, D.E. and Lindquist, E.E.(1989). Species, guilds and functional groups: Taxonomy and behaviour in nematophagous arthropods. *Journal of nematology* 21, 315- 327.

Waterhouse, D.F. and Norris, K.R.(1989). Biological control: Pacific prospects. Suppliment 1. *Hypothenemus hampei* (FerTari). Canberra: Australian Centre for Int.Agric.Reon, 123: 123pp.

Wellman, F.L. (1961). Coffee, Botany, Cultivation and utilization, 488pp.,London, Leonard Hill; N.Y., Inter Science.

Wheatley, P.E. (1963). Laboratory studies of insecticides against coffee leafminer, *Leucoptera meyricki.Bull. ent.Res.*,54:167-174.

Wheatly,P.E (1964).The Giant loopper. *Kenya coffee*. 29: 340.

Workneh, F. and Van Bruggen, A.H.C. (1994). Suppressionof corky root of tomatoes in soils from organic farms associated with soil microbial activity and nitrogen status of soil and tomatoes tissue. *Phytopathology* 84, 688-694.

Yudelman, M., Ratta, A. and Nygaard, D. (1998). Pest management and food production. *In*: Food, agriculture and the environment. Discussion paper 25, International Food Policy Research Institute, Washington DC, USA.

Zhang, Z.Q. (2003): Mites of Greenhouses: identification, biology and Control. CABI Publishing: Wallingford, Oxon OX10 8DE, UK. 44 Brattle Street, 4th Floor, Cambridge, MA 02138, USA:

Zhang Z.Q. and Sanderson J.P. (1994). A comparative life history study of immature *Amblyseius fallacies, Amblyseius andersoni, Typhlodromus occidentalis* and *Typhlodromus pyri* (Acari: Phytoseiidae) with a review of larval feeding patterns in the family. *Experimental and Applied Acarology* 18, 635-657.

Zhang, Z.Q.; Sandness, J.P. and Nyrop, J.P. (1992). Foraging time and spatial patterns of predation in experimental populations. A comparative study of three mite predator- prey systems (Acarina: phytoseiidae: Tetranychidae). *Oecologia*, 90 (2): 185-196.

APPENDICES

Appendix 1: Survey for coffee insect pests distribution (*QUESTIONNAIRE*)

1.0 BACKGROUND

Sample site No.........Farmer Name..................Province......................
District..................Division.........................Location......................
Sub-Location......... .Village..........................Agroecozone ....
Altitude .... Geograpical Position ....Farmsize.....................
Coffee Variety. ....Yr coffee planted........... Recorder...................
Date ....

2.0 LAND USE:

2.1 How much of your farm is under coffee:-

- Traditional varieties.....................ha.
- Ruiru 11..........................ha.

3.0 COFFEE INSECT PESTS MANAGEMENT:

3.1 Which of the following coffee management practices do you undertake: -

(a) Pruning (b) Weeding
(c) Pesticides use (d) Mbuni stripping
(e) Fertilization (f) Irrigation
(g) Intercropping (h) Mulching

3.2 Fertilization:

What type of fertilizer do you apply in your farm?

Type of fertilizer/manure/pulp/ foliar	Month	Rates
a)		
b)		
c)		
d)		
e)		
f)		

3.3 Insect pests control:

3.3.1 Do you experience any Insect pest problems?

[ ] Yes
[ ] No

If yes, which ones:-

a. ....
b. ....
c. ....
d. ....
e. ....

3.3.2 Do you apply Insecticides to control Insects pest in 3.4.1 above?

[ ] Yes
[ ] No

If yes, which insecticides do you apply?

Insecticides	Month	Rates
a)		
b)		
c)		
d)		

3.3.3 Apart from the use of insecticides to control Insect pests, which other methods do you apply?

Method	Insect pest controlled

3.4 Insect pests of coffee visually recorded in the farm

i)...
ii)..
iii)...
iv)...
v)..
vi)...
vii)..

Appendix 2: Analysis of Variance for the effect of cropping seasons (Years), insecticides and fertilizers on Coffee Berry Borer, Thrips and Predacious mites (*Euseuis. kenyae* (Swirski and Ragusa))

a) Coffee Berry Borer

Parameter	Source	DF	SS	MS	F Value	Pr < F
% infestation	Insecticides	2	56.672704	28.336352	0.59	0.5570ns
	Fertilizers	2	389.345941	194.672971	4.12	0.0172**
	Year	2	7675.964193	3837.982097	161.55	<.0001***
	Treatment	8	562.229530	70.278691	1.48	0.1653ns
	Year*Treatment	16	8871.401402	341.207746	15.82	<.0001***
	Rep	3	1368.427902	124.402537	5.77	<.0001***
	Error	286	6169.10093	21.57028		

b) Thrips

Parameter	Source	DF	SS	MS	F Value	Pr < F
No of Thrips	Insecticides	2	0.00288825	0.00144413	1.81	0.1660ns
	Fertilizers	2	0.00166159	0.00083079	1.03	0.3568ns
	Year	2	0.00730063	0.00365032	4.65	0.0102**
	Treatment	8	0.00537016	0.00067127	0.83	0.5753ns
	Year*Treatment	26	0.02010753	0.00077337	0.96	0.5251ns
	Rep	11	0.06240610	0.00567328	7.03	<.0001***
	Error	277	0.22339617	0.00080648		

c) Predacious mites (*Euseuis kenyae* (Swirski and Ragusa))

Parameter	Source	DF	SS	MS	F Value	Pr < F
No of mites	Insecticides	2	375.012719	187.506359	7.25	0.0008***
	Fertilizers	2	824.409172	412.204586	16.89	<.0001***
	Year	2	2044.666835	1022.333418	49.94	<.0001***
	Treatment	8	1329.668483	166.208560	7.16	<.0001***
	Year*Treatment	26	3987.205206	153.354046	9.96	<.0001***
	Rep	11	1750.419127	159.129012	10.33	<.0001***
	Error	286	4403.63090	15.39731		

Nb: Treatment = Fertilizer x Insecticide

Appendix 3: Analysis of Variance for the effect of cropping seasons (Years), treatments and fertilizers on Coffee yield, grades and weight.

a) Coffee yield

Parameter	Source	DF	SS	MS	F Value	Pr < F
Yield (Kg/Ha)	Year	2	19098254.46	9549127.23	32.06	<.0001***
	Treatment	8	1014781.53	126847.69	0.43	0.9022[ns]
	Year*Treatment	16	7026572.95	439160.81	1.47	0.1312[ns]
	Rep	3	993799.24	331266.41	1.11	0.3494[ns]
	Error	78	23235542.88	297891.58		

b) **Coffee grades**

Parameter	Source	DF	SS	MS	F Value	Pr < F
% grade AA/AB	Year	2	1568.767222	784.383611	17.77	<.0001***
	Treatment	8	358.649917	44.831240	1.02	0.4316[ns]
	Year*Treatment	16	1056.710611	66.044413	1.50	0.1228[ns]
	Rep	3	239.303270	79.767757	1.81	0.1528[ns]
	Error	78	3443.835880	44.151742		

c) **Weight of coffee beans**

Parameter	Source	DF	SS	MS	F Value	Pr < F
Weight	Year	2	412.2384889	206.1192444	135.84	<.0001***
	Treatment	8	24.8707167	3.1088396	2.05	0.0512[ns]
	Year*Treatment	16	25.0892611	1.5680788	1.03	0.4325[ns]
	Rep	3	3.3213583	1.1071194	0.73	0.5374[ns]
	Error	78	118.3572667	1.5174009		

Nb: Treatment = Fertilizer x Insecticide