

**EVALUATION OF THE EFFECT OF SYNTHETIC AND NATURAL PESTICIDES ON
PESTS AND NATURAL ENEMIES IN CITRUS ORCHARDS**

**A POSTGRADUATE DISSERTATION PRESENTED TO FACULTY OF
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AWARD OF A DEGREE OF MASTER OF SCIENCE IN AGRO-ECOLOGY**

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Master's Dissertation

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DEDICATION

This study is dedicated to my Dad, Mum, brothers and sisters with whom I share inherent bondage and mutual love. Also to my wife with who I have always shared experiences, academic struggle as well as her encouragement, I wish her the best of luck in her endeavors. Lastly, but not least, to my daughter Esther Ainembabazi and my son Dominick Tumutungye, I love you so much. To all, GOD BLESS you.

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ABSTRACT

The study was carried out on-station at Ngetta Zonal Agricultural Research and Development Institute (Ngetta-ZARDI), in mid-northern agro-ecological zone of Uganda to establish the effect of synthetic and natural pesticides on insect pests and natural enemies in citrus orchards. Neem leaf extract, a natural pesticide and dimethoate, a synthetic pesticide, were used. Three different levels of concentration were used for each pesticide. For Neem leaf extract 1 liter of neem leaf extract per 10 liters of water, (neem 1:10), 2 liters of neem leaf extract per 10 liters of water (neem 2:10) and 5 liters of neem leaf extract per 10 liters of water (neem 5:10) were used. For dimethoate 0.001 litres of dimethoate per litre of water (dim 1:1), 0.002 litres of dimethoate per litre of water (dim 2:1), and 0.003 litres of dimethoate per litre of water (dim 3:1) were used. These formed 6 experimental treatments and were applied on five citrus plants in a plot at an interval of 3 weeks. The experimental design used was randomized complete block design (RCBD) with 3 blocks, each composed of 7 plots replicated three times, with 6 treatments and a control. Natural enemies' population and pests' damage were recorded before applying pesticides. Six common pests, aphids, scales, leaf miners, orange dog, mealybugs and citrus wooly whitefly were recorded, while four natural enemies, wasps, spider, ladybird and preying mantis were observed on citrus. Severity of infestation was on a scale of 0 to 5, where: 0= no pest damage seen (0% infestation); 1=very low pests damage (1-15% infestation); 2= low pests damage (16-34% infestation); 3= moderate pests damage (35-59 infestation); 4 = high pest damage 60-70% infestation; 5= very high pest damage (71-100%). Results indicated significant difference ($P \leq 0.05$) in leaf miner severity in neem and dimethoate treatments as well as the control. Significant difference also existed between neem treatment and control. However, results did not show significant effect ($P > 0.05$) of pesticides on natural enemies prevalence but significant effect occurred between treatment levels. Spiders and preying mantis population was significantly affected by neem 1:10 and neem 5:10. Dimethoate application had significant effect on preying mantis population at 2:1 level. This shows that both neem and dimethoate have substances that can kill living organisms/insects. The study indicated that there was significant difference in pests severity between blocks but no significant difference in natural enemies' population existed between blocks. Both natural enemies and insect pests showed significant difference in population and severity respectively, between the experimental plots. Rainfall and temperature had significant effect on the population and activity of both insect pests and natural enemies in the citrus orchard. In general the experiment found out that natural enemies and insect pests have response to different pesticide concentration levels. For effective insect pest management in citrus some recommendations are presented in this report.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background information

Citrus belongs to the family Rutaceae that includes Orange, Lemon, Lime, Mandarin, Tangerine, Grapefruit, and Pameló (Cobley, 1965; Hill and Waller, 1988b; Biovision, 2010), among others. The true group consists of six genera: *Eremocitrus*, *Poncirus*, *Clymenia*, *Fortunula*, *Microcitrus* and *Citrus* (Samson, 1986). All have orange or lemon-like fruits with stalked, spindle-shaped, inward-growing juice cells. They consist mainly of evergreen aromatic trees and shrubs having their widest distribution in the tropics. The long fibrous roots do not as a rule produce root hairs and mycorrhizal associations with finer roots are common in citrus (Cobley, 1965). The leaves are persistent and simple except in *Poncirus* where they are deciduous and trifoliate. The six genera can be grafted on one another and can be crossed producing hybrids (Samson, 1986). Considerable confusion exists as to the classification of the different types of citrus due to similarity of their vegetative characteristics. According to Cobley (1965) Swingles classification of the genus is perhaps the most acceptable and is widely adopted. The cultivated species include:

<i>Citrus paradisi</i>	Grape fruit
<i>Citrus sinensis</i>	Sweet orange
<i>Citrus limon</i>	Lemon
<i>Citrus aurantifolia</i>	Lime
<i>Citrus aurantium</i>	Bitter orange
<i>Citrus reticulata</i>	Tangerine and Mandarin
<i>Citrus grandis</i>	Pameló

Citrus has its origin in Southern China, Northern East India and South East Asia. Today the citrus producing regions occupy a belt roughly extending around the world to approximately thirty-five degrees North and South of the equator (Melow, 1971). The cultivated species of citrus are native to S. E. Asia, where they originated in the drier monsoon areas, but are now grown throughout the tropics and sub-tropics (Hill and Waller, 1988b; Food and Fertilizer Technology Centre, 2007). They generally require 100cm of rain or else irrigation (Hill and Waller, 1988b). Most of the major citrus growing regions of the world are found in sub-tropical climates which seem to favour citrus production more than a strictly tropical environment (Melow, 1971). By 1971 world production stood at about 460,000,000 boxes of citrus fruit, representing more than 15,000,000 tons (Melow, 1971). The first introductions of citrus to Uganda are estimated to have been in 19th century (Thaddeus, 2009). Budded citrus (budlings) were imported into Uganda in 1929 from South Africa, Jamaica and Australia. Citrus bud wood was imported into Uganda from Spain, Hawaii and Florida in 1987 by FAO (Thaddeus, 2009). These included Washington Navel, Hamlin, Valencia, Tangelo, King Star ruby and Red blush. Citrus bud wood was later imported from Florida, USA and some from Israel-which bud wood was used to establish the Kiige, Odia and Ongom Citrus schemes. Other introductions (Nova, Minneola, Lamati and Kuno navel) came from South Africa in 1998 (Thaddeus, 2009). Commercial fruit production for domestic consumption and export was successfully undertaken in the 1960s. Government run schemes were established at Kiige (Kamuli District), Ongino (Kumi District), Odino (Soroti District) and Labori (Soroti District) with a total area of 3,000 hectares (Uganda Investment Authority, 2011).

1.2 Importance of citrus production in Uganda

According to Kongai *et al.* (2010) citrus fruit farming is one of the crop enterprises supported and promoted through National Agricultural Advisory Services (NAADS). A combination of high soil fertility and ample climate make Uganda a suitable place for horticultural production, particularly citrus. Citrus is one of the major horticultural crops produced in nearly all parts of Uganda throughout the year with practically no irrigation or fertilizer use (Agona and Muyinza (n.d.). Uganda is suitable and has abundant potential to produce mangoes, citrus, pineapples, and tomatoes (Uganda Investment Authority, 2011)

Citrus fruits are the highest value fruit crop in terms of international trade. Demand for fresh and processed oranges continues to rise in excess of production, especially in developed countries. The horticultural industry more than ever before, provides one of the most promising areas for increasing incomes in the rural areas, improving nutrition of the people, diversification of exports, provision of raw materials for agro-based industries and creation of employment for the youth (Lenny, 1991). According to Bayite-Kasule and Mugarura (2010) annual gross margins for citrus fruits in Soroti stood at Ugshs. 1,464,432 per hectare. The fruits are commonly peeled and eaten fresh as are sweet oranges, mandarin and grape fruits, or their segments may be canned (Samson, 1986). The fruits may be squeezed to extract juice, when ripe, by most agro-processing companies and can generate income locally or exported. This has stimulated development of many small scale agro-processing companies which have created employment to the people. Juice of lemon and lime is diluted in lemonades and other soft drinks (Samson, 1986). The juice of citrus fruits contains, on dry matter basis, between 80 and 90% of sugars and acids (Cobley, 1965). The relative proportions of sugar and acid vary between species, lime and lemons

containing greater proportions of acid than sugar. Citric acid is the commonest acid present but in small quantities of other organic acids and occurs in all species. It has been said that citrus juice, especially from lemon, can be used to regulate high blood pressure and diabetes. The juice also contains soluble pectins which give the juice a cloudy, colloidal appearance, together with mineral salts, glucosides, small quantities of proteins and vitamins (Cobley, 1965). Citrus pulp and molasses can be used as cattle feed (Samson, 1986). The thick bitter rind that is usually discarded can be processed into animal feed by removal of water. The majority of the members of Rutaceae produce essential oils in various parts of the plant body. They may be found in the fruits skin, mesocarp/ flesh mixed with juice), flowers, leaves, and stems of all species of citrus (Cobley, 1965). Much of the lime oil of commercial importance is got from the expressed juice of fresh, undamaged fruits. Sweet orange oil is a by-product of the juice industry produced by pressing the peel. Pectin and essential oils are made from the peel. One tonne of lemon fruit yields 5-9kg of essential oil (Samson, 1986), and it is used as a flavoring of food and drink and for its fragrance perfume and aromatherapy. Leaves, flowers and fruits are used for flavours in confectionery and in the preparation of perfumes, toilet waters and cosmetics (Cobley, 1965). Citric acid is made from lemons and limes and this can be used in manufacturing of medicines and other chemical reagents. Sweet orange oil consists of about 90% d-limonene, a solvent used in various household chemicals, such as to condition wooden furniture, and along with other citrus oils in grease removal and as a hand-cleansing agent. It is an efficient cleaning agent which is promoted as being environmentally friendly and preferable to petroleum distillates. Orange blossom essence is an important component in the making of perfume; leaves can be boiled to make tea, while the peels are used as a slug repellent. Leech lime, *Citrus hystrix* DC. leaf extract is used to control Mushroom mite (*Luciaphorus sp.*) (Bussaman *et al.*, 2012).

Citrus fruits are important for supplying essential vitamins, especially vitamin C, which is responsible for formation of good skin complexion. One glass of juice is sufficient to provide the daily requirement of vitamin C. It contains 12% sugar and other soluble solids, ascorbic acid and 1% citric acid (Samson, 1986). When you eat an orange you get not only the vitamin C but the protopectins, remarkable substances now being accorded great importance by scientists. In Uganda citrus fruit farming is one of the crop enterprises being supported and promoted through National Agricultural Advisory Services (NAADS), one of the implementation arms of Plan for Modernization of Agriculture (PMA) (Kongai *et al.*, 2010). Within the fruit processing sector, the number of companies involved in fresh fruit juice processing is still very low with four major companies (Uganda Investment Authority, 2011).

During the 2010/2011 financial year, the leading player in the fresh fruit juice industry was able to report an annual turnover of up to 6 million US dollars, while the other an average of 1.4 million dollars (Uganda Investment Authority, 2011). The farming systems and their environments are always changing and in Uganda most systems have undergone profound changes in recent years. The factors that have contributed to such changes are civil strife, decimation of cassava by African cassava mosaic virus, decline in cotton marketing system and population increase (National Agricultural Research Organization, 2001). In the northern region, in addition the recent reduction in cattle to near absent levels due to civil strife and rustling the farming system has been adversely affected and livelihoods of the communities severely impaired. This has however led to increased production of non-traditional cash crops like ground nuts, soybean, sunflower, and fruit trees mainly mangoes and citrus (National Agricultural Research Organization, 2001). Uganda is potentially endowed with suitable climatic conditions

and land resources to foster citrus production. According to Kalyango (2009) many farmers in Soroti district, eastern Uganda have taken up citrus production and made money under their umbrella organization, Teso Tropical Fruit Growers Association. In Soroti, eastern Uganda, one farmer can earn 10 million shillings a season and for this potential, the government plans to build a 10 billion shillings citrus factory in Teso region (Kalyango, 2011).

Although the government of Uganda is in preparations to rehabilitate Kiige, Odina, Labori and Atera fruit schemes, currently fruit production is purely in the hands of smallholders centered in the southern, central, and eastern regions. Currently there are over 15 companies exporting fresh fruits and vegetables largely to the EU, each exporting 2-15 tonnes of fresh fruits per week (Uganda Investment Authority, 2011). A fruit processing factory has been planned to be located in the central region of Uganda for its strategic location to collect raw materials from the fruit producing areas as well as easy access to markets and infrastructure. Under the investment opportunities in the Fruit and Vegetable Farming and Processing Sector, in the mid-term cropping programme, the government of Uganda is targeting a combination of the three fruit enterprises based on a 500 hectare nucleus farm to cover 100 hectares of mangoes, 200 hectares of oranges, and 200 hectares of pineapples. The 200 hectares of oranges are estimated to produce 27,000 tonnes of fresh fruits in the next 4 years (Uganda Investment Authority, 2011).

1.3 Constraints of citrus production

Since the beginning of agriculture, farmers have struggled with insects, weeds, plant pathogens and other pests which thrive under the hospitable conditions provided by the agro-ecosystem (Kiss and Mearman, 1992). Major crops such as sorghum, maize, cotton, millet, vegetables and

fruits suffer an overall loss of 20-30% from all categories of pests (Kasarani, 1989). Insect pests were identified as one of the most serious problems of the many problems of the African farmer which requires attention. One of the constraints in food production in Uganda is the damage caused by pests, diseases and weeds. According to van Alebeek (1989), worldwide losses due to pests, diseases and weeds in the field amount to 36% of the potential yield, losses during storage account for another 14% of the potential yield. Despite many improvements in farming systems, techniques for pest and disease management are often not available to small holder farmers or are not appropriate for their circumstances. In Uganda citrus production is constrained by a number of biotic and abiotic factors. Biotic factors significantly reduce yield in comparison to abiotic factors. The major biotic factors include diseases like citrus scab, citrus canker, foot rot and citrus greening disease; insect pests such as leaf miner, citrus psyllids, aphids, orange dog, scales, mealybugs, thrips and mites.

Climate is one of the most important factors affecting the profitability of citrus orchard. Temperature, rainfall and wind are the most important components of climate affecting citrus production. Extremely hot or extremely cold temperatures are damaging to citrus. For good citrus production, trees will require rainfall or irrigation throughout the year. Where dry seasons occur, planning for irrigation is required. Favorable rainfall ranges between 125mm-500mm but citrus is grown in areas receiving as much as 1000-1500mm of rainfall per year. A dry, hot at day cool at night climate favours good color development (Thaddeus, 2009). Although sunny periods stimulate flowering of citrus, prolonged drought may cause serious flower and fruit abortion, as well as formation of smaller fruits at maturity. Overall, low soil fertility, pests and diseases pose the biggest threat to citrus productivity, the world over, and Uganda in particular. Malingcong

(2005) reported that citrus growing that has become a lucrative enterprise for many farmers recently slowed down because the growers found out that it is significantly draining due to expensive chemical inputs. With the introduction of improved citrus varieties into Uganda, pests have become the biggest threat and are currently rated as one of the most serious constraints to citrus production in the country. Although some reports indicate that the current supply for available citrus is lower than actual demand, there are poor marketing strategies for citrus fresh fruits from where they are produced to where their potential consumers are located. Perhaps, this could be compounded by inadequate fresh fruit handling facilities as well as poor transport infrastructure.

1.4 Limitations of citrus production in Uganda

Limited attention has been directed towards marketing strategies of Uganda's horticultural produce which is one of the fastest growing, non-traditional export sectors in the economy (Kongai *et al.*, 2010). Climatic factors like too cold or too hot lower citrus production. Currently, the government of Uganda is grappling with effective farmer participation in, and access to markets as large volumes of citrus fruit have been observed to perish in farmers' fields due to lack of markets (PMA, 2009). The situation is even worse in Lira District where citrus farmers have been seen letting their ripening fruits to drop and rot from the ground. Many farmers have disclosed that the only means of marketing the fresh fruits is from local market places and on the roadside. Too cold weather slows down growth rate and maturity, while too hot conditions may influence insect pests and diseases attack or flower and fruit abortion. Various pest and disease organisms interact by predisposition, so that an infected plant may be more susceptible to pest attack and vice versa, and slight infestation may produce unusually severe symptoms (Davidson and Lyon, 1987). Pest damage is probably most conveniently considered according to the part of

the plant body attacked, that is, leaves, flowers/buds, fruits/seeds, stems, roots, tubers, and seedlings. In the recent years citrus fields in northern Uganda, particularly Lira District have been attacked by citrus canker, which has destroyed almost 100% of fruits in many citrus orchards.

Some types of damage are obviously more important than others, depending upon the part of the plant body attacked and the part of economic value. The Mediterranean fruit fly is also another very important problem facing citrus production in Lira district. A single fruit fly larva can effectively destroy a mango or orange fruit (Davidson and Lyon, 1987). Low quality and low yielding varieties reduce profitability of the citrus production enterprise. Insect pests and diseases have also limited the production potential of citrus farmers. Citrus canker, a bacterial disease of citrus causes premature leaf and fruit drop (Putman and Gaskalla, 2004). This is a new disease of citrus in Uganda and has caused significant destruction of citrus in the country. Insect pests, especially red armored scales, aphids and leaf miners feed on the plant tissues such as leaves and cause defoliation and retarded growth to the plant. In severe cases the insect pests may lead to dieback or complete death of both young and mature plants. This leads to low plant population in citrus orchards, thus less economic viability of the enterprise.

1.5 Problem statement:

Improved and high yielding citrus varieties were introduced into Uganda and have been adopted by many farmers in the mid-Northern agro-ecological zone (AEZ) of Uganda. However, the productivity of these new and improved varieties is being threatened by insect pests. In Uganda the major insect pests of citrus include hard armoured red scales (*Aonidiella aurantii*), soft

brown scales (*Coccus hesperidum*), soft green scales (*Coccus viridis* or *C. alpinus*), citrus woolly whitefly (*Aleurothrixus floccosus*), aphids (*Toxoptera citridus* and *T. aurantii*), citrus leafminer (*Phyllocnistis citrella*), and the swallowtail butterfly or orange dog (*Papilio demodocus*) (Biovision, 2010). Quite often, attempts have been made by many farmers to manage the insect pests with application of synthetic insecticides with little success. Many pest problems in conventional citrus production are related to the almost complete elimination of natural enemies through the excessive use of synthetic pesticides (Biovision, 2010). These chemical pesticides are expensive, and not easily accessed by the majority small scale farmers. It should be noted that frequent application of the synthetic chemical pesticides poses a threat to various biological entities in the agro-ecosystem.

Information about crop protection techniques and methods is scarce in many tropical and sub-tropical countries, especially for rural communities. Most of the information available comes from sources like pesticide shopkeepers, company salesmen and is almost exclusively oriented on chemical control (van Alebeek, 1989). Such information is often oversimplified to suit the interests of the chemical companies, thereby tending to give only the positive side of chemical pesticide use. Besides, most synthetic pesticides used are not selective and kill any organism including beneficial insects in the agro-ecosystem. This could result into elimination of natural enemies and rise of pest populations of some pests like the leaf miner and thrips, which are often not easily affected by the applied synthetic pesticides. Therefore, integration of natural pesticides in the control of citrus insect pests could reduce the use of synthetic chemicals in citrus production and enhance the prevalence of biological control agents in citrus orchards.

The goal of this study therefore, was to generate information on the prevalence of natural enemies/ biological control agents in citrus orchard agro-ecosystems where synthetic pesticides have been applied and in comparison to those where natural pesticides are in use. It was also thought to provide information about the severity of insect pests in the citrus orchards where a synthetic pesticide and a natural pesticide of different concentration levels have been applied.

1.6 Objectives of the study

1.6.1 Overall objective

The overall objective of the study was to establish the severity of insect pests and the population of biological control agents where natural pesticides and synthetic pesticides are applied in the citrus agro-ecosystem and its impact on the viability of the citrus industry.

1.6.2 Specific objectives

- i) To establish the prevalence of biological control agents in natural pesticide sprayed citrus orchards versus synthetic pesticide sprayed citrus orchards;
- ii) To determine the optimum concentration of natural and synthetic pesticides to manage major insect pests but also retain biological control agents population in a more balanced ecosystem;
- iii) To establish the effectiveness of natural pesticides on the control of citrus insect pests.
- iv) To determine the effect of weather on the severity variations of the insect pests and population variation of natural enemies in citrus orchards.

1.7 Hypotheseis of the study

- Ho: a) Synthetic pesticides have a negative effect on the prevalence of natural enemies/ biological control agents of insect pests in citrus orchard agro-ecosystems
- b) Level of concentration of both natural and synthetic pesticides has effect on insect pests and natural enemies
- HA: a) Natural pesticides can effectively control citrus insect pests
- b) Climatic factors have influence on the population of insect pests and natural enemies in citrus orchards

1.8 Scope of the study

The study intended to evaluate the prevalence of natural enemies/ biological control agents in citrus orchard agro-ecosystems where synthetic pesticide has been applied and in comparison to those where natural pesticides are used. It also looked at the efficacy of both natural and synthetic pesticides in the control of citrus pests but with a view of retaining biological control agents' population in a more balanced ecosystem. The research study was designed to last for 9 months, that is, from October, 2011 to June, 2012.

1.9 Significance of the study

Destructive agriculture is a model of agriculture pushed by agrochemical corporations whose main aim is to profit from sales of pesticides (Tirado, 2009). Conversely, farmers can find long-term solutions to pest problems by designing diverse crop fields and using low-input technologies locally available (Tirado, 2009).

It is thought that frequent use of synthetic pesticides, which are usually not selective, can kill any organism including beneficial insects in the agro-ecosystem hence upsetting the ecological balance. This may result into a rise in population of some pests like the leaf miners, and thrips, which are often not easily affected by applied synthetic pesticides as well as development of pest resistance. The study therefore, intended to generate information on the effect of synthetic and natural pesticides on natural enemies/ biological control agents in citrus orchard agro-ecosystems.

CHAPTER 2

LITERATURE REVIEW

2.1 Major pests of citrus

According to Davidson and Lyon (1987); Hill and Waller (1988b) citrus crop similar to all other crops, is attacked by many pests. Many species of these pests have been transported around the world with planting materials. They include armoured scales such as purple scales (*Lepidosaphaes beckii*), yellow scales (*Aonidiella citrina*), and Florida red scales (*Chrysomphalus aonidum*); unarmoured scales include black scale (*Saissetia oleae*), cottony cushion scale (*Icerya purchasi*), and brown soft scale (*Coccus hesperidum*); citrus mealybug (*Planococcus citri*), longtailed mealybug (*Pseudococcus longispinus*); citrus whitefly (*Dialeurodes citri*), cloudywinged whitefly (*Diarodes citrifolii*), citrus wooly whitefly (*Aleurothrixus floccosus*), citrus blackfly (*Aeurocanthus woglumi*), avocado whitefly (*Trialeurodes floridensis*). Others are citrus thrips (*Scirtothrips citri*); citrus red mite (*Planonychus citri*); citrus rust mite (*Phyllocoptruta oleivora*); spirea aphid (*Aphis citricola*); Mediterranean fruitfly (*Ceratitis capitata*), citrus psyllid (*Trioza erytaeae*) and swallowtail butterflies (caterpillars) also known as orange dog (*Papilio cresphontes* Cramer), *P. demodocus*, *P. demoleus*, *P. xanthus* L., *P. glaucus* L., and *P. troilus* L. (Davidson and Lyon 1987; Hill and Waller 1988b). The Argentine ant (*Iridomyrmex humilis* M.) is important in citrus groves because of its relationship with aphids, scales and mealybugs. It is attracted to these insects because of the honeydew they produce, and it may carry them from place to place, thus furthering their spread (Davidson and Lyon, 1987). *I. humilis* M is also detrimental because it destroys both eggs and active forms of predators and parasites. Observations indicate that, where ants are

absent from citrus gloves, natural pest control of mealybugs and other pests is greater (Davidson and Lyon, 1987).

2.2 Major insect pests of citrus in Uganda

The major insect pests of citrus in Uganda include hard or armoured scales, that is, the red scales (*Aonidiella aurantii*), the mussel purple scale (*Lepidosaphes beckii*), and the cicular scale (*Chrysomphalus aonidum*). The most important soft scales are the soft brown scales (*Coccus hesperidum*), and the soft green scales (*Coccus viridis* or *C. alpinus*). Others are citrus mealybugs (*Planococcus citri*), red fire ants or African weaver ants (*Oecophylla longinoda*), citrus woolly whitefly (*Aleurothrixus floccosus*), aphids (*Toxoptera citridus* and *T. aurantii*), citrus leafminer (*Phyllocnistis citrella*), citrus thrips (*Scirtothrips aurantii*), fruit flies (*Bactrocera invadens*, *Ceratitidis capitata* and *C. rosa*), and the swallowtail butterfly or orange dog (*Papilio demodocus*) (Thaddeus, 2009; Biovision, 2010).

Scales suck sap on all plant parts above the ground. Their feeding may cause yellowing of leaves followed by leaf drop, poor growth, dieback of branches, fruit drop, and blemishes on fruits. Leaves may dry when heavily infested and young trees may die. The scales are attacked by a large range of parasitic wasps and predators. These natural enemies usually control scales. Outbreaks are generally related to the use of broad-spectrum pesticides that kill natural enemies, and or to the presence of large number of ants (Biovision, 2010).

Citrus leafminer is likely to cause damage in nurseries and new plantings because the growth of young trees is retarded by leafminer infestations (University of California faculty specialists and farm advisers, 2011). The young stages of citrus whitefly produce large quantity of honeydew

that leads to the growth of sooty mould on the infested trees. This may cause defoliation, loss of fruits and dwarfing of trees. The adults of this whitefly resemble small white moths, covered with mealy white wax. Eggs are laid on the lower surface of young leaves. The young stages resemble soft scale insects and have a woolly appearance. They produce large quantity of honeydew that leads to the growth of sooty mould on the infested trees. This may cause defoliation, loss of fruits and dwarfing of trees (Biovision, 2010). Caterpillars of swallowtail butterfly (*P. demodocus*) feed specially on the new flush growth of citrus trees. The caterpillars sometimes defoliate the trees, and all stages feed at the edge of either flush or hard leaves. Although defoliating caterpillars and beetles do not usually cause significant effect on crop yield, they can cause extensive damage to young trees, thus retardation (Hill and Waller, 1988b) especially in citrus nurseries where their feeding can cause complete defoliation of the plant. The fruit boring flies and caterpillars can cause damage in that each infestation means a ruined fruit, and the adult insects are difficult to kill (Hill and Waller, 1988b).

2.3 Effect of natural enemies on insect pests

Natural enemies or farmer's friends are animals that predate or parasitize on other animals such as ladybird beetle, bird or spider feeding on pest insects (Biovision, 2010). Other natural enemies include lacewings, hover-flies, predatory bugs, preying mantis, predatory wasps, and parasitic wasps. The adults and larvae of ladybird beetles are important predators of aphids. A single ladybird can eat 200-300 aphids over its lifetime (Biovision, 2010). Ladybirds can also prey on leafhoppers, mealybugs, mites, scales, and whiteflies. Hill and Waller (1988b) noted that in most cases aphids and scale insects are kept under control by natural predators and parasites. The lacewings feed on mites and soft-bodied insects, especially aphids, mealybugs, scales

whiteflies, small caterpillars, and insect eggs, while predatory bugs are important predators of thrips, mites, aphids, insects eggs and small caterpillars (Biovision, 2010). As mentioned earlier, pest problems can be controlled effectively with the help biological control agents. This is because the bio-control methods and agents usually help to decrease the level of pests rather than to eradicate them. This natural interaction helps to keep ecosystems in a balanced and stable state.

Natural enemies can be categorized as predators, parasitoids or pathogens. Predators catch and eat other insects and mites, including pest species (their prey). Parasitoids lay eggs in or on other species of insect (called hosts) and the larval stage kills the host as it feeds on it and develops, while pathogens cause diseases to arthropod pests, thus killing them. They include fungi, nematodes, bacteria, viruses, and other microbes. Indigenous biological control agents such as parasites, predators, and antagonists generally prevent large-scale outbreaks of pests (Kiss and Mearman, 1992). As noted earlier outbreaks of pests do occur when the ecological equilibrium is disturbed-for example by some types of agricultural practices. Farmers can help to keep the balance of ecosystems and natural enemies in their favour by avoiding harming predatory insects such as ladybirds, spiders and hoverfly larvae which feed on plant-eating pests such as aphids and caterpillars. This can be achieved through use of selective pesticides, if pesticides are unavoidable, and providing suitable habitat like mixed cropping. Insect pests and some ant species cause severe damage to crops, while others attack buildings, thus causing ecological and health impacts. Many attempts to control such pests, mainly with the use of chemical pesticides have always not succeeded. Biological control is the alternative to chemical control and has gained great prominence in research (Moiri *et al.*, 2012). Fungi and nematodes are some of the

successful organisms controlling insects. A study conducted by Fernanda *et al.* (2012) revealed that entomopathogenic nematodes, *Heterorhabditis sp.* and the fungi *Beauveria bassiana* can be used to control ants.

2.4 Effect of insecticides on the ecosystem

Pest management should aim at keeping pests below economic injury levels rather than eliminating them. Intensification of farming systems has generally resulted in increased pest problems because it involves adoption of practices such as monoculture, elimination of crop rotation, and use of high-yielding varieties (Kiss and Mearman, 1992). This therefore means that in case of pest emergence the problem will be dealt with by application of pesticides. Many farmers react to reduced effectiveness by increasing application frequency, applying pesticide doses well above the advised concentrations, or using more aggressive pesticide (Kasarani, 1989). This raises levels of pesticide residues in the harvested product. The situation can lead farmers enter into the pesticide treadmill of increasing costs and decreasing effectiveness of pest control as well as environmental contamination. Some chemicals have a long life and in the process of going underground the chemical or its residues are carried along and may poison ground water reserves which people use. The use of chemical pesticides has also brought environmental pollution. Carson (1962) documented detrimental effects of pesticides on environment, and particularly on birds whose singing noise could no longer be heard. DDT was widespread used after World War II to control lice and insect-borne diseases and insect crop pests. For stored products, the use of synthetic chemical insecticides is either not permitted or restrictively used because of the residue problems and risk to consumers (Rajashekar *et al.*, 2012). For that matter, there is need to utilize pesticides derived from plant extracts, which can

provide suitable alternatives to synthetic chemical pesticides for pest management. According to Bull (1982), cited in van Alebeek (1989), it has become clear that, in the long term, large scale use of non-selective chemical crop protection causes severe problems, which are more important and pronounced in developing countries. Carson (1962) believed the modern environmental practices overused pesticides, which led to the destruction of wildlife habitats. She noted that the most alarming of all man's assault upon the environment is the contamination of air, earth, rivers, and sea with dangerous and even lethal materials. Botanical pesticides are considered the best alternative to synthetic chemical pesticides in pest management because they pose no threat to the environment and human beings.

2.5 Effect of synthetic insecticides on insect pests

Citrus, like other crops is attacked by a number of insect pests. To most farmers, whenever there is an outbreak of pests in crop fields the most preferred management option is application of insecticides. Kiss and Mearman (1992) reported that in the early 1940s the chemical approach was attractive because pesticides killed pests simply and cheaply. This made the use of chemical pesticides to grow quickly and become the main type of insect pest control. However, frequent application of synthetic pesticides can result into insecticide resistance by pests. Repeated use of same class of pesticide to control a pest can result into undesirable changes in the gene pool of the pest leading to another form of artificial selection, pest resistance (Carson, 1962; Bush, 2005; Larry *et al.*, 2011). A study conducted by Hernandez *et al.* (2009) revealed that *Spodoptera exigua* larvae developed > 30-fold resistance to Cry1Ab in 13 generations. Morse *et al.* (1988) observed that several pyrethroids would be registered for citrus thrips control by 1990-91. Indeed these pesticides have been manufactured and used against thrips but instead the pesticide

resistance has kept increasing. Frequent applications (up to 30 per season), (Kasarani, 1989) have created pesticide resistance in whiteflies, and red spider mites. Dimethoate (an organophosphate) field failures caused by resistance have been documented (Morse and Brawner, 1986; Immaraju *et al.*, 1989). It has also been noticed that leaf miner species have become established and are causing serious problems to crops because many of the chemical control options are not very effective. Thaddeus (2009) noted that leaf miners are resistant to most insecticides used in citrus insect pest control. Kasarani (1989) observed that indiscriminate and intensive use of pesticides increases the risk of resistance in pests and diseases. This is supported by Erdogan *et al.* (2012) who reports that broad-spectrum insecticides/ miticides that have been used to control mites on flowers, vegetables and fruit crops are no longer effective due development of resistance.

2.6 Effect of synthetic insecticides on natural enemies

According to Kiss and Mearman (1992) the use of chemical pesticides grew quickly and became the main type of insect and other invertebrate pest control. As previously mentioned in the early 1940s the chemical approach was attractive because of the synthetic pesticides being able to kill pests simply and cheaply. By 1960s, however, serious problems began to emerge which brought this unilateral chemical approach into question (Kiss and Mearman, 1992). The impact of pesticides on the natural enemies of the target pests also undermined their long-term effectiveness. Beneficial insects die along with the targeted insects (Kasarani, 1989). The removal of predators and parasites, many pest species returned at much higher numbers, pest resurgence (Kiss and Mearman, 1992). Many pest problems in conventional citrus production are related to the almost complete elimination of natural enemies through the excessive use of

synthetic pesticides (Biovision, 2010). For example outbreaks of citrus scales are generally related to the use of broad-spectrum pesticides that kill natural enemies. It is important to note that pesticide applications should not adversely affect existing natural control of the pest population. It is desirable that knowledge of the local predators and parasites of key pests be documented so that whenever possible, existing levels of natural control may be maintained in addition to artificial control measures that are being applied (Davidson and Lyon, 1987). Mealybugs on citrus are frequently under effective control by a wide range of natural enemies that include parasitic wasps, lacewings, and ladybird beetles and do not cause economic damage. However, if the natural balance is disturbed by application of pesticides or by presence of ants, which scare away the natural enemies, mealybug population may increase to damaging levels. In Kenya, where no insecticides are used (Kiss and Mearman, 1992), particularly the large-scale coffee farmers, there is adequate control levels of insects pests by natural enemies. Kiss and Mearman (1992) reported that indigenous species of insect pests, which had previously been economically insignificant, emerged in an important role (secondary pests) due to chemical pesticide use. It was also reported that on a local level, chemical control could provide impressive short-term results but, over a long-term, costs went up and effectiveness went down (Kiss and Mearman, 1992). The value of the product obtained may sometimes be just equal to that of the chemical input. Small holder farmers, who use these expensive chemicals, usually do not break even (Kasarani, 1989). For big trees like mangoes and citrus most farmers use knapsack sprayers which do not cover the tall trees, thus farmers waste chemicals/ money with no effective pest management. Rapid increase in the use of chemical pesticides has been unable to offset crop losses to insect pests and has in many instances been regarded as the major contributing factor to pest problems. From this view point many entomologist and

environmentalists have observed that continued reliance on chemical pesticide use could lead to serious repercussions that could be irreversible.

In a study conducted to determine the insecticide toxicity to pest insects and natural enemies (Gang *et al.*, 2007) it was found out that Piperonyl butoxide (PB), an insecticide, exhibited low toxicities to the herbivorous pest insects and ladybirds, but high toxicities to the eight parasitoids. On the other hand, however, some pesticides, especially mineral pesticides like copper oxychloride are easily biodegraded and are said to have no or less effect on the prevalence of natural enemies. Hill and Waller (1988b) mentioned that a general guideline is to avoid spraying pesticides whenever possible for almost invariably the natural enemies suffer more than do the crop pests. Biological control is strongly recommended whenever possible.

2.7 Effects of natural pesticides on beneficial organisms and citrus insect pests

Many herbaceous plants have been recognized as having properties to control insect pests in crops. Some of these can kill the pest, repel or cause stomach disorder of the insect when eaten (Biovision, 2010). Most common plants with such properties include neem, moringa, artemisia, black jack, tephrosia, marigold, tithonia, tomato and tobacco leaves, hot pepper, phytolaca dodecandra and getropha sapa. Others are *Ocimum* spp., horse radish tree (*Moringa leifera*), ginger (*Zingibar officinale*), and red river gum (*Eucalyptus camaldulensis*) (Bussaman *et al.*, 2012).

Several plants have been found to contain bioactive compounds with a variety of biological actions against insects and mites, including repellants, antifeedant, anti-ovipositional, toxic, chemosterilant and growth regulatory activities (Bussaman *et al.*, 2012).

The plant neem (*Azadirachta indica*) has over 100 compounds with pesticidal properties; the best known is azadirachtin (Biovision, 2010). This substance is found in all parts of the tree. It acts as a broad spectrum repellent, insect growth regulator and insect poison. Neem extracts do not kill insect pests immediately. They change the feeding behaviour and life cycle of the pests until it is no longer able to live or reproduce. The effect of neem as a pesticide depends on the concentration of the active principles, on the formulation, on the pest type and on the crop. Therefore, neem extracts are not immediately effective. Effects are often not visible before 10 days after application (Biovision, 2010).

According to Biovision (2010) adults of predatory insects are apparently not affected by dosages of neem products recommended for effective pest control. However, their activity, fecundity and longevity may be negatively affected with high dosages. Hoverflies, for example, are one of the most sensitive groups to neem applications. Parasitoids are in general less sensitive to neem products than predators. However, especially in very small species of parasitic wasps, treatment of the developmental stages of the host, for instance eggs or puparia of whiteflies, may have negative effects on the emergence rate, walking ability, searching ability, longevity and fecundity of the natural enemy (Biovision, 2010).

Neem is believed to control nematodes, aphids, caterpillars, beetles, scales, mealybugs, whiteflies, and thrips. Neem products reduce fecundity and longevity of flies and disrupt the

development of maggots (Biovision, 2010). Experiments in Sudan showed that spraying aqueous neem seed and neem leaf extracts 3 times at weekly intervals, starting directly after tuberisation reduced early infestation by cutworms on potato leaves (Siddig, 1987). Neem oil extract was found effective in controlling bark beetles (*Ptyogenes chalcographus* L.) (Institute for Scientific Co-operation, 1991). Marigold is said to be used in the control of aphids, caterpillars, flies, nematodes; tephrosia controls aphids; tithonia controls aphids, bollworms, and bean weevil, while phytolacca dodecandra and getropha sapa (*Kilowa*) control aphids and diamond back moths. Onions and garlic are belived to repel aphids, caterpillars, and cabbage worms and tomato leaves are good repellants of cabbage worms and diamond back moths. The use of plant extracts for controlling agricultural pests has become increasingly popular in the recent years (Bussaman *et al.*, 2012). Extracts from rhizomes and leaves of *Curcuma xanthorrhizai* and *Ocimum sanctum* respectively resulted in 100% mortality of mushroom mite (Bussaman *et al.*, 2012). According to Liu *et al.*, (2004) ethanol extracts of *Eupatorium adenophorum* can cause mortality of citrus red mite (*Panonychus citri*) to over 70%.

Fumigants in greenhouse with essential oils of *Camimum cynimum*, *Origanum syriacum* and *Artimisia annua* cuased 100% mortality of carmine spider mite (*Tetranychus cinnabarinus*) and Hawthorn red spider mite (*T. viennensis*) (Tunc and Sahinkaya, 1998; Wu and Fan, 2008). Chayengia *et al.* (2010) noted that volatile oils of *Citrus reticulata* and *C. longa* could cause mortality of *Sitophilus oryzae* as high as 100 and 90% respectively. A study conducted by Erdogan *et al.* (2012) to determine the efficacy of extracts from plants against mites yielded high mortality.

In some cases, preventive and bio-control measures are not sufficient and the damage by a pest or a disease may reach a level of considerable economic loss. This is when direct control measures with natural pesticides, such as pyrethrum, derris, neem, soaps, mineral and plant oil as well as mass trapping and confusion techniques may become appropriate (Biovision, 2010).

It should also be noted that most of the natural pesticides used to control pests are broad spectrum and perhaps may, thus, have negative effect on the beneficial organisms, especially when used in quantities and concentrations that may exceed the minimum levels. For pest management it is cheaper and safer to the environment to use biological methods (Davidson and Lyon, 1987).

2. 8 Effect of weather on citrus insect pests and natural enemies in citrus orchards

Pests increase in numbers when weather and other conditions are right (Kiss and Mearman, 1992). Knowledge of plant varieties and species density-environmental relationships provides insights on how to predict and manage pest populations in the field (Teodoro *et al.*, 2008). In the more humid tropics, high temperatures and humidity without cold winters or long dry season provide ideal conditions for reproductive, survival and dispersal for many potential pest species (Kiss and Mearman, 1992). Either directly or indirectly, climatic factors control pest numbers (Hill and Waller, 1988a). Understanding pest density patterns in the field is important to account for distinct environmental variables potentially influencing populations across different habitat types (Teodoro *et al.*, 2008). Studies conducted by Baker *et al.* (2006) on the influence of relative humidity (R.H.) and temperature on the survival rate and fecundity of coffee berry borer (*Hypothenemus hampei*) indicate that high R.H. (93.5%) and low temperature (20°C) influenced

higher survival rates. Maximum fecundity was also obtained at 90-93.5% R.H. A study conducted by Marchioro and Foerster (2012) on *Plutella xylostella* L. indicates that temperature affects the length of pre-oviposition after adult emergence, oviposition period, longevity, total fecundity and egg viability. Egg production and oviposition period decreased at temperatures below 15°C and above 25°C. It also reveals that population growth increases with temperature from 10°C to 25°C and starts to decrease with temperature above 28.6°C. A study conducted by Tumwine (2008) established that climatic factors, mainly temperature and rainfall influence insect pest populations in arabica coffee.

Several ecological factors influence populations of scales and mealybugs directly or indirectly. Many records refer to increase in populations in periods of relative drought. *P. citri* population, for instance, was observed to markedly increase in periods of dry weather (Bernard, 1926) and to attain its peak three to four months from the beginning of the dry season (Betrem, 1936). In Java, incidence of striped mealybugs (*F. virgata*) was also noticed to be favoured by dry weather (Bernard, 1926) and peak population also occurred in the dry season (Begemann, 1929). A study done by Rahmathulla (2012) on the effect of weather on silkworm growth found out that increased temperature during silkworm rearing particularly in late instars accelerates larval growth and shortens the larval period. It also notes that at low temperature, the growth is slow and larval period is prolonged. Besides increase in population of mealybugs during dry weather, ant-tending increases densities of the obscure mealybugs (Kent *et al.*, 2007). A study conducted on effects of rainfall to coccid insects (Moran and Hoffman, 1987) reveals that most of the colonies of the insects are found on sheltered parts of the plant. Natural rainfall washes off wax

from coccid insect bodies and thus exposes them to biological control agents (Moran and Hoffman, 1987).

Most studies have concluded that insect pests will generally become more abundant as temperatures increase (Raymond, 1998). This is in agreement with the earlier study by Jonathan and Thompson (1990) who noted that increase in temperature leads to higher feeding rates and faster development rates. Gordon (1989) found out that adult emergence is synchronized by favourable summer temperatures of about 33°C. On the other hand, Jose and Carlos (1993) said that rainfall may cause considerable drift in the emergence of early instars and a decrease in the feeding activity. This has been supported by Masahide (2007). However, according to Basset (1991) minimum temperatures, rainfall and relative humidity influence arthropod activity. He added that seasonal pest ranges are significantly related to food resource availability in time, and the environment.

In some insects, larval survival, growth rate and pupal weight are reduced, and development time increased when they are fed on foliage from plants of water stress (Grant and Edward, 1990). Plant physiology and growth characteristics are also influenced by climatic conditions, which in turn influence the nutritional content of the plant. Scheirs *et al.* (2002) noted that some phytophagous insects prefer and perform better on phenologically young plants than old plants.

It can be noted that changes in average temperature and rainfall as a result of climate change will influence population dynamics of insect pests. The distribution, abundance and effect of insect pests on crop plants in some parts of the world will equally be affected.

CHAPTER 3

MATERIALS AND METHODS

3.1 Site location and description

The study was carried out on-station at Ngetta Zonal Agricultural Research and Development Institute (Ngetta-ZARDI). The Institute is found in Lira District, located 356km north of Kampala city, 6 km along Lira - Kitgum road, mid-northern agro-ecological zone of Uganda. According to National Agricultural Research Organization (2001) the mid-northern agro-ecological zone of Uganda is composed of Lira, Kole, Oyam, Apac, Dokolo, Amolator, Aleptong, and Otuke Districts. The physical factors namely rainfall distribution/ water availability soils and landforms, social economic factors such as population and infrastructure influence farming systems. Rainfall distribution, soils and landforms are responsible for the ecological divisions of the country resulting into regions as unimodal, bimodal, montane and semi-arid (National Agricultural Research Organization, 2001). These factors also determine the number of growing seasons, seasonal length, type of crops, natural vegetation and biodiversity.

The latitude of the study site is 2⁰ 17'N and its longitude is 32⁰ 56'E. It receives annual mean rainfall of 1305.3mm, and average temperature of around 30.43°C. The place has an altitude of 1170.1m above sea level. The soils are sandy-clay loams and in the south near Lake Kioga alluvial clays of medium fertility are found. The vegetation is predominantly *Hyperthermia* Savanna grasses (National Agricultural Research Organization, 2001).

3.2 Experimental design

The study was super-imposed on the already established citrus field which was planted at Ngetta ZARDI in 2009. A natural pesticide, neem leaf extract and dimethoate, a synthetic pesticide were used in the study. The natural pesticide was formulated from local material, that is, Neem leaf extract, while the synthetic pesticide was Dimethoate. Neem leaves were ground and mixed with equal volume of water, aqueous neem leaf extract 50%, strained and soapy water added (Figs.1. a-d below).



Fig. 1 a) Freshly collected neem leaves for biorational extraction



Fig. 1. b) Neem leaves being crushed in a mortar to extract biorational



Fig. 1. c) Crushed neem leaves mixed with water in a bucket and left overnight (covered)



Fig. 1. d) Researchers filter neem leaf extract for field application on citrus insect pest

The treatments were applied on seven (7) lines of the improved citrus varieties, with 5 plants in each line, forming a plot.

Three different levels of concentration were formulated from each pesticide. For Neem leaf extract, the three concentrations were 1 litre of neem per 10 litres of water, 2 litres of neem per 10 litres of water and 5 litres of neem per 10 litres of water. The Dimethoate concentrations were 0.001 litres per litre of water, 0.002 litres per litre of water, and 0.003 litres per litre of water. These formed 6 experimental treatments and were applied on five plants in a plot at an interval of 3 weeks. This interval was thought ideal based on the lifecycle of major insect pests of citrus and practical application of chemical pesticides by smallholder farmers to manage citrus insect pests. Whereas the conventional chemical pesticide use in the management of citrus insect pests may recommend pesticide application at 2 weeks interval, this is often not consistently followed by majority of the farmers due to socio-economic factors. One line (plot) out of the 7 lines was not sprayed and this formed the control. Randomized complete block design (RCBD) was used, with 3 blocks, each composed of 7 plots replicated three times. Inter plant and inter row spacing was 5M×5M respectively.

3.3 Data collection and tools

Data collection was done by counting of insects/damage and the natural enemies present before each application of the pesticides. The tools used in data collection included pens, data sheets, and a camera for taking photographs. Data was collected for a period of 8 months, from Oct, 2011 to June, 2012.

Data collection concentrated on the following parameters:

- Type of insect pests causing damage in each treatment;
- Population estimates of each pest on plants;
- Severity/level of damage caused to the plants by different pests, based on the 0-5 ranking;
and
- Number of different natural enemies present in each experimental treatment.

Assessment of insect pests was done by physical observation of pests in the entire tree canopy of leaves, branches and stems of each of the 5 citrus trees in the plot and counting or estimating the number of the pests on the tree. Severity of infestation was determined on a scale of 0 to 5, where: 0= no pest damage seen (0% infestation); 1=very low pests damage (1-15% infestation); 2= low pests damage (16-34% infestation); 3= moderate pests damage (35-59 infestation); 4 = high pest damage (60-70% infestation); and 5= very high pest damage (71-100%).

The population of natural enemies was determined by physical observation and counting their numbers present in each of the citrus tree canopy and recording the observations. Mean observations per plot were calculated from the collected data and entered into excel spread sheet for analysis and or description. Climatic data was obtained from the meteorology department at Ngetta Zonal Agricultural Research and Development Institute.

3.4 Data analysis and reporting

The data collected was analysed using one way ANOVA, with SAS statistical analysis package for treatment levels. The means were separated using Least Significant Difference (LSD)

($P \leq 0.05$). Descriptive statistics of excel was also used to illustrate the efficacy of the natural and synthetic pesticides on major citrus insect pests and their effect on the prevalence of natural enemies as well as the influence of climatic factors, that is, rainfall and temperature on the population and incidence of insect pests and natural enemies. These included line and bar graphs as well as tables.

3.5 Limitations of the study

The citrus plants in the experimental field had some age and size disparity. This was thought to have some effect on the natural interaction of living entities in the agro-ecosystem. There was also a severe dry condition, though anticipated, it was more prolonged and lasted for 4 months, from December, 2011 to March, 2012. This dry weather experienced in zone had a negative effect the growth rate and development of the citrus plants. However, measures were devised to water and mulch around the most affected plants to reduce the negative impact of the dry weather on the plants. Despite the interventions to mitigate the effect of the dry weather condition some 4 citrus plants wilted and dried up, but these were subsequently replaced. There were added costs in the maintenance of the experimental field due to hiring of labour to water plants during the prolonged drought that was experienced.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Major insect pests of citrus observed in the experimental field

During the study six major insect pests of citrus were recorded. They include aphids (*Toxoptera citridus*), hard/ armoured red scales (*Aonidiella aurantii*), the soft brown scales (*Coccus hesperidum*), citrus leafminer (*Phyllocnistis citrella*), the swallowtail butterfly or orange dog (*Papilio demodocus*), citrus mealybugs (*Planoccous citri*), and citrus woolly whitefly (*Aleurothrixus floccosus*). Black attendant ants were found in association with aphids, brown scales, and mealybugs. The ants are attracted to these insects because of the honeydew they produce, and it is said that these ants may carry the insects from place to place, thus furthering their spread (Davidson and Lyon, 1987). They are also of importance because they destroy both eggs and active forms of predators and parasites, besides scaring away the natural enemies and protecting the insects they associate with. Insect pests recorded on citrus plants during the study period are shown in (Figs 2-6).

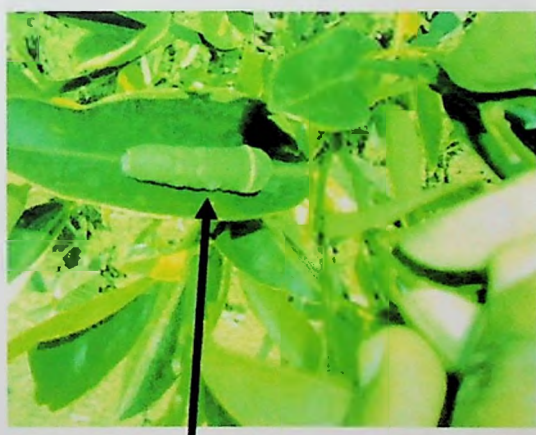


Fig. 2. a) Fully grown orange dog (*Papilio demodocus*) caterpillar



Fig. 2. b) Fourth instar orange dog larva



Fig. 2. c) Second instar larva of orange dog



Fig. 2. d) Citrus leaves infested with aphids, deformed



Fig. 2.e: Citrus leaves damaged by orange dog larvae



Fig.3: Armoured red scales (*Aonidiella aurantii*) on citrus plant



Fig. 4: Mealybugs (*Planoccous citri*) on Citrus leaf with attendant ants



Fig. 5: Citrus woolly whitefly (*Aleurothrixus floccosus*) leaf infestation



Fig. 6. a). Leaf damaged by leaf miner (*Phyllocnistis citrella*)



Fig. 6. b) Reduced leaf surface area due to leaf miner

4.2 Major natural enemies observed in the citrus experimental field

Several natural enemies were reorded in the citrus orchard during the study. The most prevalent ones include spiders, lady bird beetles, and preying mantis as shown in Figs. 7-8 below.

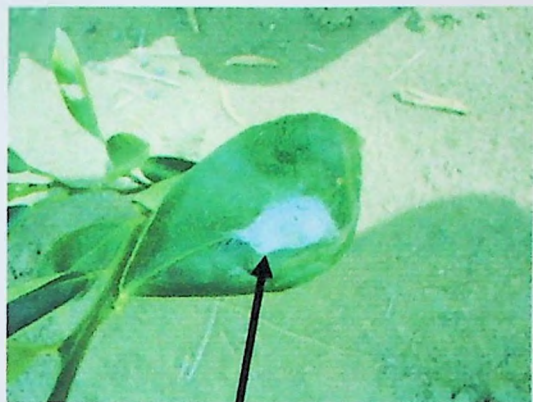


Fig. 7. a) Spider in a cocoon on citrus leaf



Fig. 7. b) Spider emerges from a cocoon

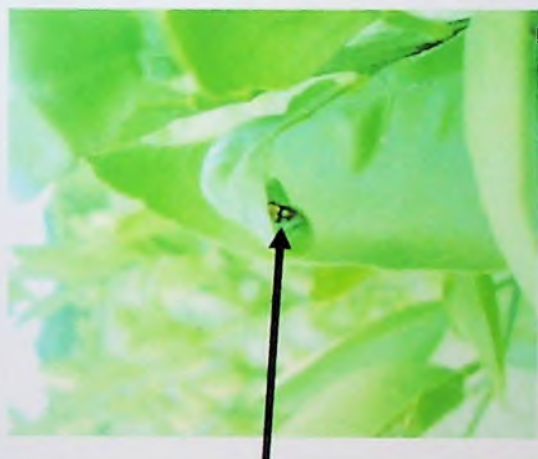


Fig. 8. a) lady bird beetle rests under a rolled citrus leaf



Fig. 8.b) A lady bird beetle on an orange branch



Fig. 8. c) Preying mantis on citrus leaf

4.3 Variation of insect pest severity and natural enemies prevalence on citrus orchards.

Results revealed that there were variations in some insect pests severity between different experimental treatments, while in others there were no significant variations (Table 1). However, overall effect of the treatments had significant effect ($P \leq 0.05$) on insect pests.

Table 1: Analysis of variance (ANOVA) for insect pests

Variables	Source	DF	S. of squares	M. squares	F value	P value
Aphids	Treatment	24	7.94	0.31	2.42	0.0005
	Error	184	23.87	0.13		
	Total	208	31.41			
Scales	Treatment	24	16.8	0.7	3.38	0.0001
	Error	184	38.1	0.21		
	Total	208	54.9			
L. miner	Treatment	24	74.47	3.1	4.6	0.0001
	Error	184	124.2	0.68		
	Total	208	198.69			
O. dog	Treatment	24	35.98	1.5	2.77	0.0001
	Error	184	99.68	0.54		
	Total	208	135.66			
M. bug	Treatment	24	10.32	0.43	11.32	0.0001
	Error	184	6.99	0.04		
	Total	208	17.32			
C.W. Whitefly	Treatment	24	1.39	0.06	2.58	0.0002
	Error	184	4.13	0.02		
	Total	208	5.52			

The P values from the ANOVA table indicate that there was significant effect ($P \leq 0.05$) of the treatments on the insect pests.

4.3.1 Effect of treatments on the severity of insect pests and natural enemies' population variation

From the means (Table 2) there was no significant difference ($P \geq 0.05$) between aphids, scales, orange dog and citrus wooly whitefly severity from pesticide treatments (mean differences between treatments are less than LSD). However, there was significant difference in leaf miner

severity ($P \leq 0.05$) between neem treatment and dimethoate as well as control but no significant difference existed between dimethoate and control treatments. There was also no significant difference in mealybug severity between neem and dimethoate treatments but significant difference existed between dimethoate and control as well as between neem and control treatments (Table 2).

Table 2: Treatment means showing variation of insect pests serverity between treatments

Treatment	Aphids	Scales	L. miners	O. dog	M. bugs	C. W. whitefly
Neem	0.24a	0.56a	1.11b	1.37a	0.14a	0.07a
Dimethoate	0.22a	0.51a	1.52a	1.35a	0.12a	0.06a
Control	0.20a	0.41a	1.48a	1.27a	0.03b	0.09a
G. mean	0.22	0.49	1.37	1.33	0.1	0.07
S E	0.36	0.46	0.82	0.74	0.19	0.15
LSD (5%)	0.14 ^{ns}	0.17 ^{ns}	0.31	0.28 ^{ns}	0.07	0.06 ^{ns}
CV	161.6	88.2	61.5	54.7	168.4	230.1

ns = not significant

Means followed by different letters are significantly different at ($P \leq 0.05$)

Means followed by same letters are not significantly different at ($P \geq 0.05$)

For the natural enemies the results showed that there was no significant difference ($P \geq 0.05$) in natural enemies prevalence in all the experimental treatments (Table 3).

Table: 3 Analysis of variance (ANOVA) for natural enemies

Variables	Source	DF	S. of squares	M. squares	F value	P value
Wasp	Treatment	24	0.35	0.015	1.46	0.085
	Error	184	1.83	0.01		
	Total	208	2.18			
Spider	Treatment	24	7.36	0.31	1.49	0.076
	Error	184	37.94	0.21		
	Total	208	45.3			
L. bird	Treatment	24	1.38	0.06	0.98	0.498
	Error	184	10.86	0.06		
	Total	208	12.24			
P. mantis	Treatment	24	3.2	1.13	1.48	0.078
	Error	184	16.59	0.09		
	Total	208	19.79			

The P values from the ANOVA table also indicate that there was no significant effect ($P \geq 0.05$) of the treatments on the natural enemies. The mean differences between treatments are less than LSD (Table 4).

Table 4: Treatment means showing variation of natural enemies between treatments

Treatment	Wasps	Spider	Lady bird	P. mantis
Neem	0.03a	0.35a	0.1a	0.03a
Dimethoate	0.03a	0.34a	0.07a	0.09a
Control	0.04a	0.39a	0.04a	0.07a
G. mean	0.03	0.36	0.1	0.06
S E	0.1	0.45	0.24	0.3
LSD (5%)	0.04 ^{ns}	0.17 ^{ns}	0.09 ^{ns}	0.11 ^{ns}
CV	356	129.2	259	482

ns =not significant

4.3.2 Effect of treatment levels on the severity of insect pests and natural enemies' population variation

Results revealed that there was variation in insect pest severity among the treatment levels, except leaf miners. From the table of treatment level means (Table 3) there was significant difference between aphids and orange dog severity in neem treatment level 5:10 (5ltrs of neem:10ltrs of water) while the rest of treatment levels showed no significant difference. Scales showed significant difference in severity for dimethoate treatment level 2:1 (0.002ltrs:1ltr of water), but no significant difference existed between other treatment levels. For mealybugs the severity was significantly affected by neem treatment level of 5:10, while there was no significant difference in severity between neem 1:10 (1ltr of neem:1ltr of water and dimethoate level 1:1 (0.001ltrs of dim:1ltr of water). Neem 2:10 (2ltrs of neem:10ltrs of water) and dimethoate 2:1 (0.002ltrs of dim:1ltr of water) treatment level showed no significant effect on mealybug severity. However, there was significant effect on mealybug severity between dimethoate 3:1 (0.003ltrs of dim:1ltr of water) and other treatment levels but no difference with the control. The citrus wooly whitefly severity was significantly affected by neem 5:10 as well as dimethoate 3:1 treatment levels but no significant effect existed between neem 1:10, neem 2:10, dimethoate 1:1, and dimethoate 2:1 (Table 5).

Table 5: Means showing variation of insect pests between treatment levels

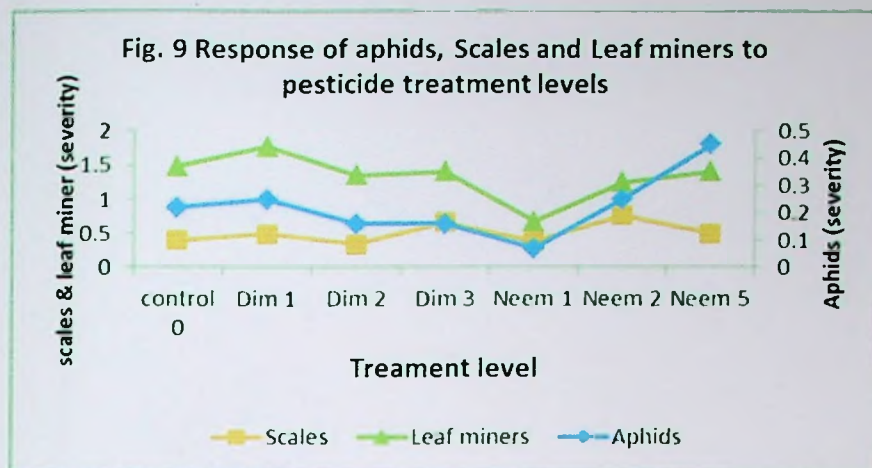
T. level	Aphids	Scales	L. miners	O. dog	M. bugs	C. W. White fly
Neem 1:10	0.16b	0.45ab	1.33a	1.5a	0.15b	0.07bc
Neem 2:10	0.19b	0.56ab	1.3a	1.42a	0.07bc	0.04bc
Neem 5:10	0.45a	0.51ab	1.4a	1.23a	0.33a	0.15a
Dimethoate 1:1	0.16b	0.45ab	1.23a	1.5a	0.15b	0.07bc
Dimethoate 2:1	0.19b	0.56ab	1.3a	1.42a	0.07bc	0.04bc
Dimethoate 3:1	0.19b	0.66a	1.41a	1.08b	0.0c	0.01c
Control	0.22b	0.41b	1.48a	1.27ab	0.03c	0.09ab
G. mean	0.22	0.51	1.34	1.35	0.11	0.07
LSD (5%)	0.16	0.21	0.38^{ns}	0.34	0.09	0.07

ns = not significant

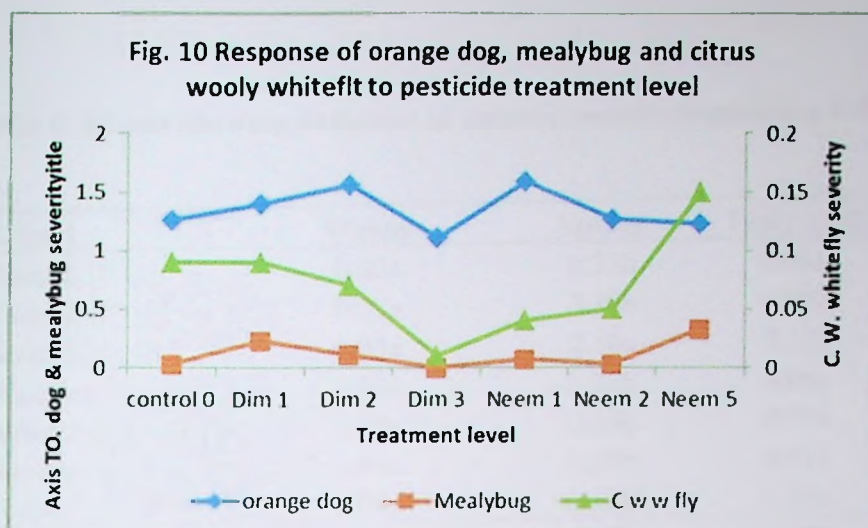
Means followed by different letters are significantly different at ($P \leq 0.05$)

Means followed by same letters are not significantly different at ($P \geq 0.05$)

For the response of insect pests to pesticide treatment levels (Fig. 9) results show that the trend of severity of aphids, scales and leaf miners was high when dimethoate treatment level of dim 1 (0.001ltrs of dim:1ltr of water) and neem 5 (5ltrs of neem:1ltr of water) were applied. This suggests that dimethoate level of 0.001ltrs of dim:1ltr of water) and neem 5 (5ltrs of neem:1ltr of water) should not be used to manage these insect pests in citrus. Fig. 9 again shows that neem at treatment level of 1:10 (1ltr of neem:10ltrs of water) generally registered the lowest severity among the insect pests, beyond which the insect pests severity started to increase again. It therefore proposes that neem at this rate of 1:10 (1ltr neem:10ltrs of water) is the most suitable for the management of aphids, scales and leaf miners in citrus orchards. It can also be noted from the figure (Fig. 9) that leaf miners were the least affected by neem at the level of 1:10 among the three insect pests.



The severity of the orange dog was highest at treatment levels dimethoate 2 and neem 1, orange dog was high at treatment levels of dimethoate 2 and neem 1, while the citrus wooly whitefly had high severity at neem 5 (Fig. 10). The figure indicate that orange dog, mealybugs and citrus wooly whitefly severity was lowest when dimethoate was applied at treatment level of 3, suggesting that this could be most suitable treatment level for managing these pests in citrus. However, it can be seen from the figure (Fig. 10) that while mealybugs and citrus wooly whiteflies could effectively be managed by applying dimethoate at the rate of 3:1, orange dog can be less effected.



Key: c w w fly = citrus wooly whitefly

Among the natural enemies, spiders and preying mantis population was significantly affected by various treatment levels (Table 6). Spider population did not show significant difference ($P \geq 0.05$) between neem 1:10 and neem 2:10 but there was significant difference between neem 1:10 and neem 5:10 as well as between neem 2:10 and neem 5:10 ($P \geq 0.05$). Dimethoate treatment levels did not significantly affect the population of spiders. However, there was significant difference in spider population between control and the three dimethoate levels. Significant difference in preying mantis population existed between neem 1:10 and neem 2:10 application, but no difference between neem 1:10 and neem 5:10. Dimethoate application levels had significant effect on preying mantis population, but no significant difference existed between application of dimethoate 2:1 and control. However, all the treatment levels did not have significant effect on the population of wasps and lady bird beetles (Table 6). This proposes that wasps and ladybirds' population may not be affected by application of these pesticides at these levels.

Table 6: Means showing variation of natural enemies population between treatment levels

T. level	Wasps	Spider	Lady bird	P. mantis
Neem 1:10	0.02a	0.33b	0.06a	0.02b
Neem 2:10	0.02a	0.29b	0.09a	0.06ab
Neem 5:10	0.05a	0.56a	0.15a	0.03b
Dimethoate 1:1	0.02a	0.33b	0.06a	0.02b
Dimethoate 2:1	0.02a	0.29b	0.09a	0.06ab
Dimethoate 3:1	0.04a	0.29b	0.07a	0.17a
Control	0.04a	0.39ab	0.14a	0.07ab
G. mean	0.03	0.35	0.09	0.06
LSD (5%)	0.05^{ns}	0.21	0.11^{ns}	14

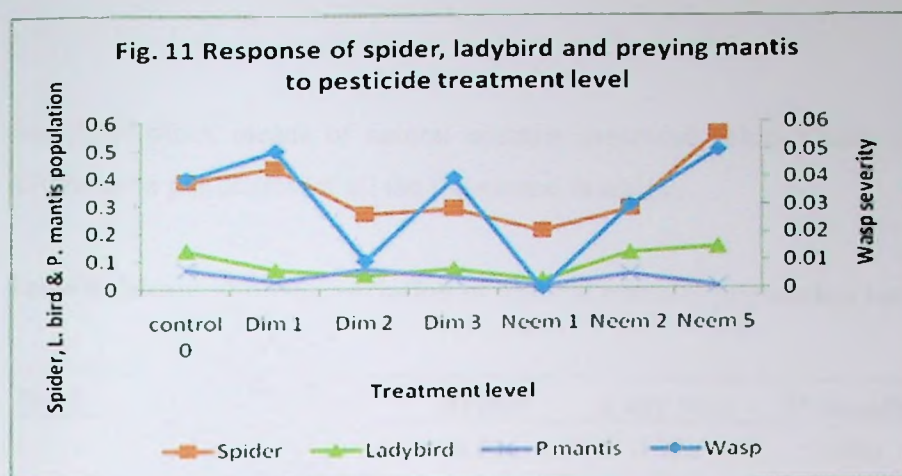
ns = not significant

Means followed by different letters are significantly different at ($P \leq 0.05$)

Means followed by same letters are not significantly different at ($P \geq 0.05$)

The population of the natural enemies varied under different pesticide treatment levels (Fig. 11).

Wasps and spiders had the highest population when dimethoate of 1:1 and neem 5:10 were applied. However, like for the insect pests, wasps, preying mantis and ladybirds had low population at neem 1 (1ltr:1 ltr of water). This result could indicate that the population of natural enemies fluctuates with the fluctuation of insect pests' population on which they prey or parasitise. It was previously seen that neem 1 treatment level reduced the severity of most of the insect pests, thus the natural enemies could not be attracted to such areas of low insect pest population. On the hand, however, as earlier reported by Biovision (2010) predators are very sensitive to neem application.



Results of block means for insect pests (Table 7) showed significant difference in scales severity between block 1 and 3 as well as between block 2 and 3, but no significant difference was detected between block 1 and 2. Orange dog and citrus wooly whitefly severity indicated significant difference in all the three blocks. Mealybugs showed significant difference in severity between block 1 and 2; and between block 1 and 3, but no difference existed between block 2 and 3. Aphids and leaf miners did not show any significant difference in severity in all the three blocks.

Table 7: Means showing variation of insect pests severity between blocks

Block	Aphids	Scales	L. miners	O. dog	M.bugs	C. W. white fly
1	0.21a	0.54a	1.19a	1.36ab	0.06b	0.03b
2	0.27a	0.67a	1.46a	1.2b	0.14a	0.11a
3	0.19a	0.34b	1.36a	1.48a	0.15a	0.06ab
G. mean	0.22	0.52	1.34	1.35	0.12	0.07
LSD (5%)	0.12ns	0.15	0.27ns	0.25	0.07	0.05

ns = not significant

Means followed by different letters are significantly different at ($P \leq 0.05$)

Means followed by same letters are not significantly different at ($P \geq 0.05$)

Results of block means of natural enemies presented below (Table 8) showed no significant difference in population of all the the natural enemies.

Table 8: Means showing variation of natural enemies population between blocks

Block	Wasps	Spider	Lady bird	P. mantis
1	0.01a	0.31a	0.07a	0.04a
2	0.03a	0.34a	0.13a	0.1a
3	0.04a	0.4a	0.08a	0.04a
G. mean	0.03	0.35	0.09	0.06
LSD (5%)	0.03^{ns}	0.15^{ns}	0.08^{ns}	0.1^{ns}

ns = not significant

Results of the plot means for the insect pests severity indicated significant differences between plots as a result of application of different treatments (Table 9). Aphids severity, for example, showed significant difference between plot 1 and 2 but no significant difference was detected between plots 1, 3-7. All other insect pests indicated significant difference in severity from various plots. This difference could justify the view that besides application of treatments, with-in a given crop field there are micro factors that affect pest behavioural patterns.

Table 9: Means showing variation of insect pests severity between plots

Plot	Aphids	Scales	L. miners	O. dog	M. bugs	C. w. whitefly
1	0.06c	0.24bc	0.42bc	1.78ab	0.0c	0.02bc
2	0.02c	0.44bc	0.64bc	1.42ab	0.0c	0.0c
3	0.8a	0.06d	0.84bc	2a	0.0c	0.0c
4	0.1ab	0.18bc	2.16ab	1.76ab	0.0c	0.02bc
5	0.2ab	0.96ab	2.88a	1.72ab	0.0c	0.14ab
6	0.1bc	0.66ab	1.6ab	1.5ab	0.0c	0.04bc
7	0.3ba	0.32bc	1.1b	1.04b	0.04bc	0.04bc
8	0.12bc	1.06a	1.04b	0.52c	0.0c	0.0c
9	0.2b	0.26bc	1.36ab	1.28b	0.04bc	0.06bc
10	0.36ab	0.62ab	1.66ab	1.46ab	0.12b	0.06bc
11	0.22b	0.9ab	1.82ab	1.34b	0.0d	0.0d
12	0.14bc	0.58ab	2.26a	1.52ab	0.28b	0.1ab
13	0.34bc	0.0c	0.76bc	1.12ab	0.08bc	0.0c
14	0.68a	0.58ab	1.44b	1.2ab	0.84a	0.34a
15	0.12bc	0.5ab	0.98b	1.58ab	0.2b	0.1ab
16	0.33ab	0.31bc	1.33b	0.82c	0.71a	0.13ab
17	0.26b	0.4bc	0.94b	1.16ab	0.06bc	0.1ab
18	0.36ab	0.74ab	1.04b	0.96c	0.0c	0.0c
19	0.24b	0.26bc	1.16b	1.62ab	0.02bc	0.02bc
20	0.38ab	0.32bc	1.48b	1.04b	0.06bc	0.16ab
21	0.1bc	0.42bc	1.16b	1.36ab	0.0b2	0.04bc
G. mean	0.26	0.47	1.34	1.34	0.11	0.07
LSD (5%)	0.32	0.4	0.72	0.65	0.17	0.13

Means followed by different letters are significantly different at ($P \leq 0.05$)

Means followed by same letters are not significantly different at ($P \geq 0.05$)

Results of the plot means of the natural enemies indicated significant difference between natural enemies' plot population. Only wasps population did not show significant difference between plots (Table 10). This trend also suggests that besides the effect of treatments applied in the various plots, there are other micro factors that influence the behaviour of living agents in a given environment. As observed earlier, besides treatments the population of natural enemies in a given environment may be influenced by the presence and numbers of insect pests on which they prey/ parasitise.

Table 10: Means showing variation of natural enemies' population between plots

Plot	Wasps	Spider	Lady bird	P. Mantis
1	0.0a	0.16c	0.02c	0.0b
2	0.0a	0.18c	0.02c	0.04b
3	0.02a	0.22c	0.0c	0.08b
4	0.08a	0.54abc	0.06abc	0.02b
5	0.08a	0.7a	0.12abc	0.02b
6	0.02a	0.36abc	0.04bc	0.02b
7	0.02a	0.54abc	0.02c	0.08b
8	0.0a	0.16c	0.08abc	0.44a
9	0.02a	0.48abc	0.14abc	0.12b
10	0.06a	0.46abc	0.18abc	0.0b
11	0.0a	0.16c	0.08abc	0.06b
12	0.0a	0.4abc	0.06abc	0.04b
13	0.0a	0.32abc	0.18abc	0.08b
14	0.08a	0.68ab	0.26a	0.0b
15	0.0a	0.28bc	0.06abc	0.0b
16	0.02a	0.44abc	0.2c	0.09b
17	0.0a	0.2c	0.1abc	0.08b
18	0.04a	0.16c	0.06abc	0.06b
19	0.0a	0.22c	0.1abc	0.0b
20	0.08a	0.32abc	0.24ab	0.06b
21	0.08	0.4abc	0.12abc	0.02b
G. mean	0.03	0.35	0.1	0.06
LSD (5%)	0.09^{ns}	0.4	0.22	0.27

ns = not significant

Means followed by different letters are significantly different at ($P \leq 0.05$)

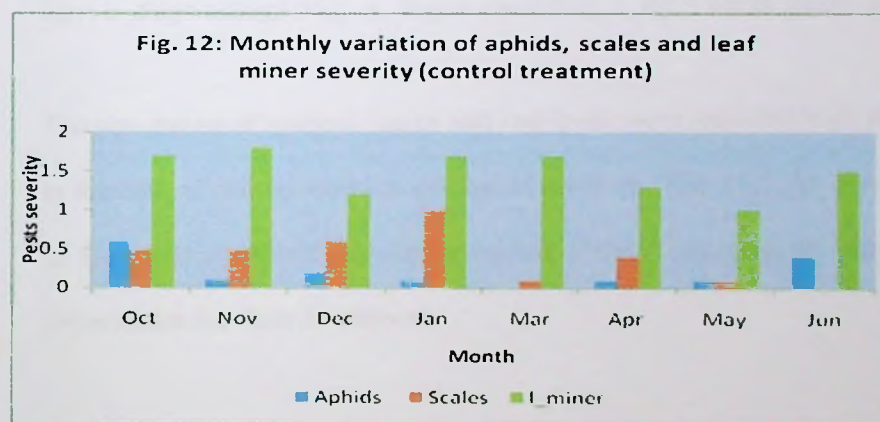
Means followed by same letters are not significantly different at ($P \geq 0.05$)

4.4 Monthly variation of citrus insect pests and natural enemies due to synthetic and natural pesticides application

The study results indicated some monthly variations of insect pests severity and natural enemies population in the different experimental treatments.

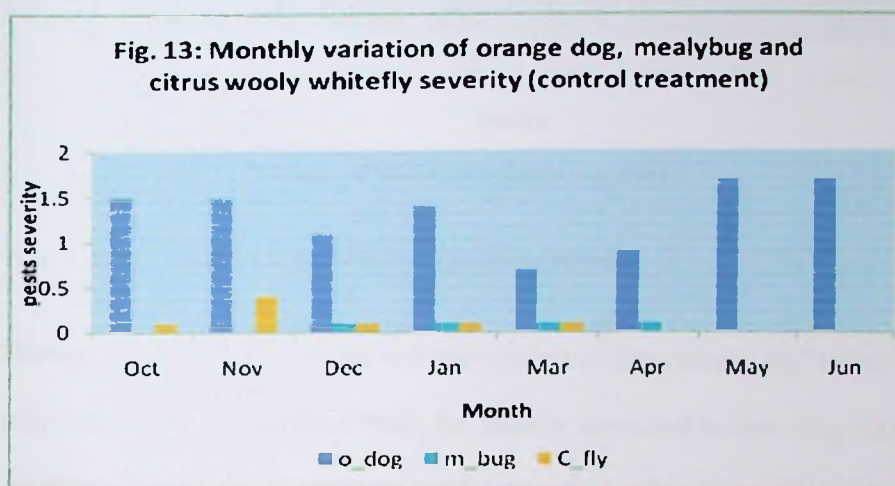
Some natural enemies like spiders appeared more prevalent in the control treatment than where neem and dimethoate were applied. The natural enemies' prevalence; however appeared to have no significant variation between dimethoate and neem treatments (Figs. 12-14).

Aphids had high severity at the start of the experiment, that is in October. This severity showed a declining trend to almost zero (0) during the month of March. This could be associated with the serious dry weather condition that prevented formation of new fresh leaves that are most preferred by the aphids. Scales severity increased as temperature increased while, rainfall decreased but reduced in the months of March. As noted earlier by Hill and Waller (1988b) the decline in aphids and scales damage could also be due to their natural predators and parasites that keep them under check. It was observed that the severity of leaf miners kept relatively high throughout the study period since they can continue to damage even the mature leaves. (Fig. 12).



In the control the severity of the orange dog kept relatively high but only lowered in the months of March and April. The decline in the month of March could be associated with absence of fresh leaves, usually preferred by this defoliating insect pest. The damage started increasing rapidly

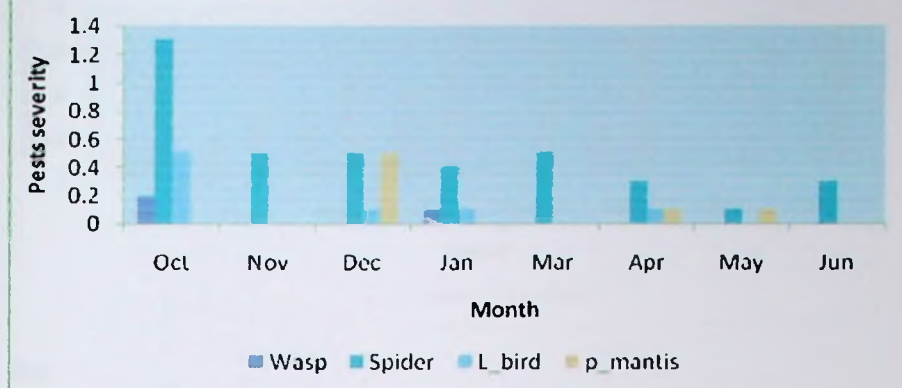
from the month of April, perhaps due to the development of fresh leaves when the rains started. The citrus wooly whiteflies and mealybugs only had their severity increased slightly in November to March thereafter declined to zero (Fig 13). This could have been due to the population check up by the natural enemies since no pesticide application was done.



Key: o_dog= orange dog; m_bug = mealybug; c_fly = citrus wooly whitefly

The population of spiders, wasps and ladybirds were recorded high at the start of the experiment in the control and appeared to decline in numbers (Fig. 14). As observed earlier, this trend may be the result of general population decline of the insect pests on which these natural agents prey or parasitise for their livelihoods.

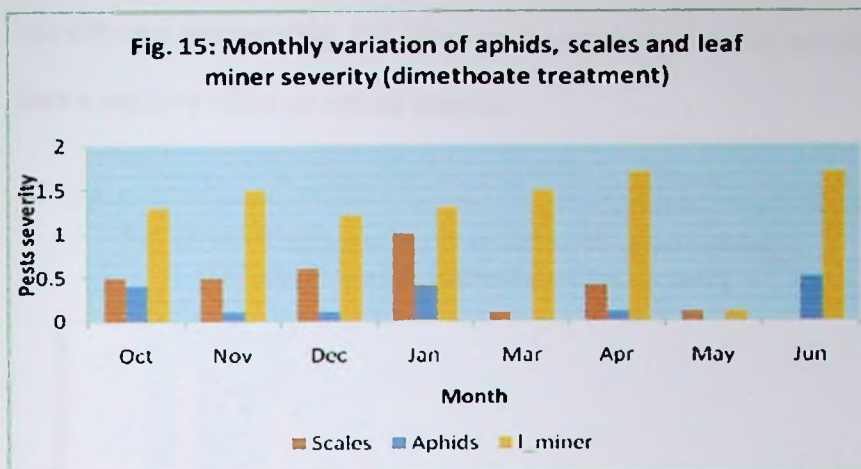
Fig. 14 Monthly variation of waps, spider, lady bird and preying mantis severity (control treatment)



Key: l_bird = ladybird; p_Mantis = preying mantis

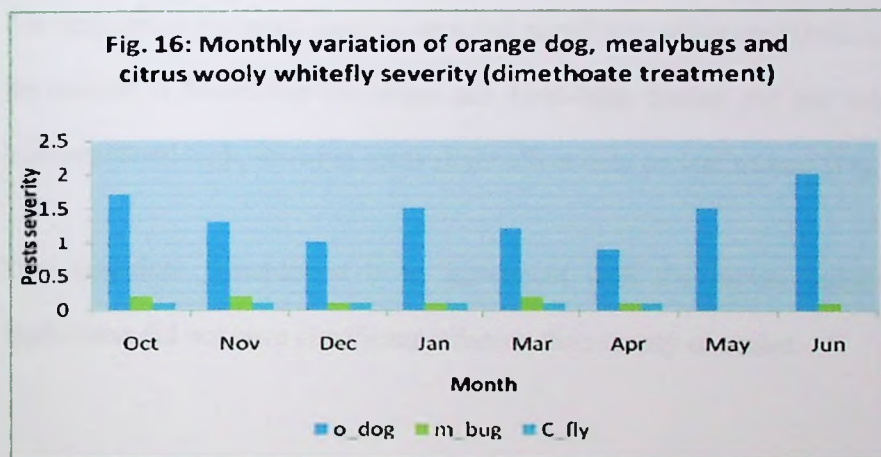
During the study period under the application of dimethoate, leaf miner severity remained high, only reduced in the month of May, but shortly increased in June (Fig. 15). This consistently high severity indicates that dimethoate application did not have significant effect on leaf miners.

The high severity of aphids and scales during the month of January could be associated with the dry weather condition, which enhances their population build up, thus high severity on the crop. This is further supported by earlier report by Marchioro and Foester (2012) that the growth of insects reduces when temperature is above 28°C.



Key: l_miner = leaf miner

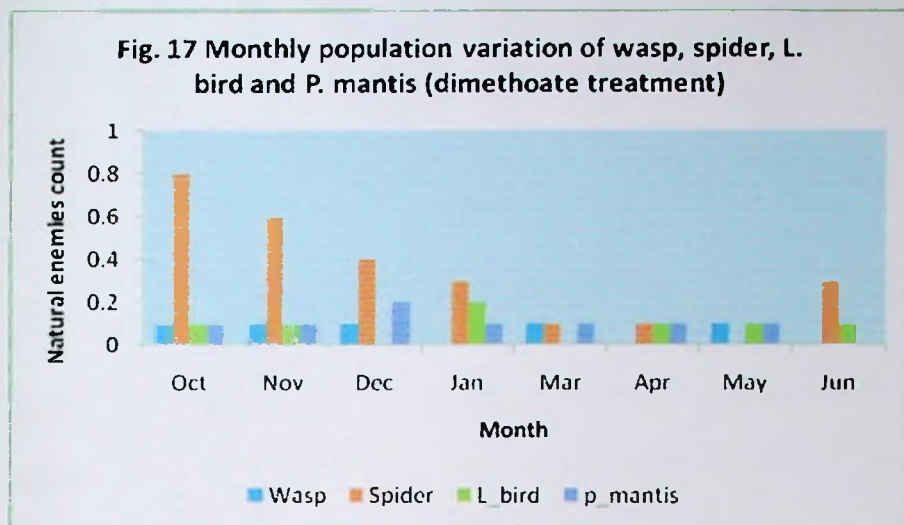
As noted before, like the leaf miners the severity of the orange dog kept relatively high throughout the study when dimethoate was applied (Fig. 16). Only mealybugs and citrus wooly whitefly severity was kept low.



Key: o_dog= orange dog; m_bug = mealybug; c_fly = citrus wooly whitefly

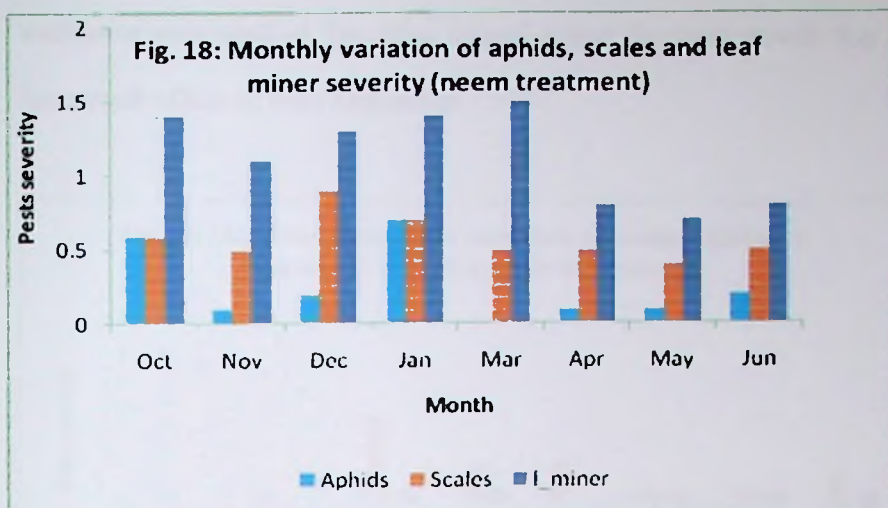
The graphical presentation of the effect of dimethoate on the population of the natural enemies in the citrus study field indicate that only spiders were somehow affected by the pesticide, while the

rest were not affected (Fig. 17). This result seem to oppose the assertion that synthetic pesticides have a negative effect on natural enemies.

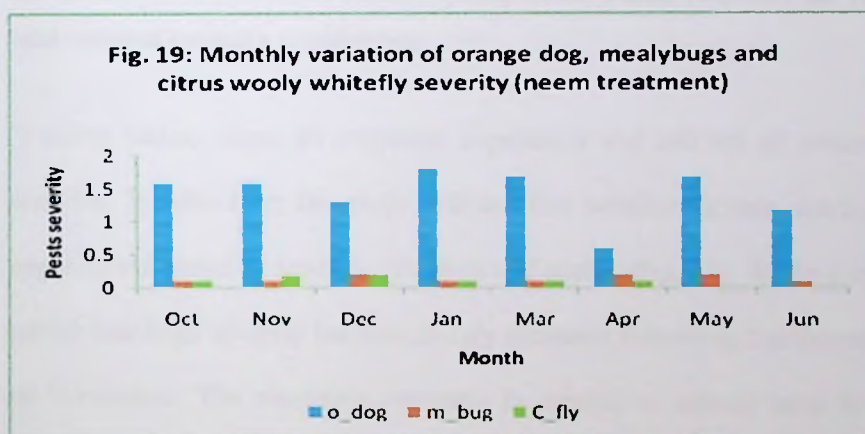


The application of neem seem to have had significant effect on aphids severity especially during the months of November-December and April-May. Scales and leaf miner severity appeared to have remained high, showing some slight effect only on leaf miners (Fig. 18).

This graphical presentation is in agreement with the earlier sttistical analysis that neem application did not have significant effect on the severity of scales.

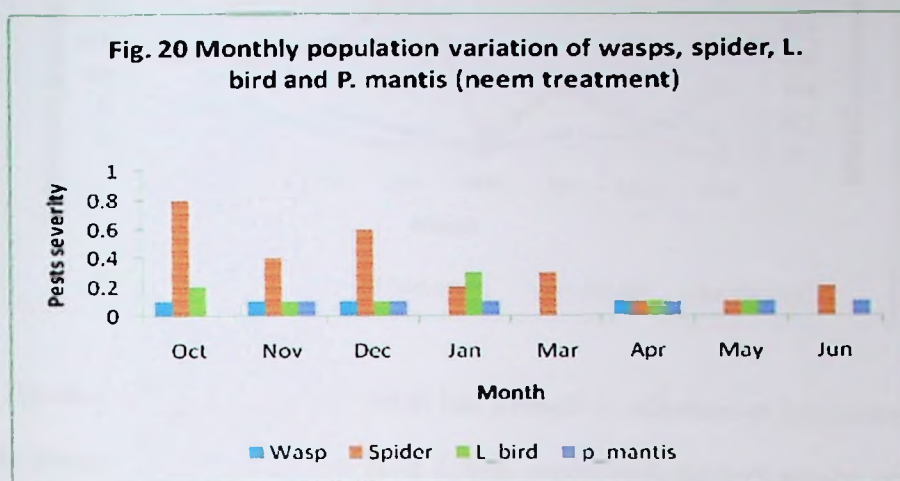


Results from monthly variation of orange dog, mealybugs and citrus wooly whitefly under the application of neem indicate generally that no significant effect existed on the insect pests. A slight effect was shown during the month of April (Fig. 19).



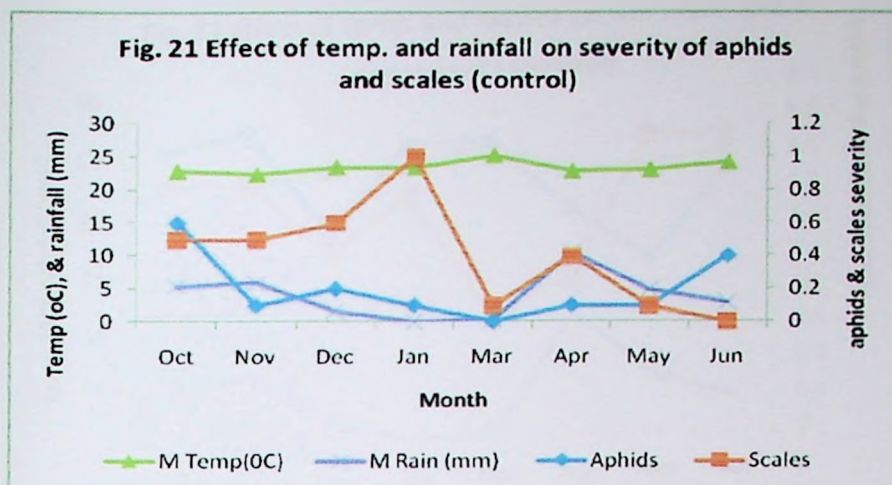
The effect of neem on the natural enemies seems to have been more significant on spider population and less on wasps, ladybirds and preying mantis (Fig.20). This is because the population of spiders, which was high at the start of the experiment reduced progressively as the

treatments were applied. For other natural agents the trend reveals that neem application did not have much effect on their population.

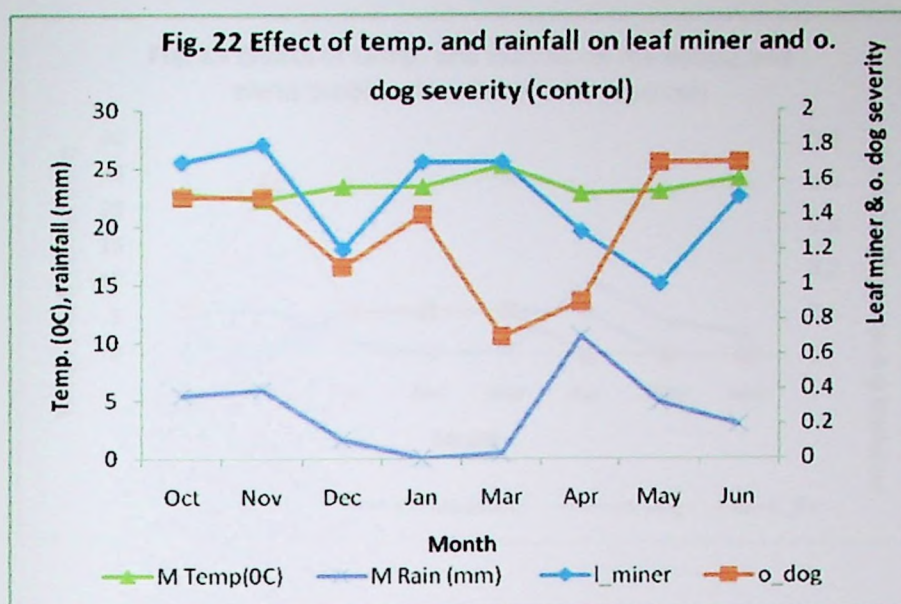


4.5 Influence of climatic factors (temperature and rainfall) on citrus insect pest damage and natural enemies population

Weather factors seem to influence population and activity of citrus insect pests and natural enemies. Results from the study indicate that weather factors, rainfall and temperature, had a negative influence on severity of aphids and scales (Fig. 21). At the start of the study, in October, aphids had high severity but this sharply decreased following the increase in rainfall in the month of November. The continuous decrease in rainfall to almost zero in January led to a drastic increase in scales' severity. This is in agreement with Moran and Hoffman (1987) who reported that coccid pests may be washed off the plant by heavy rains. Temperature appeared highest in the month of March, while rainfall amount was zero (0) mm. This excessive hot and dry weather significantly reduced the severity of aphids and scales. The severity subsequently picked up when the rains appeared.

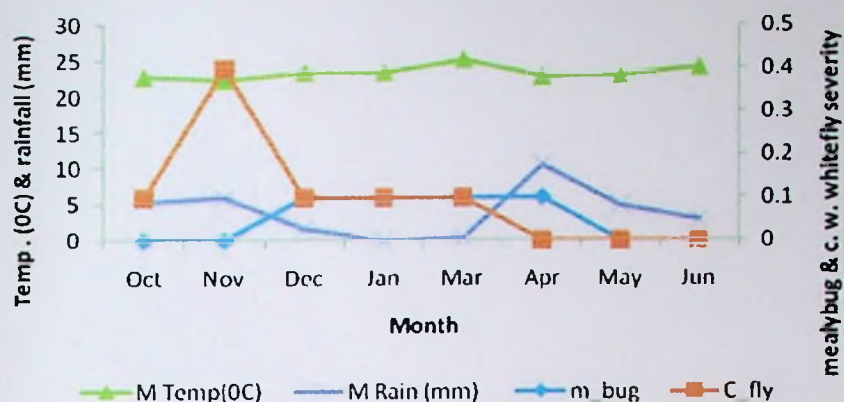


The study also revealed that rainfall had a negative influence on leaf miners and the orange dog. In January when rainfall was at its lowest record both the leaf miners and orange dog had the high severity (Fig. 22). However, while the severity of leaf miners kept high in March when the temperature was highest with low rainfall, the severity of the orange dog went down. Perhaps as noted before, this could be due to the absence of fresh leaves that are the most preferred by most insect pests.



Results showed that the severity of mealybugs started to increase in the month of November when rainfall reduced while temperature was increasing (Fig. 23). This was earlier reported by Barnerd (1926) that the population of *P. citri* increases when temperature increases. This continued up to April when rainfall increased and the severity of mealybugs declined. This justifies earlier reports that high temperature and low rainfall influence increase in mealybug population ((Bernard, 1926); Tumwine, 2008). The severity of citrus wooly whitefly was recorded highest in November and reduced. Its severity kept stable between December and March, when rainfall was lowest but reduced further in April when rainfall increased (Fig. 23).

Fig. 23 Effect of temp. and rainfall on mealybug and citrus wooly whitefly severity (control)



In the control increase in rainfall caused a decline in the population of wasps, preying mantis and ladybirds in the study field (Figs. 24 and 25). Except spiders, the population of other natural enemies reduced to almost zero (0) in the month of March when temperature was very high and with very low rainfall. This could be related to the reduction in the population of the insect pests on which these natural enemies prey, maybe forcing them to migrate to other places.

Fig. 24 Effect of temp. and rainfall on spider and wasp population (control)

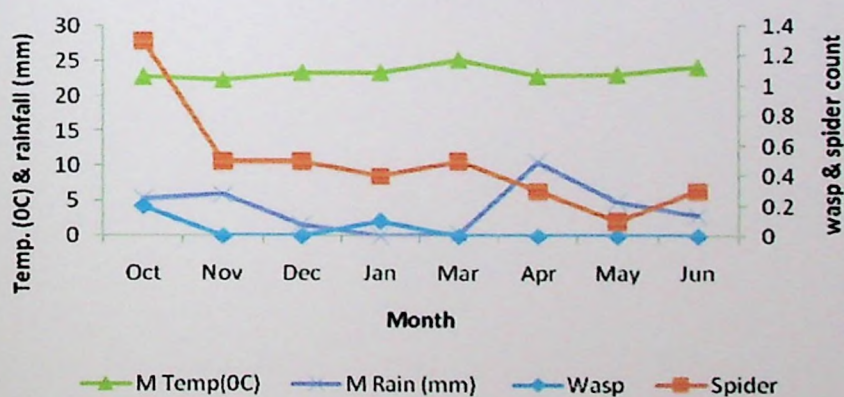
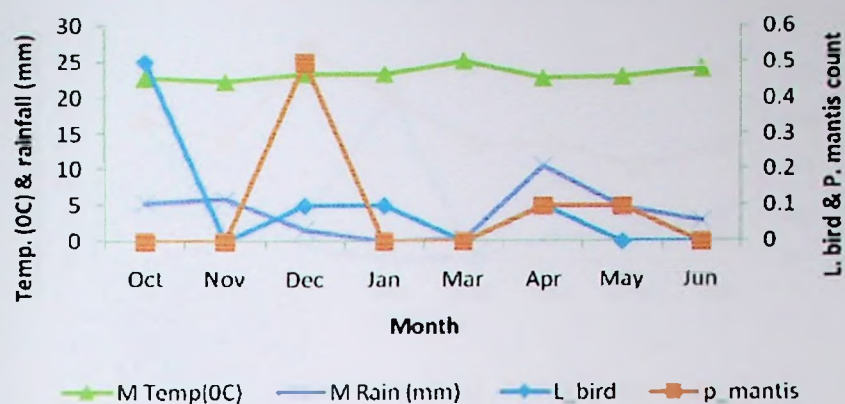
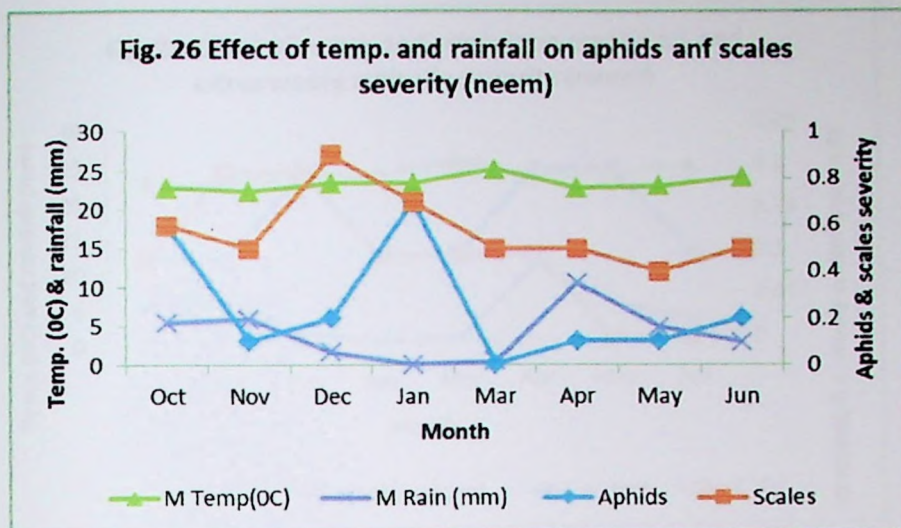


Fig. 25 Effect of temp. and rainfall on Ladybird and Preying mantis population (control)



In the neem treatment aphids, scales, leaf miners and orange dog severity increased when rainfall declined. It is believed that heavy rainfall can wash away some aphids and scales from plants, thus reducing in population as well as severity. As seen in the control treatment, increase in temperature also influenced increase in pests severity, except, for the month of March, when the temperature was highest pests (Figs 26-28). This is thought to have been due to the absence of freshly growing leaves that are preferred by the insect pests for feeding and reproduction (Schiers *et al.*, 2002).



Unlike the previous observations on aphids and scales severity that reduced during the month of March, in this treatment the severity of leaf miners and orange dog did not decline when rainfall was low and temperature high. This could be related to the low population of the natural enemies, especially lady birds and preying mantis (Fig. 30), which besides the effect of neem influence pest population, thus severity on the crop. This agrees with Biovision (2010) that predators are very sensitive to neem application.

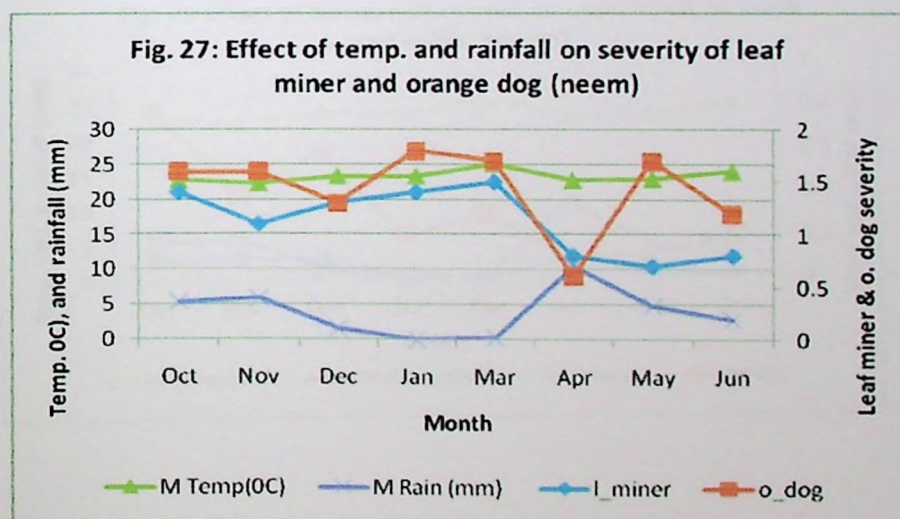
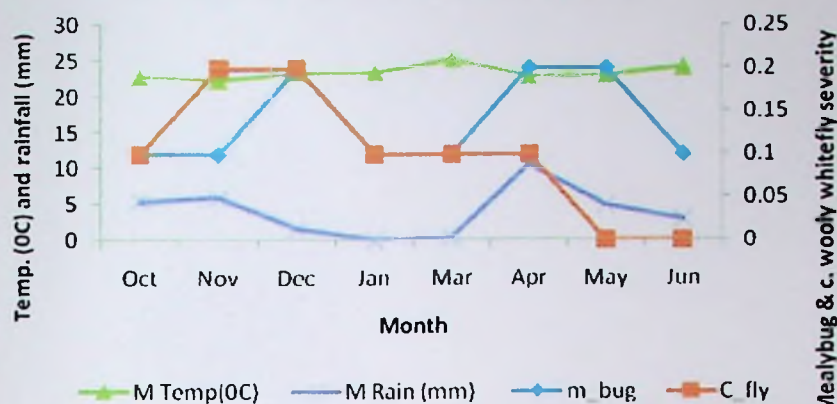


Fig. 28 Effect of temp. and rainfall on mealybug and citrus woolly whitefly severity (neem)



Like for insect pests under the neem treatment the population of spiders, ladybirds and preying mantis increased when rainfall reduced (Figs. 29 and 30). All the natural enemies' population except spiders, declined to zero (0) in the month of March when temperature was high with very low rainfall. As noted before this could be due to the reduction in the population of the insect pests on which these natural enemies derive their food requirements for a livelihood.

Fig. 29 Effect of temp. and rainfall on population of wasp and spider (neem)

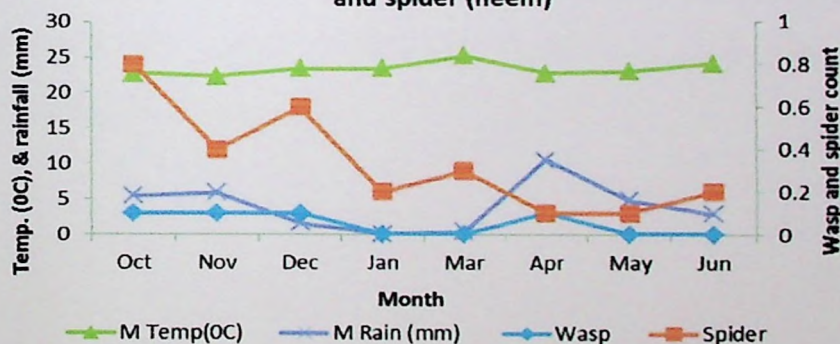
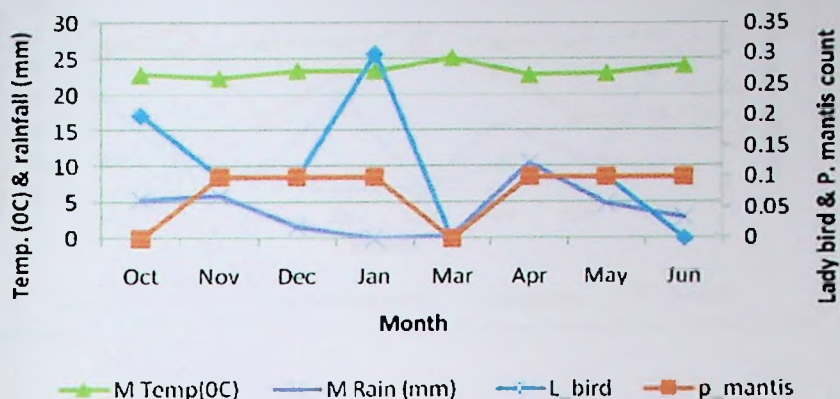
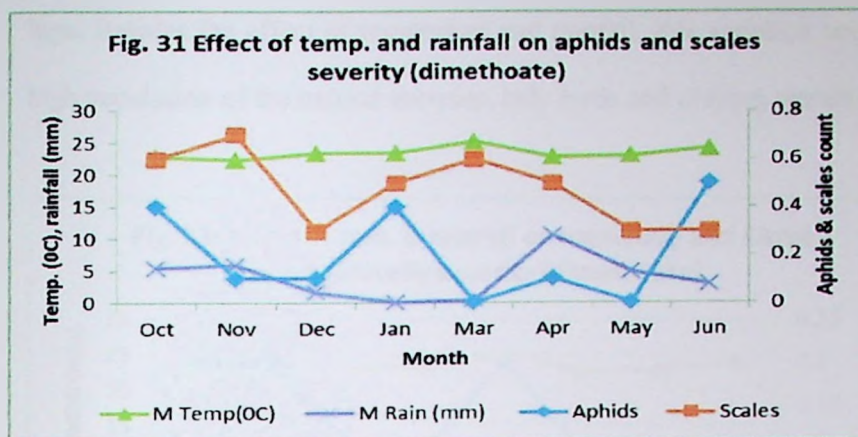


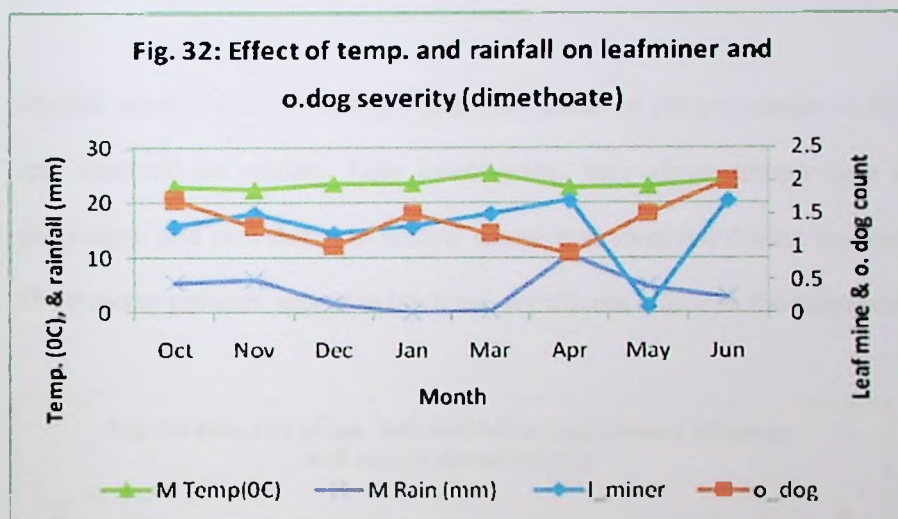
Fig. 30 Effect of temp. and rainfall on population of lady bird and preying mantis (neem)



In dimethoate treatment rainfall decrease appeared to have negative effect on the severity of all the insect pests, while temperature increase had a corresponding rise in severity, except citrus wooly whitelfies where the effect was less significant (Figs 31-33). However, during the month of March temperature increase resulted into decline in aphid severity. Related to the previous obserations increase in rainfall may wash away some insect pests like aphids, scales, mealybugs and citrus wooly whiteflies from plants (Moran and Hoffman, 1987). This, subsequently, results into reduction in severity of such pests. On the other hand temperature increase favours the growth and development of these pests. This is supported by earlier studies done by Raymond (1998) and Kent *et al.* (2007).

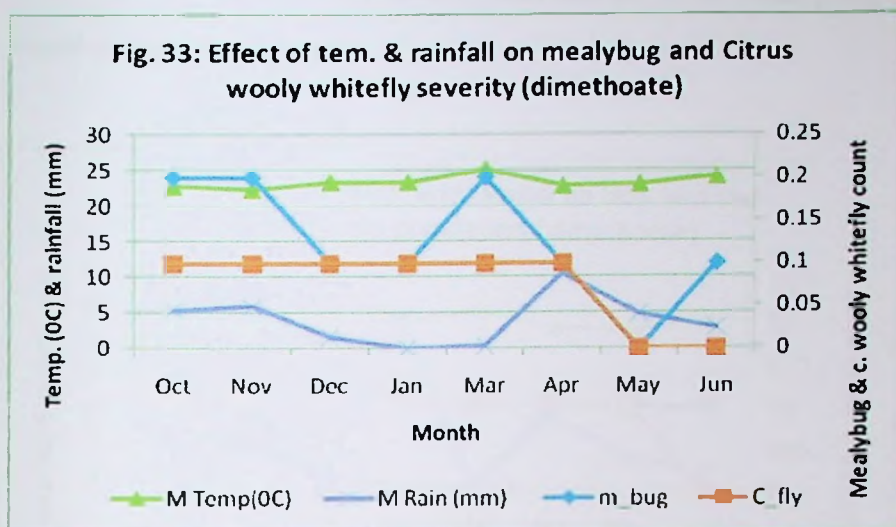


Besides the high temperatures favouring insect pests population increase (Raymond, 1998; Thompson, 1990) as noted before, heavy rains can wash away insect pests from plants (Moran and Hoffman, 1987).

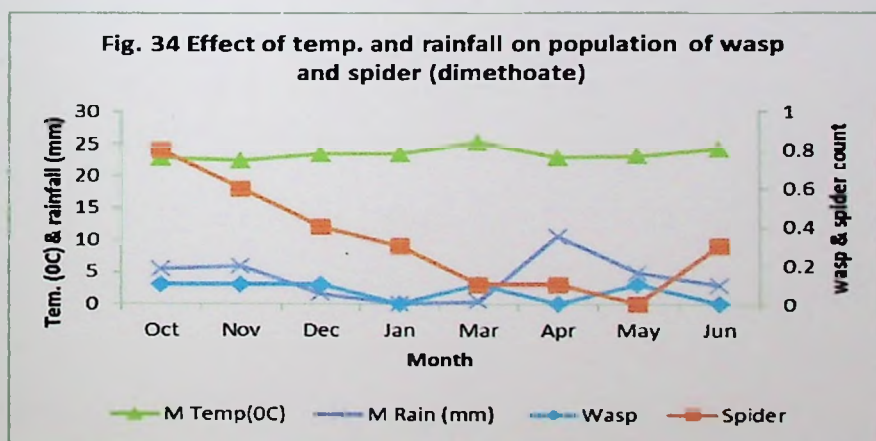


While rainfall was decreasing and temperature increasing, the severity of leaf miners, mealybugs and the citrus wooly whiteflies was significantly reduced during the month of May (Figs. 33, 34). The increase in pests severity may also be related to the absence of heavy of rainfall that would reduce feeding activity of insect pests (Masahide, 2007). Only the orange dog severity remained

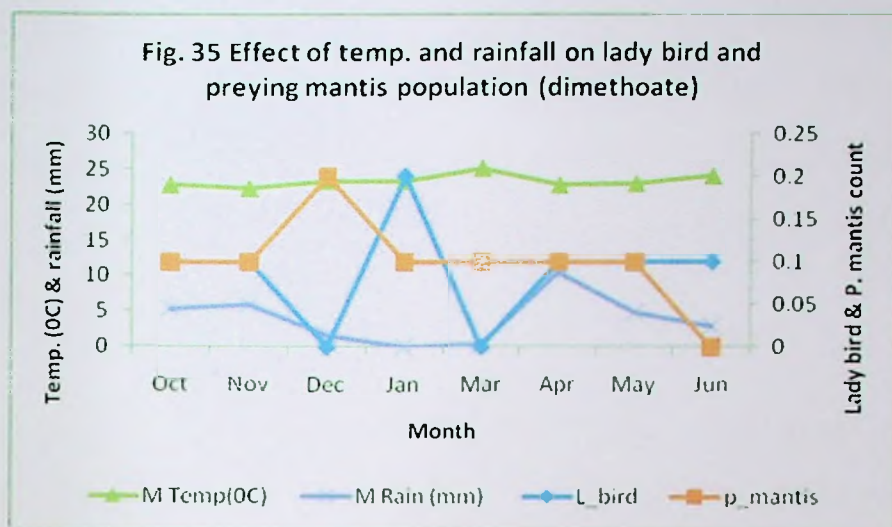
high. Besides the effect of temperature and rainfall, this variation could be influenced by the high population of the natural enemies, lady birds and preying mantis (Fig. 35).



Rainfall seemed to have had no significant effect on the population of the wasps but some effect was observed on spiders. Like insect pests, very high temperature appeared to reduce the population/ and prevalence of natural enemies as recorded during the month of March (Fig. 34). The weather patterns appear to have had significant effect on the population of ladybirds.



During the month of March when the temperature was high and rainfall very low the population of the ladybirds correspondingly reduced to zero (0) (Fig. 35). This situation may also be attributed to the excessive dry weather, thus absence of the insect pests, which could attract the natural enemy into the field.



CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The study was developed to determine the effect of synthetic and natural pesticides on the prevalence of natural enemies in citrus orchards. It also intended to establish the optimum concentrations of the natural and synthetic pesticides to manage insect pests in citrus orchards, while sustaining the life of the natural agents in the ecosystem. The influence of weather factors on the severity of citrus insect pests as well as the population of natural enemies was also determined.

Six insect pests, that is, aphids (*Toxoptera citridus*), hard/ armoured red scales (*Aonidiella aurantii*), the soft brown scales (*Coccus hesperidum*), citrus leafminer (*Phyllocnistis citrella*), the swallowtail butterfly or orange dog (*Papilio demodocus*), citrus mealybugs (*Planoccous citri*), and citrus woolly whitefly (*Aleurothrixus floccosus*) were recorded in the citrus study field. Four natural enemies were also observed in the citrus study field. They are wasps, spiders, lady bird beetles, and preying mantis. The results showed that there was no significant difference in natural enemies prevalence in all the experimental treatments of neem and dimethoate. However, significant effect of the pesticides on natural enemies was revealed from the application of different levels of the pesticide. For insect pests significant effect of the pesticides was shown on both pesticide treatments and treatment levels. Both insect pests and natural enemies indicated significant difference between plots that were used in the experimental study. The study also established that climatic factors, mainly rainfall and temperature had significant effect on the population and activity of both insect pests and natural enemies in citrus orchards.

It can be noted that the study did not establish negative effect of synthetic pesticide on the population of natural enemies in citrus study field. However, significant effect on the population of natural enemies was shown on the application of different treatment levels of both natural and synthetic pesticides. Neem at treatment of 1 litre of neem:10 litres of water significantly reduced the severity of aphids and leaf miners and showed some effect on the population of wasps, preying mantis and ladybirds. Dimethoate at the treatment level of 0.003 litres of dimethoate:1litre of water was found to have significant effect on the severity of mealybugs and citrus wooly whitefly. Weather factors, especially rainfall and temperature were found to influence the severity of citrus insect pests as well as the prevalence of natural enemies, especially the ladybirds, in the citrus study field. Increase in rainfall was found to reduce the population and thus severity of citrus insect pests, mainly aphid, scales and citrus wooly whiteflies perhaps due to the washing off of these pests from the plants as well as the unfavourable conditions for pest feeding and development. During dry weather conditions the severity of the insect pests was found increasing. This could be attributed to suitable warm conditions that enable quick growth and development of the young ones.

Recommendations

For effective management of insect pests in citrus orchards, especially scales, leaf miners and aphids it is better to apply neem leaf extract at the rate of 1litre of neem per 10 litres of water. Dimethoate at the rate of 0.003 litres per litre of water can be used to manage mealybugs and citrus wooly whiteflies. This study did not consider varietal response to insect pest damage. It is recommended that a related study be conducted on different citrus varieties to establish their susceptibility to pest attack.

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APPENDICES

Appendix I: Mean climatic data

Month	Mean Temp (OC)		Mean Rainfall (mm)		Mean R.H (%)	
Oct	22.8		5.4		57.7	
Nov	22.3		5.9		45	
Dec	23.4		1.6		29	
Jan	23.4		0		36	
Mar	25.2		0.4		35	
Apr	22.8		10.5		56.3	
May	23		4.8		56.7	
Jun	24.1		2.9		52.7	

Appendix II: Response of citrus insect pests and natural enemies to pesticide treatments levels

Insect pests							Natural enemies			
T. level	Aphids	Scales	L. miner	O. dog	M. bug	C w w fly	Wasp	Spider	L. bird	P mantis
control	0.22	0.41	1.48	1.26	0.03	0.09	0.04	0.39	0.14	0.07
Dim 1:1	0.25	0.51	1.77	1.4	0.23	0.09	0.05	0.44	0.07	0.03
Dim 2:1	0.16	0.35	1.35	1.56	0.11	0.07	0.01	0.27	0.05	0.07
Dim 3:1	0.16	0.67	1.4	1.11	0	0.01	0.04	0.29	0.07	0.04
Neem 1:10	0.07	0.39	0.68	1.59	0.07	0.04	0	0.21	0.03	0.01
Neem 2:10	0.25	0.77	1.25	1.27	0.03	0.05	0.03	0.29	0.13	0.05
Neem 5:10	0.45	0.51	1.4	1.23	0.33	0.15	0.05	0.56	0.15	0.01

Appendix III: Monthly variation of insect pests severity and natural enemies population on the citrus orchard (control)

	Insect pests						Natural enemies			
Month	Aphid	Scales	L. miner	O. dog	M. bug	C.w. fly	Wasp	Spider	L. bird	P. mantis
Oct	0.6	0.5	1.7	1.5	0	0.1	0.2	1.3	0.5	0
Nov	0.1	0.5	1.8	1.5	0	0.4	0	0.5	0	0
Dec	0.2	0.6	1.2	1.1	0.1	0.1	0	0.5	0.1	0.5
Jan	0.1	1	1.7	1.4	0.1	0.1	0.1	0.4	0.1	0
Mar	0	0.1	1.7	0.7	0.1	0.1	0	0.5	0	0
Apr	0.1	0.4	1.3	0.9	0.1	0	0	0.3	0.1	0.1
May	0.1	0.1	1	1.7	0	0	0	0.1	0	0.1
Jun	0.4	0	1.5	1.7	0	0	0	0.3	0	0

Appendix IV: Monthly variation of insect pests severity and natural enemies population on the citrus orchard (dimethoate treatment)

	Insect pests						Natural enemies			
Month	Aphids	Scales	L. miner	O. dog	M. bug	C.W.fly	Wasp	Spider	L. bird	P. mantis
Oct	0.4	0.6	1.3	1.7	0.2	0.1	0.1	0.8	0.1	0.1
Nov	0.1	0.7	1.5	1.3	0.2	0.1	0.1	0.6	0.1	0.1
Dec	0.1	0.3	1.2	1	0.1	0.1	0.1	0.4	0	0.2
Jan	0.4	0.5	1.3	1.5	0.1	0.1	0	0.3	0.2	0.1
Mar	0	0.6	1.5	1.2	0.2	0.1	0.1	0.1	0	0.1
Apr	0.1	0.5	2.1	0.9	0.1	0.1	0	0.1	0.1	0.1
May	0	0.3	0.1	1.5	0	0	0.1	0	0.1	0.1
Jun	0.5	0.3	1.7	2	0.1	0	0	0.3	0.1	0

Appendix V: Monthly variation of insect pests severity and natural enemies population on the citrus orchard (neem treatment)

	Insect pests						Natural enemies			
	Aphids	Scales	L. miner	O. dog	M. bug	C. w.fly	Wasp	Spider	L. bird	P. mantis
Oct	0.6	0.6	1.4	1.6	0.1	0.1	0.1	0.8	0.2	0
Nov	0.1	0.5	1.1	1.6	0.1	0.2	0.1	0.4	0.1	0.1
Dec	0.2	0.9	1.3	1.3	0.2	0.2	0.1	0.6	0.1	0.1
Jan	0.7	0.7	1.4	1.8	0.1	0.1	0	0.2	0.3	0.1
Mar	0	0.5	1.5	1.7	0.1	0.1	0	0.3	0	0
Apr	0.1	0.5	0.8	0.6	0.2	0.1	0.1	0.1	0.1	0.1
May	0.1	0.4	0.7	1.7	0.2	0	0	0.1	0.1	0.1
Jun	0.2	0.5	0.8	1.2	0.1	0	0	0.2	0	0.1