EFFECTS OF HOST AVAILABILITY ON SEASONAL ABUNDANCE OF THE FRUIT FLY *BACTROCERA INVADENS* DREW, TSURUTA & WHITE IN MOROGORO

BY

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ABSTRACT

Fruit flies (Diptera: Tephritidae) are listed among the major fruit pests distributed in all fruit growing areas of the world. Fruit flies compete with human beings for food resources by causing direct damage to fruits and vegetables. The damage they cause brings about negative economic and social impacts to man since he depends on fruits for important food nutrients, employment and income. The fruit fly problem in Tanzania and Africa has been aggravated since the invasion of the new fruit fly probably of Asian origin, described as *Bactrocera invadens* (Drew, Tsuruta and White). The newly invasive fruit fly that was first reported in Kenya in 2003, then in Tanzania in 2004, thereafter from the rest of Africa, has shown ability to spread fast within a short time as it is suspected to displace the indigenous fruit flies in the African region. Earlier studies in Morogoro, revealed that the fruit fly does well in low to medium altitude areas than in high altitude areas of the region. This study was conducted at SUA horticultural unit in Morogoro, to assess the temporal and spatial presences of *B. invadens* in relation to the fruiting of economically important fruit crop species. To achieve the objective, phenological events of important fruit species and varieties were recorded while fruit fly trapping was also done. At the same time weather parameters including temperature, rainfall and relative humidity were recorded. The data were all recorded at weekly basis for a period of 48 weeks. The phenology recording experiment followed a Randomized Complete Block Design while the trapping experiment followed a split-split plot design. Fruit fly trapping results were analysed using Genstat Statistical Package whereby Analysis of Variance (ANOVA) was performed to determine the efficacy of attractants and the difference in fruit fly catches between sub-orchards. The study results reveal that temperature, rainfall and relative humidity influence phenological events in plants which as a result influence the abundance of fruit flies and that weather has a direct impact on the population dynamics of fruit flies. It is

therefore recommended that knowledge in fruit phenology can be used as a tool in Integrated Pest Control because of the quick response plants have to weather changes hence become accurate timers as to when to start fighting against fruit flies for effective and inexpensive pest management.

DECLARATION

I, Lilian Shechambo, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and that it has not been submitted for a degree award in any other University.

Lilian Shechambo Date

(MSc. Candidate)

The above declaration is confirmed

Prof. A.P. Maerere Date

(Supervisor)

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DEDICATION

To my beloved father Fanuel Christopher Mazunde Shechambo and mother Dorothy Mwivei Msagati Shechambo.

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LIST OF ABBREVIATIONS AND SYMBOLS

CABI	Centre for Agriculture and Biosciences International
EMAN	Ecological Monitoring and Assessment Network
FAO	Food and Agriculture Organisation
IPM	Integrated Pest Management
SIT	Sterile Insect Technique
SUA	Sokoine University of Agriculture
TMA	Tanzania Meteorological Agency
UK	United Kingdom
URT	United Republic of Tanzania
USA	United States of America

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Fruits are important as a source of nutrients to supplement daily dietary requirements. They provide the bulk of vitamin C and vitamin A and also supply essential minerals such as iron and calcium. Apart from being a source of nutrients, fruits are a source of income and employment to many Tanzanian growers and traders. Both tropical and temperate fruits are produced in different parts of the country (Verheij, 1982). Production of temperate fruits occurs in the highland areas (Van Epenhuijsen, 1976) while production of tropical fruits takes place in the plateau, river basin and valley areas.

Morogoro is one of the major fruit producing regions in Tanzania. It produces most tropical and some temperate fruits which are supplied to urban centres like Dar-es-salaam and Dodoma [United Republic of Tanzania (URT), 2002]. Presence of both tropical and temperate fruits in the country increases fruit diversity to local consumers, also the potential to supply fruits overseas especially during the time when they are not abundant there, like during winter. Some of the tropical fruits produced include mango, guava, soursop, jew plum, breadfruit, loquat and papaya. Subtropical fruits include citrus and grape while temperate fruits include pear, plum, peach and apple.

Tropical and subtropical regions are becoming important areas for fruit production. There is a great potential for export of fruits from these regions to international markets if export qualities can be met. The most challenging task is to export pest free fruits. Fruit flies (Diptera: Tephritidae) have been listed among the major pests of many fruits (CABI, 2004). The main losses that fruit flies cause are through direct damage to fruits and fruit vegetables. Fruit flies compete with humans for food resources, thus create negative impact on sustainable rural livelihoods and loss of marketing opportunities due to imposition of strict quarantine regulations by importing countries (Ekesi and Billah, 2005).

Fruit flies are reported to be present in all fruit growing regions of the world, where 35% of the species attack soft fruits causing losses as high as US $ 910 millions (White and Elson-Harris, 1992). Lux (1999) reported losses of up to 40% in mangoes in East Africa. In Tanzania the quantity of exported fresh fruits fell from 180 metric tonnes in 2000 to 10 metric tonnes in 2002. Fresh fruits and vegetables quantities fell from 0.21% in 2001 to 0.18% in 2004 (FAO, 2004). The decrease in export quantities may be associated with the presence of a newly invasive fruit fly which was reported shortly afterwards (Mwatawala *et al.*, 2004).

In Tanzania a number of fruit flies have been recorded (CABI, 2004) while the status of fruit fly research has been reviewed by Mwatawala *et al*. (2005). Recently, two new species of fruit flies were introduced into the country and reported (Mwatawala *et al*., 2004; 2007). The first species was described by Drew *et al*. (2005) as *Bactrocera invadens*. The species, thought to have been introduced from Asia, was first detected in Kenya (Lux *et al*., 2003). Since then the species has been reported to be spreading fast throughout Africa (Drew *et al*., 2005). The second species described as *Bactrocera latifrons* (Hendel), also of Asian origin, was reported in Tanzania and Africa for the first time in 2006 (Mwatawala *et al*., 2007). The species is known elsewhere to be a major pest of solanaceous fruits. Introductions such as these threaten the export potential of the country as well as the economy of individual farmers.

Management of tephritid fruit pests has become a worldwide problem (White and Elson-Harris, 1992). Fruit flies rank among the world's most serious pests of horticultural crops (Gopaul *et al*., 2000). Various methods for managing the flies have been reported by White and Elson-Harris (1992). Lack of adequate information and local expertise in fruit fly management especially in Africa, make it difficult to respond in timely and efficient manner to fruit fly challenges.

Fruit fly eradication in the past relied mainly upon insecticides. However the ecological, toxicological and environmental shortcomings like evolving insect resistance, public concern on pesticides residues in food and increasing levels of pesticides in the environment have raised some restrictions (Jackson *et al*., 1998; Cohen and Yuval, 2000). Insecticides are also expensive and not affordable to smallholder farmers in Tanzania (Mlambiti and Isinika, 1997).

Integrated Pest Management (IPM) remains to be a more sustainable method to fruit growers in Tanzania. However, currently there is no IPM package for managing fruit flies in Tanzania (Mwatawala *et al*., 2005). Plant phenology, which studies plants and their response to seasonal changes in their environment (Stoller, 2002; Diver, 2002) is regarded as a modern tool in pest management since it can be correlated with insect emergence (Herms, 1997; Diver, 2002). Moreover, phenology studies for fruit crops have not been done in Tanzania.

On the other hand, accurate prediction of insect development and emergence is essential for effective pest management since improperly timed pesticide applications are expensive and even make the problem worse (Herms, 2002). Many insects are difficult to detect and monitor, further complicating the accurate timing of pesticide application. For a long time pesticide application has been scheduled on a calendar-day basis but due to tremendous variation in the weather from location to location and year to year it becomes inaccurate. Monitoring the emergence of insects in relation to weather elements and plant phenological events is now regarded as a modern IPM tool because it is more accurate to use (Diver, 2002).

Knowledge in fruit phenology will enable fruit growers to know the accurate timing for pesticide application or for employing other control methods hence reduce amounts of pesticides in the environment. Gathering detailed facts about fruit fly hosts through fruit phenology and population dynamics studies under our agro-ecological condition will bring accurate and reliable contributions in formulating an IPM package in Tanzania. Thus, this study was undertaken in order to contribute to bridging up of the above existing gaps. The focus of the study is on the new invasive *B. invadens* because since its invasion, the fruit fly problem in East Africa has been aggravated. According to Mwatawala *et al*. (2006b) the species appear to be present throughout the year at low and mid-altitude areas (380-520m above sea level) in Morogoro, and it has a broad host range. *B. invadens* also attracts attention as it appears in extremely high numbers as compared to other fruit fly species present in Tanzania.

1.2 Objectives

1.2.1 Overall objective

The overall objective is to asses the temporal and spatial presences of the fruit fly *Bactrocera invadens* in Morogoro, in relation to the fruiting of economically important fruit crop species.

1.2.2 Specific objectives

i. Record the phenology of selected fruit species; mango, guava, citrus, soursop, jew plum, breadfruit, loquat and papaya under the ecological conditions of Morogoro (Sokoine University of Agriculture [SUA] Horticultural Unit).

ii. Assess the population dynamics of *Bactrocera invadens* in the field environment by lure trapping.

iii. Determine the impact of weather (rainfall, relative humidity and temperature) on seasonal abundance of *Bactrocera invadens*.

iv. Determine the effect of fruit development stages (phenology) and weather on fruit fly population dynamics.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance and status of fruit production

A fruit is the reproductive body of a flowering plant with a more or less succulent flesh that is edible and useful to man usually consumed as or in a dessert. The fruit crop is a plant that bears those fruits. There are woody and non-woody, annual, biennial and perennial fruit crops, also tropical subtropical and temperate fruits basing on the classification criteria one decides to employ (Thain and Hickman, 2000; Samson, 1986).

According to Kavishe (1993) cited by Ruffo *et al.* (2002), about 2000 to 4000 children in Tanzania go blind each year due to lack of vitamin A in their diet which can easily be obtained in fruits such as mango and papaya. Fruits are compulsory in daily food intake for provision of readily available energy required by the human body. Other important organic substances found in fruits apart from vitamins and minerals, are proteins as in avocado (Gaillard and Godefroy, 1995), carbohydrates and fats (Chin and Yong, 1982). Fruits are also economically important not only as direct sources of income to growers but also for creating job opportunities in various processing factories and for their social importance in land tenure. Fruit trees are important for providing shade in many residential areas, parks and avenues.

Fresh fruits have a higher worldwide demand both in the producing countries as well as in non-producing countries. Quality tropical fruits have a growing demand in Europe, America, Japan and the Middle East (Lux *et al*., 2003). The African region follows after South America and Asia in fruit production and export (FAO, 2004). In Tanzania, most fruit trees can be found around homes. This is the most common situation in Morogoro, the Coast region and Zanzibar (Mbuya *et al.*, 1994). The production is mainly done by smallholders and is intended for household consumption and sale to the local urban markets (Lux, 1999). Exportation of fruits takes place at all Tanzanian borders to neighbouring countries although these exports have not been quantified and recorded. There are a few fruit growers who produce for export overseas, but there are as well no statistics of quantities involved.

Fruit production in Tanzania still requires more attention in order for it to be more beneficial. For a long time, emphasis has been on production of traditional crops like coffee, sisal and cotton. According to Lux *et al*. (2003) fruit farms in equatorial Africa are not grouped into uniform production blocks (orchards). This shows how fruit growers in this area meet many production constraints. There are economic and developmental constraints, some of which are lack of education in profitable fruit production, unavailability of quality planting materials, high cost of inputs, poor infrastructure, inadequate information on market opportunities and pests. Fruit flies (Diptera: Tephritidae) are the most important and notorious insect pests. Others are aphids and weevils. Moreover, many pathogenic diseases affect fruit production.

2.2 Fruit fly pests

Fruit flies are picture-winged flies of variable size with more than 4000 species in 500 genera (Thompson, 1999). The behaviour shown by larvae of most species to develop in the seed-bearing organs of plants brought the name ‘fruit flies’ (White and Elson-Harris, 1992; Ekesi and Billah, 2005). Upon maturation, the larvae leave the fruit and pupate in the soil. Adult emergence of the next generation depends on the presence of suitable fruits for adequate food supply.

2.2.1 Major fruit fly pest species of the world

Globally, about 1400 Tephritidae species are known to develop in fruits. Out of these, about 250 species already are, or may become, pests by attacking fruits of economic value (White and Elson- Harris, 1992; Thompson, 1999). The major pest genera are *Anastrepha*, found in South and Central America, West Indies and a few in the South of USA. The genus *Bactrocera* is found in tropical Asia, Australia and South Pacific regions, with a few species in Africa, warm temperate areas of Europe and Asia. The genus *Ceratitis,* is native to tropical Africa. The genus *Dacus,* is mostly found in Africa, while the genus *Rhagoletis*, can be found in South and Central America, Europe and North America (White and Elson-Harris, 1992).

2.2.2 Major fruit fly pest species of the Afro-tropical region

Major fruit fly pest species of the Afro-tropical region that is formed by countries located on the south of the Sahara, belong mainly to four genera of *Dacus*, *Bactrocera*, *Ceratitis* and *Trirhithrum* (Lux *et al*., 2003). Most of the species are highly polyphagous with overlapping host ranges. About 140 genera are known in this region including 14 *Bactrocera* spp., 65 *Ceratitis* spp., and 170 *Dacus* spp (White and Elson- Harris, 1992).

2.2.3 Major fruit fly pest species of Tanzania

2.2.3.1 Indigenous species

According to collections made by Mwatawala *et al*. (2005) from various sources, about 50 species were found in Tanzania mainland and Zanzibar. Ten of them were of more economic importance, some of them were indigenous and the others were introduced. The following are the indigenous species;

- ***Ceratitis capitata* Wiedemann:** This is also known as the Mediterranean fruit fly. It is the most widely distributed attacking many fruits.
- ***Ceratitis cosyra* Walker:** This is commonly known as the mango/marula fruit fly. It is wide spread in Africa and is known to attack mango, guava, marula and sour orange.
- ***Ceratitis fasciventris* Bezzi:** This attacks mango, guava and coffee.
- ***Ceratitis rosa* Karsch:** This is known as the Natal fruit fly. It damages mango, papaya, guava, apple and coffee.

2.3.2 Introduced species

Many species mainly from the genus *Bactrocera* and *Dacus* have been introduced in Tanzania. Out of them *Bactrocera invadens* (Drew, Tsuruta & White) is the most destructive as it damages a wide range of fruits and it has been reported to out- compete and displace the indigenous fruit fly species (Mwatawala *et al*., 2006a). Other introduced species are *Bactrocera latifrons* Hendel, *Bactrocera cucurbitae* Coquillett, *Dacus bivittatus* Bigot, *Dacus ciliatus* Loew, *Dacus punctatifrons* Karsch and *Dacus vertebratus* Bezzi.

According to descriptions made by Drew *et al*. (2005), *B. invadens* is similar to *Bactrocera (Bactrocera) dorsalis* (Hendel) from Southeast Asia and *Bactrocera (Bactrocera) kandiensis* from Sri Lanka, in possessing a very narrow costal band and anal streak, black scutum in some species, parallel-sided lateral postsutural vittae and some abdominal tergites III-V with dark ‘T’pattern and narrow dark lateral markings on all three terga. It differs from both of them in having a scutum base colour that is dark orange-brown with a dark fuscous to black lanceolate pattern.

Major hosts for *B. invadens* in Africa according to Drew *et al*. (2005) are Guava (*Psidium guajava* L.), Mango (*Mangifera indica* L.), Citrus species, Papaya (*Carica papaya* L.) and some wild hosts. Since the first records in Kenya (Lux *et al*., 2003) and shortly after in Tanzania, the pest has subsequently been found in countries across tropical Africa spreading very fast (Drew *et al*., 2005). It is speculated that establishment of *B. invadens* has been a result of modern fresh fruit movement from other continents and due to the growth of intercontinental tourist industry (Mwatawala *et al*., 2005).

2.3 Fruit fly control

2.3.1 Fruit losses due to fruit flies

Presence of fruit flies in any fruit growing region becomes an added cost in fruit production. Growers will have to carry out expensive disinfestation treatments in order for them to harvest and export high quality fresh fruits. Lux *et al*. (2003) reports that, out of 1.9 million tonnes of mangoes produced in Africa about 0.76 million tonnes is lost due to fruit flies infestations ranging from 5% to 100%.

2.3.2 Fruit fly control methods

2.3.2.1 Prevention and eradication

Prevention of fruit fly attack can be achieved by strictly enforced quarantine regulations by forbidding the import of fruit fly susceptible crops from infected areas or by forcing producing countries to implement expensive post-harvest disinfestations treatments. The cost of eradicating fruit flies from even a small island is very high, for instance Japan used

Y5 billion (about US $ 32 million) and 200,000 man days to eradicate *B. dorsalis* (Hendel) from south-western islands (White and Elson-Harris, 1992). Three main eradication procedures are known, namely bait spraying, male annihilation, sterile insect release, and a combination of these methods.

2.3.2.2 Bait spraying

This is based on the use of food baits made from hydrolysed protein derived from industrial waste materials such as brewers yeast or corn syrup. They are neither species specific nor very powerful, but they directly reduce the number of fruit flies hence become a useful tool in fruit fly control. Food baits target also pre-reproductive females and kill them before they lay eggs into the fruits. A major problem with baits is that they are expensive and inaccessible to a large number of growers (White and Elson-Harris, 1992; Lux *et al*., 2003). This method can be potentially used in Tanzania when combined with other management methods.

2.3.2.3 Male annihilation

This method aims at reducing the male population of fruit flies to such low levels that mating does not occur. It utilizes the attraction of many male species to brightly coloured artificial angling baits ranging from actual biological materials to chemical extracts or their mimics. These are used widely as lures, some of them are for example; Methyl euginol (4 allyl-1, 2-dimethoxybenzene-carboxylate). This is a highly attractive naturally occurring compound which has been used for trapping *B. dorsalis* (Hendel) (Vargas *et al*., 2000). *B. invadens* are also attracted to it (Drew *et al*., 2005). Cuelure (4-(*p*-acetoxyphenyl)-2-butanone) for *Bactrocera* and *Dacus* species and Trimedlure, a synthetic compound chemically described as tert-butyl 4 and 5-chloro-2-methylcyclohexane-1-carboxylate that attracts *Ceratitis* species. Lures are used in combination with an approved killing agent (White and Elson-Harris, 1992). This method also, can be used in Tanzania in the same conditions as those in the bait spraying method.

2.3.2.4 Sterile Insect Technique

The Sterile Insect Technique (SIT), which involves the release of mass-reared sterile males to the wild population, has been proven to be a successful technology capable of suppressing or eradicating fruit fly populations on an area in different parts of the world (Hendrichs, 1996). However, this can not be effectively used in Tanzania because the land is far too big and also more fruit flies can simply keep on invading the country from neighbouring countries.

2.4 Integrated Pest Management (IPM)

The prevention and eradication procedures cannot succeed on their own hence require combinations of strategies like the IPM. According to Dent (1995) IPM is considered as a pest management system that utilizes all suitable techniques in as compatible manner as possible and maintains the pest population level below those causing economic injury. The different control measures like using pesticides, host plant resistance, biological control, cultural control and interference methods are the essential tools with which an IPM programme is constructed. The major challenge for pest control methods to be successful and cost-effective is realising the exact time to start the control and knowing for how long the process should continue. Plant development among other things, is also weather dependent meaning that plants respond to weather changes as they occur. This is also the same for insect development (Herms, 2002). This brings about the fact that plant development events i.e., phenological events can be used as indicators of pest activities.

2.5 Plant phenology

2.5.1 Origin and meaning

Phenology is derived from the Greek word “phainomai” which means show, appear or come into view (Stoller, 2002). Phenology is the science of periodic biological events in the animal and plant world as influenced by the environment especially weather and climate (Diver, 2002). According to Stoller (2002), phenology is a subordinate branch of the study of climate, focusing on those events of plant and animal life which are repeated year after year and which when taken together make up a calendar of seasons. Sprouting and flowering of plants in the spring, colour changes of plants in the fall, bird migration, insect hatches and animals’ hibernation are all examples of phenological events.

According to the UK phenology network and the Canadian Ecological Monitoring and Assessment Network (EMAN) as compiled by Diver (2002) phenology has been recorded and used since ancient time in association with ancient festivals, indicators of the spring season, and plant-watch activities for tourists. Plant phenology can as well be useful in various ways like when it is correlated with crop planting dates, designing orchards for pollination and ripening sequence, designing bee forage plantings, designing perennial flower beds, wild flower plantings, and in prediction of global warming trends (Diver, 2002).

2.5.2 Factors for Phenological development, features and monitoring

Plant phenological development is determined by biotic/internal factors like genetics and abiotic/external factors like climate, soil characteristics as well as management factors and a combination or interaction of both kinds of factors (Ramirez, 2002). In fully grown and developed fruit trees changes in weather and most specifically temperature, remain to be the most important factor for phenological development (Herms, 1997; Diver, 2002). Among the different plant phenological features, flowering is probably the most famous. Any plant phenology feature can be useful depending on recorder’s requirements. Usually flowering is recorded from bud swell, first bloom, half bloom and full bloom and then correlated with temperature changes (Diver, 2002). Other important plant phenological features are fruiting, leafing, leaf shedding in temperate regions and vegetative growth.

According to Herms (2002), the sequence in which phenological events occur is the most significant thing in phenology monitoring. Five-year monitoring studies were conducted in central Michigan and north-eastern Ohio in the United States involving phenology of a large number of plants and pests from 1985-1989 and 1997-2001 respectively. Plants were monitored at least three times each week whereby the dates of first-bloom (the date on which the first flower bud opens) and full-bloom (the date on which 95% of the flower buds have opened) were recorded. Herms (2002) further revealed that phenological sequences can be used very effectively as biological calendars for scheduling pest management activities. Also, that the great consistency in phenological patterns from year to year demonstrated that even one year of observations is useful for timing pest management decisions. The high degree of correspondence between observations from Michigan and Ohio suggests that a phenological sequence developed in one region can be useful elsewhere although to be on the safe side, one year observation can be done for confirmation.

2.5.3 Importance of phenology in fruit fly pest management

Phenology can be used in correlation with insect emergence and pest control; for example the flowering sequence of ornamental plants as a tool for predicting the phenology of insect pests in Ohio (Herms, 1997). During fruit phenology monitoring, when a pest is observed or a pesticide is applied, plant development stages at that time should be noted. If the pest application shows to be effective then the timing can be accurately duplicated the following season when monitoring the same plant (Herms, 2002). Since the ultimate goal is to develop a simple and cheap IPM programme, plant phenology becomes a very useful biological calendar to anticipate the order and time when fruit flies and other pests can be monitored through chosen methods. The correlation between phenology of host fruits and seasonal abundance of fruit flies will be very useful in control decisions not only of fruits but also of other field crops.

This study intends thus, to examine the relationship between fruit phenological development and fruit fly catches under the normal atmospheric weather influences over almost one year, so as to provide basic information necessary for the development of an integrated fruit fly control programme to reduce the damage caused by the invasive fruit fly *B. invadens* and others.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study area

The work was conducted in Morogoro region, at the Horticultural Unit of SUA, located at latitudes S6°50’- S6°45’, longitudes E37°35’- E37°40’ and an altitude of 520m above sea level. The study area was chosen because it contains several varieties of fruit trees of economic importance for research, demonstration and semi commercial activities. Its size of 15ha was large enough to allow enough space for allocation of lure traps. Presence of a meteorological station nearby was another advantage of the site in ensuring accuracy of weather data.

3.2 Climate of the study area

SUA Horticultural unit experiences a sub-humid tropical climate. The ten year mean rainfall data between 1987/88-1996/97 presented in Figure 1, indicate that the area experiences a bimodal rainfall distribution, with short rains normally from October to the end of January. Long rains start between mid-February or mid-March ending in May. The onset and distribution is irregular and unreliable. The total annual rainfall during the ten year period ranged from 711-1044mm with an average of 850mm. In the same period, the monthly total evaporation varied from 74.3mm in May to 176.9mm in December. The mean air temperature was lowest in June and July and highest in December to February. The Mean monthly maximum air temperature ranged from 27.4 to 32.4°C while the average monthly minimum air temperature ranged from 15.5°C to 21.3°C (Fig. 1).

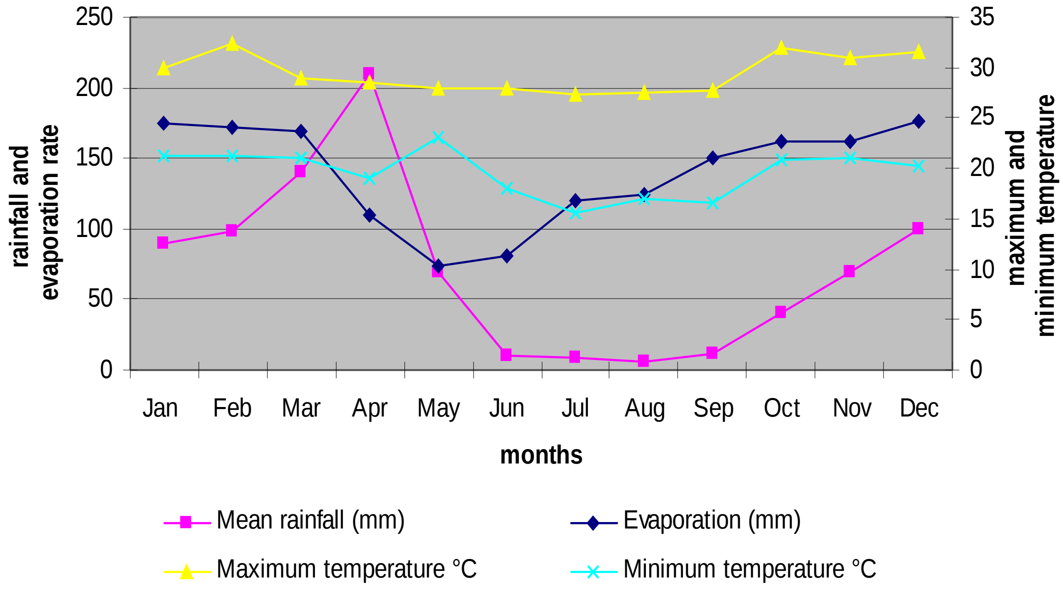

Figure 1: The ten year period average weather condition at SUA from 1987/88 to 1997/98

3.3 Materials

3.3.1 Fruit species for phenology recording

A total of twenty one trees of different varieties of fruit species were randomly picked for fruit phenology observations. Mango, citrus, guava and papaya fruit species were selected because they are known to be hosts for *B. invadens* (Drew *et al*., 2005). According to Herms (1999), any flowering plant can be used as indicator plants when correlating fruit phenology and pest emergence. Varieties chosen were all randomly selected. Many fruit trees were used so as to increase the diversity and precision in decision making. The fruit trees and varieties selected are shown in Table 1.

Table 1: Fruit species and varieties selected for phenology recording

Fruit species	Variety
Mango (*Mangifera indica* L.)	Red Indian, Tommy Atkins, Kent, Dodo and Sindano nyeusi
Guava (*Psidium guajava* L.)	Pink and white fleshed (var. unknown)
Sweet orange (*Citrus sinensis* (L.) Osbeck.)	Valencia late, Hamlin, Cassa grande, Jaffa, and Matombo sweet
Tangerine (C*itrus reticulata* Blanco)	Variety Morogoro
Grape fruit (*Citrus paradisi* Macfad.)	Triumph
Lime (*Citrus latifolia* Tan.)	Tahiti
Pawpaw (*Carica papaya* L.)	(Unknown)
Breadfruit (*Artocarpus altili*s (Parkins.) Fosb.)	(Unknown)
Soursop (*Annona muricata* L.)	(Unknown)
Jew plum *(Spondias cytherea* Sonn.)	(Unknown)
Star fruit (*Averrhoa carambola* L.)	(Unknown)
Loquat (*Eriobotrya japonica* (Thunb.) Lindley)	(Unknown)

3.3.2 Fruit fly traps/lures

Modified McPhail traps (Scentry Cie, Billings, MT, USA) were used, baited with a liquid attractant or non liquid attractants in combination with DVDP (2,2 dichlorovinyl dimethyl-phosphate) acting as a killing agent. The traps were hung on mango (var. Dodo and Sindano nyeusi), Citrus (var. sweet seedling and Tahiti lime) and guava (unknown var.) at a height of about 2m from the ground. Placement of traps was done according to the guidelines by IAEA (2003). Methyl eugenol (ME) was used for trapping males of *B. invadens*. Protein bait (PB) based on borax pellets dissolved in water, served as attractants for capturing local flies around the trap and as sources of food material. Trimedlure (TM) was used as a control since it attracts *Ceratitis* species and not *Bactrocera* species.

3.4 Methods

3.4.1 Recording of fruit phenology

Fruit phenology recording was done for a period of 48 weeks, from mid-July 2006 to mid-June 2007. Phenological events from fruit species and varieties included in the study were monitored visually and recorded at weekly intervals. The events included presence of flower buds (FB), open flowers (OF), presence of flower pollen (P), presence of swollen flower bases (SB); immature fruits on the tree (IFT), mature fruits on the tree (MFT) and on the ground under the tree (M.F.G), presence of ripen fruits (R.F) and vegetative growth without fruits or flowers (N.F.F). The experimental layout followed a randomized complete block design with unequal number of replications. The fruit trees were the treatments and varieties the replications (Mango and sweet orange with five replications each, guava with two replications and the rest with a single replication each).

3.4.1.1 Monitoring of phenological events

Flower buds, open flowers, pollen and swollen flower bases were recorded as soon as they showed up to the time they were no longer available. Immature fruits were recorded from the time when other flower parts disappeared and the smallest fruit start showing up. At the time when the fruit skin-colour just start to change, the fruits were recorded as matured. To record fruits as ripe, the whole skin-colour had to change, whether the fruit is still on the tree or has already fallen down.

2.4.2 Recording of trapped fruit flies

The experiment was done for a period of 48 weeks from mid-July 2006 to mid-June 2007. ME, PB and TM baited traps were emptied at weekly intervals. The trapped flies were collected in tubes that were numbered in correspondence to a data sheet with tree name, variety name and the type of bait. The numbered tubes containing the trapped fruit flies were then taken to the laboratory for counting and recording. Due to its nature PB was re-baited weekly while other lures and DVDP strips were renewed after every four weeks.

3.4.2.1 Experimental design for fruit fly trapping

The trapping period was fragmented into twelve trapping cycles, each with four weeks corresponding to lure changing dates. There were two replicates for mango and citrus, and one for guava. The set up of the experiment followed a split-split-plot design where the cycles were the main plot, attractants the sub plot and orchards the sub-sub plot.

3.4.3 Collection of weather data

Weekly weather data (rainfall, temperature and relative humidity) were obtained from the Tanzania Meteorological Agency (TMA), Morogoro station located at SUA about 1km from the horticultural unit where the experiments were conducted.

3.5 Data analysis

To analyse *B. invadens* catches, Analysis of variance (ANOVA) based on the experimental model for split-split plot design was performed. During the analysis guava catches were left out since there was only a single replicate in the guava orchard.

For the purpose of analysing the population dynamics of *B. invadens* two major tests were performed. The first test was done to determine the differences in catches of *B. invadens* by the three attractants (ME, PB and TM) where TM was a control. In this test, trapping cycles were the main plot, attractants the sub plot and orchards the sub-sub plot. The second was done to test for significant differences in fruit fly catches between orchards where, trapping cycles were the main plot, orchards the subplot and attractants the sub-subplot. The experimental model used was according to Gomez and Gomez (1984). The model was as follows;

$Yijk = \mu + Ai + e a + Bj + ABij + e b + Ck + Aik + Bjk + ABCijk + e ijk$

Where,

μ= overall mean

A= Main factor

B= Subfactor

C= sub-subfactor

a, b and c = Number of main plots, subfactor and sub-subfactor

e= Error to the experimental unit

Data for phenology of the different fruit species/varieties were plotted in relation to fruit fly catches over time. Data on weather (temperature, relative humidity and rainfall) were plotted in comparison with fruit fly catches and the fruit species/varieties phenological events.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Weather conditions during the study period

According to the general climate of SUA as evidenced by the ten year data from 1987/88 to 1997/98 (Figure 1), April is the wettest month. The hottest months start from October to February and the coolest months from June to July. A record of weather conditions including rainfall, maximum and minimum temperature and relative humidity during the study period (July 2006 to June 2007) is presented in figure 2. During the period the site received a total rainfall of 1142.9mm, with two peaks in December for the short rains and in April for the long rains. The mean monthly maximum air temperature ranged from 27.9 to 33.3°C while the mean monthly minimum air temperature ranged from 17.3 to 22.0°C. The mean monthly maximum relative humidity ranged from 89 to 96.5% while the mean monthly minimum relative humidity ranged from 43.7 to 58.2%.

During the study period as presented in figure 2, February was the hottest month and July was the coolest while March was the wettest month and June the driest. With reference to the ten year weather records at SUA (Fig. 1), the rainfall received during the study period was high, in particular the short rains received from October to January were very high. Temperature and relative humidity were also higher as compared to the general ten year records. In general, the hottest, coolest and wettest months were not far from the usual ones.

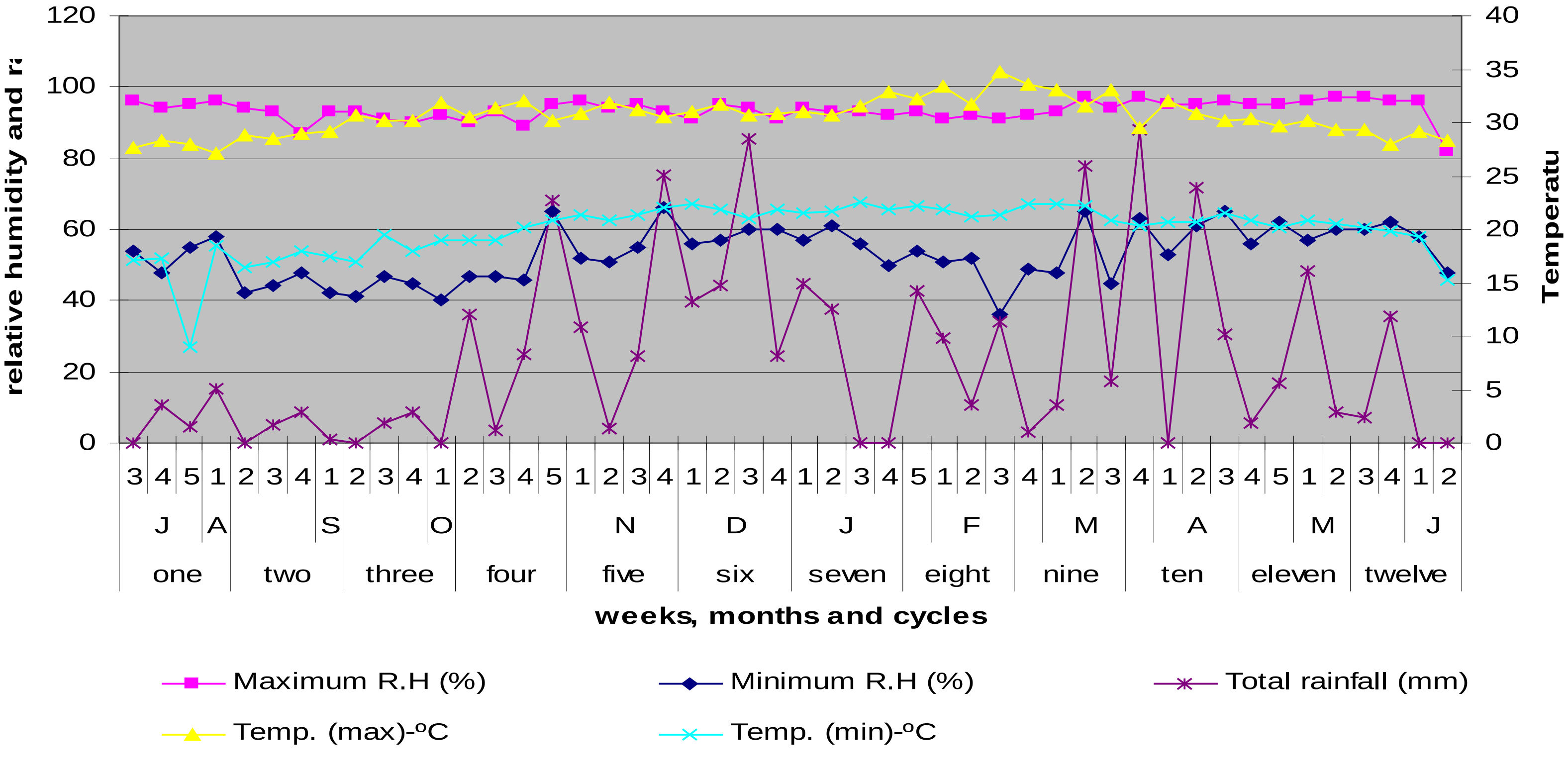

Figure 2: Weather condition during the study period from July 2006 to June 2007

4.2 Phenological development of selected fruits species and varieties

4.2.1 Mango

Figure 3 summarizes the phenological development of mango varieties over 48 weeks. Flower buds in mango varieties ‘Red Indian’, ‘Tommy Atkins’, ‘Sindano nyeusi’ and ‘Dodo’ started showing up from the third week of July while flower buds in variety ‘Kent’ showed up as late as the first week of October. Open flowers and pollen appeared from the fifth week of July in the first four varieties and during the third week of October in ‘Kent’. Immature fruits on trees were seen from the third week of August in the other varieties and during the third week of November in ‘Kent’. Immature fruit drop which is a common phenomenon in mango trees occurred during the third week of September in all varieties except in ‘Kent’ where it was seen during the third week of December. Fruits appeared to mature from the third week of November in all other varieties and from the third week of January in ‘Kent’. Ripe fruits were seen from the last week of December up to the first week of February for the four varieties and from the first week of February to the second week of March in ‘Kent’. This shows that ‘Kent’ is a late bearing variety as compared to the other four varieties. From the fourth week of January up to the last week of March there were many matured and ripening mango fruits on the ground under the experimental trees and others around the mango sub-orchard.

Mango varieties took about 126 days from flower buds to fruit maturation. Literally, mangoes require about 100 to 150 days from flowering to maturation of fruits. Therefore the time observed was normal. As a common knowledge, high soil moisture brings about more vegetative growth than other phenological stages in plants including mango and eventually poor production in the next season. This may be the reason behind an abnormal mango season of 2006/2007.

Looking at Fig. 2, it is noted that there were extensive rains with a discontinuous pattern from July to September. When compared to the ten year weather in figure 1, those months are usually dry. The mango variety ‘Kent’ which is late maturing could not flower normally in July. Apart from the seasonal abnormalities, mangoes were present as hosts to fruit flies from November to March.

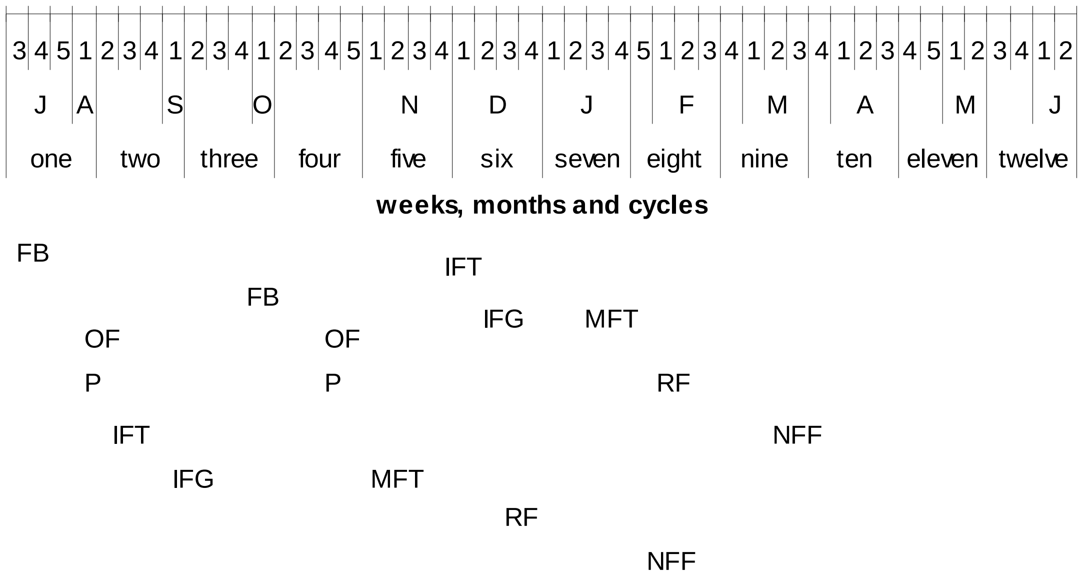

Figure 3: Phenological events of Mango varieties

FB-Flower buds; OF-Open flowers; P-Pollen shedding; IFT-Immature fruits on the tree; IFG-Immature fruits on the ground; MFT-Mature fruits on the tree; MFG-Mature fruits on the ground; RF-Ripe fruits; NFF-Neither fruits nor flowers present.

Phenology of mango variety ‘Kent’.

Phenology of mango varieties ‘Red Indian’, ‘Tommy Atkins’, ‘Sindano nyeusi’ and ‘Dodo’

4.1.2 Citrus

4.1.2.1 Sweet orange varieties

Figure 4 presents the phenological events for sweet orange varieties ‘Hamlin’, ‘Cassa grande’, ‘Valencia late’, ‘Jaffa’ and ‘Matombo sweet’. Figure 4 shows that the varieties followed a normal pattern taking about eight months from flowering to fruit maturation. According to Samson (1986), in the tropics the period that citrus fruits can take from fruit set to maturation may vary from six to twelve months.

At the time when phenology recording started (from the third week of July) sweet orange varieties had immature, matured and ripening fruits on their trees except for the variety ‘Jaffa’ which was undergoing vegetative growth. Flower buds on variety ‘Jaffa’ showed up from the third week of October and from the first week of November on the other varieties. Open flowers and pollen were observed from the last week of October on ‘Jaffa’ variety while on the other sweet orange varieties, open flowers and pollen were seen from the third week of November. Immature fruits were formed during the third week of November on ‘Jaffa’ variety and during the first week of December on other varieties. Mature and ripe fruits were observed during the first week of March and the last week of April on the variety ‘Jaffa’ and from the third week of March and fourth week of May on other sweet orange varieties respectively.

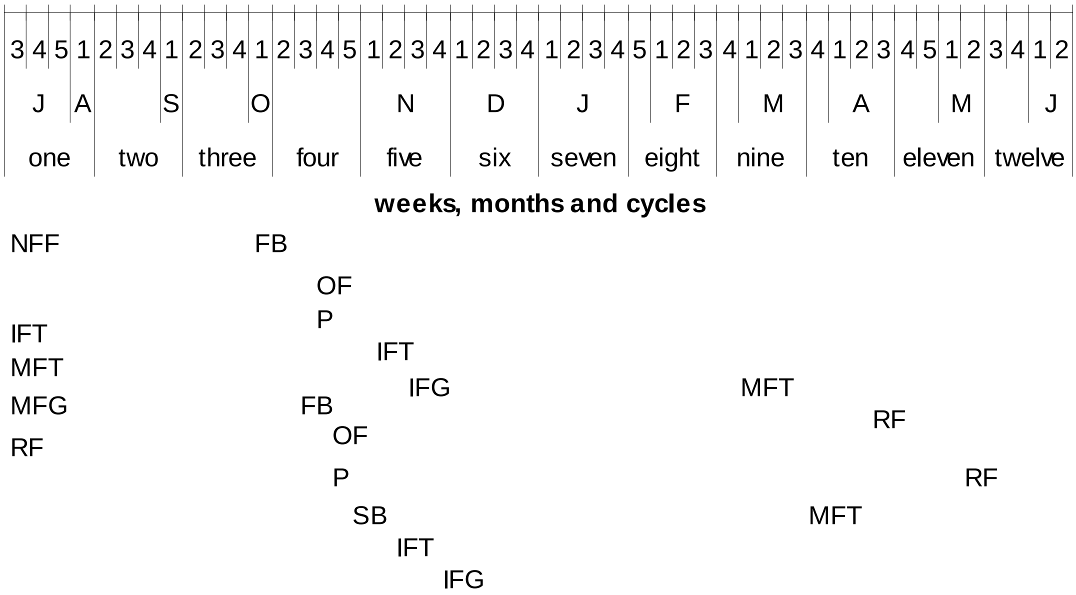

Figure 4: Phenological events of sweet orange varieties

FB-Flower buds; OF-Open flowers; P-Pollen shedding; IFT-Immature fruits on the tree; IFG-Immature fruits on the ground; MFT-Mature fruits on the tree; MFG-Mature fruits on the ground; RF-Ripe fruits; NFF-Neither fruits nor flowers present.

Phenology of sweet orange variety ‘Jaffa’.

Phenology of all other sweet orange varieties ‘Matombo sweet’, ‘Hamlin’, ‘Valencia late’, and ‘Cassa grande’.

4.1.2.2 Lime variety ‘Tahiti’

The phenology of lime variety ‘Tahiti’ is shown in Figure 5. This variety had flower buds, open flowers, pollen, swollen flower bases and immature fruits from the third week of July. Mature and ripe fruits showed up from the end of July and the second week of August respectively. Flower buds, open flowers, pollen and swollen flower bases showed up again from the last week of November.

The variety had yet another flush from the last week of January. Due to the three flushes, the species had immature fruits during the whole time of the study. The reason to this trend of development of the variety could be attributed to its known characteristics of being a continuous bearer (Purseglove, 1968).

Immature fruit drop occurred from the last week of December to the end of January. Mature and ripen fruits on the tree became available again from the end of February to the end of May. Ripening and decaying lime fruits were present almost throughout the data recording time but mostly from August to November and from March to June. According to the figure, phenological events in this variety especially blooming were weather dependent.

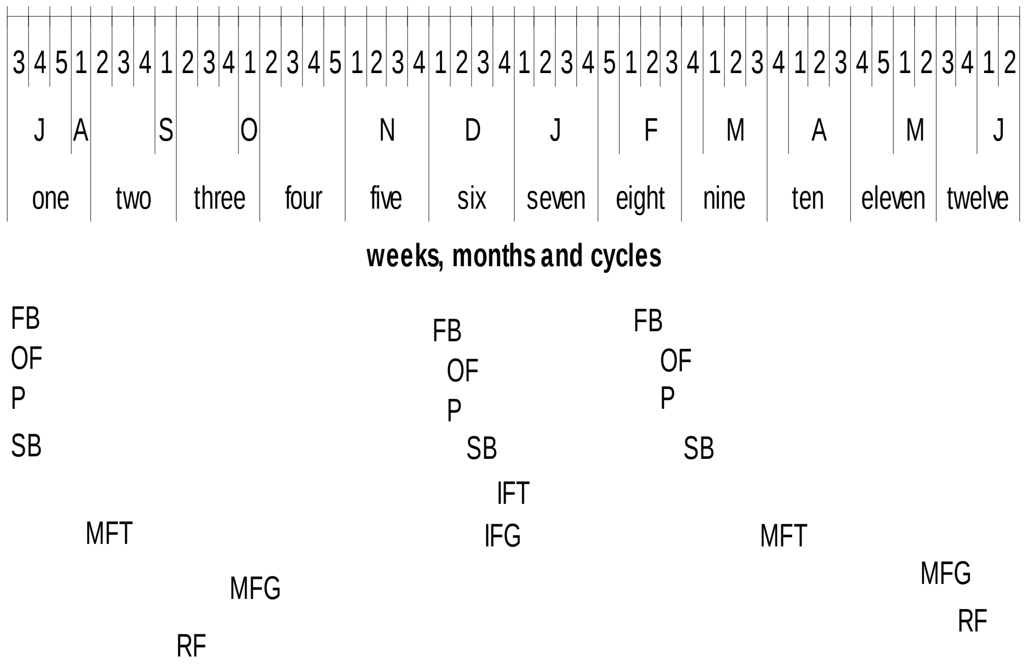

Figure 5: Phenological events of lime variety 'Tahiti'

FB-Flower buds; OF-Open flowers; P-Pollen shedding; IFT-Immature fruits on the tree; IFG-Immature fruits on the ground; MFT-Mature fruits on the tree; MFG-Mature fruits on the ground; RF-Ripe fruits; NFF-Neither fruits nor flowers present

4.1.2.3 Grapefruit variety Triumph

Figure 6 presents phenological events in grapefruit during the study period. At the beginning of phenology recording, grapefruit had immature, mature and ripe fruit stages. From the fourth week of July, flower buds were formed followed by open flowers with pollen a week later and swollen flower bases from the first week of August. These stages repeated themselves from the first to the third week of November. Immature fruit stage was present as from July to the first week of March, while mature fruits were present throughout. Ripening fruits showed up again from the first week of October and again from the first week of March. Decaying mature to ripe fruits were also available from July to September, October to the end of December and from March to May.

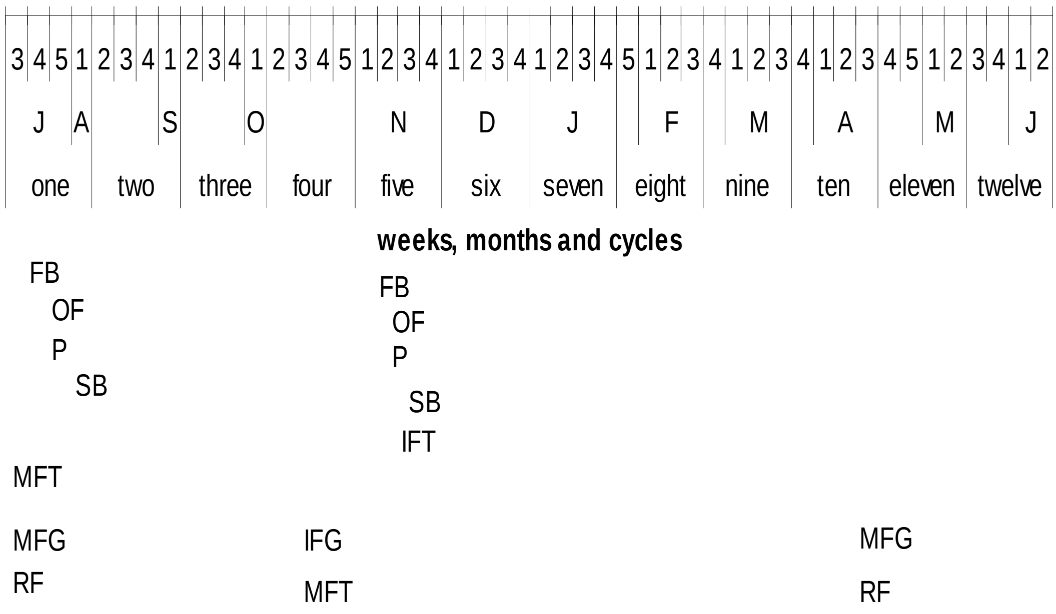

Figure 6: Phenological events of Grapefruit variety 'Triumph'

FB-Flower buds; OF-Open flowers; P-Pollen shedding; IFT-Immature fruits on the tree; IFG-Immature fruits on the ground; MFT-Mature fruits on the tree; MFG-Mature fruits on the ground; RF-Ripe fruits; NFF-Neither fruits nor flowers present.

4.1.2.4 Tangerine

At the beginning of phenology recording from the third week of July all phenological stages were available in this citrus tree except for immature fruit drop. Mature and ripening fruits on the tree were available until November. Immature fruits on the tree continued to be available throughout the study period. From the last week of November there was a second flush in Tangerine while mature and ripening fruits became available again from the second week of March (Fig. 7).

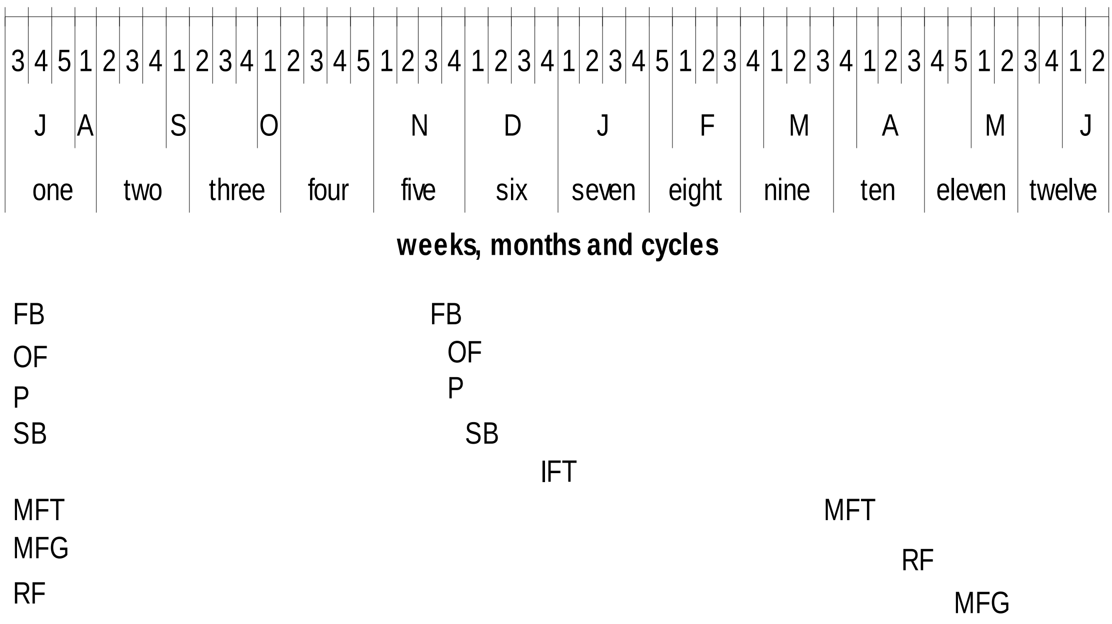

Figure 7: Phenological events of Tangerine variety 'Morogoro'

FB- Flower buds; OF- Open flowers; P- Pollen shedding; IFT- Immature fruits on the tree; SB- Swollen flower bases; IFG- Immature fruits on the ground; MFT- Mature fruits on the tree; MFG- Mature fruits on the ground; RF- Ripen fruits; NFF- Neither fruits nor flowers present.

Literally, citrus fruits can have up to four or five flushes each year if conditions are favourable. While citrus fruits take six to twelve months to mature in the tropics and even longer in the subtropics (Samson, 1986), citrus fruits in this study took a minimum of six months from flowering to fruit maturation.

4.1.3 Guava

Phenological events on guava trees are shown in Figure 8. Both white and red fleshed guava trees had flower buds, open flowers, pollen and swollen flower bases at the beginning of data recording, then from the first week of November, the last week of January and the first week of March. Immature fruits were present throughout due to the many flushes that showed up. Mature fruits were present all the time except during the last week of October and most weeks of January. Ripe fruits also had a continuous availability except for a short period from the third week of January to the third week of February and towards the end of data recording from the last week of May. Presence of fruits almost all the time in this orchard left many ripening and decaying fruits around the orchard throughout the recording time.

According to California Rare Fruit Growers Inc. (1996) guava ripens all year in warmer regions. Based on Fig. 8, new flushes in guava trees appear to be directly influenced by weather especially rainfall and temperature. On average guava fruits took about four months from flowering to fruit maturation. The duration taken is normal since the expected duration is between four and five months (Samson, 1986).

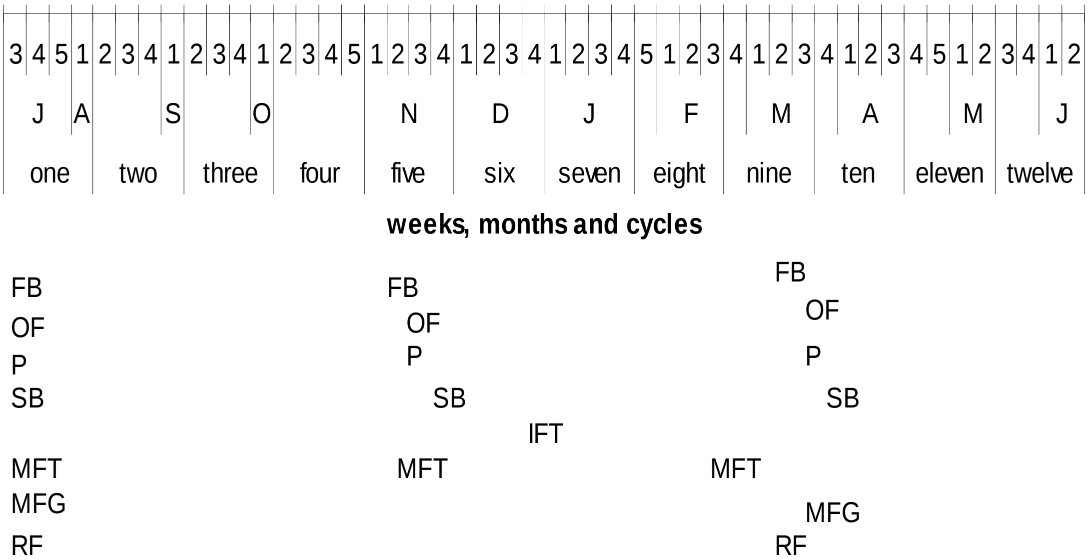

Figure 8: Phenological events of Guava

FB- Flower buds; OF- Open flowers; P- Pollen shedding; IFT- Immature fruits on the tree; SB- Swollen flower bases; IFG- Immature fruits on the ground; MFT- Mature fruits on the tree; MFG- Mature fruits on the ground; RF- Ripen fruits; NFF- Neither fruits nor flowers present.

4.1.4 Papaya

Phenological events observed in papaya are presented in Figure 9. This fruit tree is continuously growing throughout the year (Samson, 1986) as a result it had all the studied phenological events throughout the study time. Like in other tropical fruits, rate of growth and fruiting is reduced during the cool and dry season (June, July and August). Ripe papaya fruits were not left to decay because they were always harvested as soon as ripening started. The events followed a normal pattern. Papaya fruits mature after about five months since flowering.

4.1.5 Star fruit

As in papaya, star fruits showed all the phenological events throughout the study period, except that the intensity of the events was not always the same. Most of the vegetative growth occurred during the rainy seasons in October and March. The phenological events observed in star fruit are also presented in Figure 9.

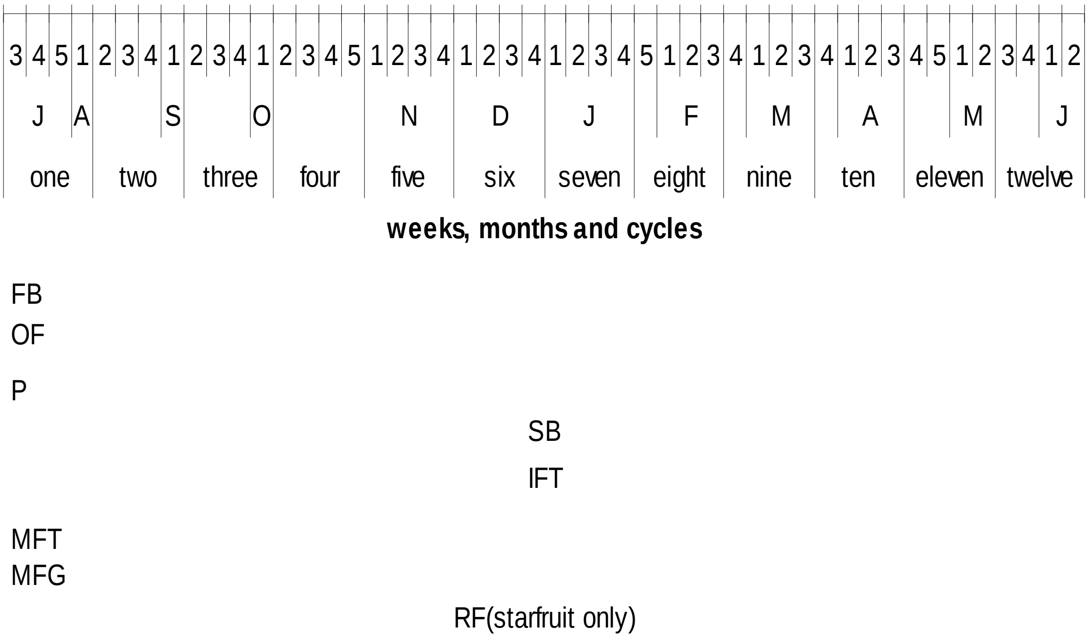

Figure 9: Phenological events of Starfruit and Papaya

FB- Flower buds; OF- Open flowers; P- Pollen shedding; IFT- Immature fruits on the tree; SB- Swollen flower bases; IFG- Immature fruits on the ground; MFT- Mature fruits on the tree; MFG- Mature fruits on the ground; RF- Ripen fruits; NFF- Neither fruits nor flowers present.

4.1.6 Jew plum

Phenological events of Jew plum fruit are shown in Figure 10. From the last week of August there were flower buds while open flowers with pollen followed a week later. The flowers were available throughout the short rainy period up to the end of January. From the second week of February to the first week of March flowers were formed again. Immature, mature and ripe fruits from this tree were available from the beginning to the end of phenology recording with many decaying fruits scattered on the ground under the trees.

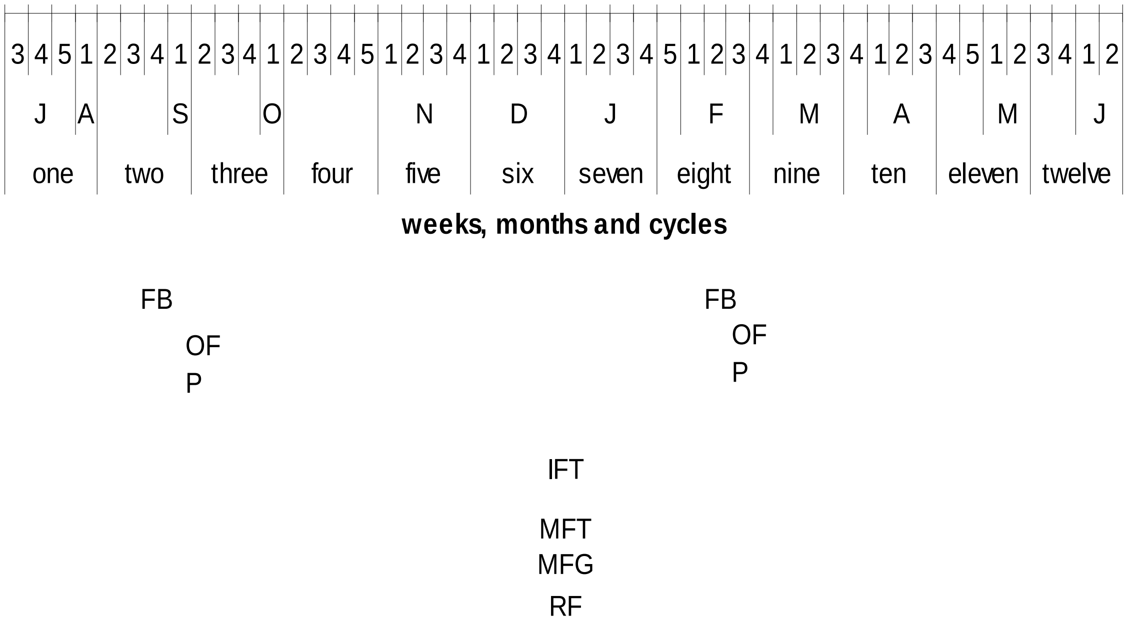

Figure 10: Phenological events of Jew plum Spondias cytherea

FB- Flower buds; OF- Open flowers; P- Pollen shedding; IFT- Immature fruits on the tree; SB- Swollen flower bases; IFG- Immature fruits on the ground; MFT- Mature fruits on the tree; MFG- Mature fruits on the ground; RF- Ripen fruits; NFF- Neither fruits nor flowers present.

4.1.7 Breadfruit

Figure 11 presents the phenological events in breadfruit. Flower buds in breadfruit started showing up during the third week of July, open flowers and pollen shedding stages followed from the first and second weeks of August, respectively. Immature fruits showed up from the first week of September, mature fruits from the last week of October and ripening fruits from the last week of November. From the second week of December, mature and ripening fruits could be seen decaying on the ground under the trees.

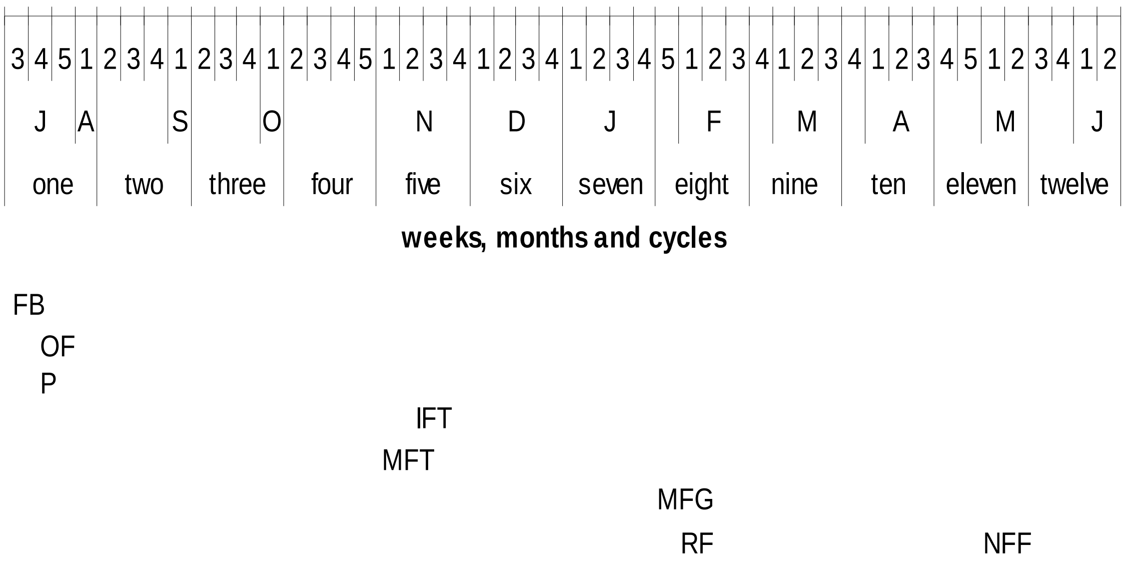

Figure 11: Phenological events of Breadfruit

FB- Flower buds; OF- Open flowers; P- Pollen shedding; IFT- Immature fruits on the tree; SB- Swollen flower bases; IFG- Immature fruits on the ground; MFT- Mature fruits on the tree; MFG- Mature fruits on the ground; RF- Ripen fruits; NFF- Neither fruits nor flowers present.

4.1.8 Loquat

Loquat trees had flower buds, open flowers, pollen, immature, mature and ripen fruits at the beginning of fruit phenology recording. Flower buds, open flowers and pollen showed up again from the second week of September and from the third week of November. Immature, mature and ripe fruits were formed again from the first week of February to the end of data recording time. Figure 12 presents the phenological events of loquat as they occurred during the study period.

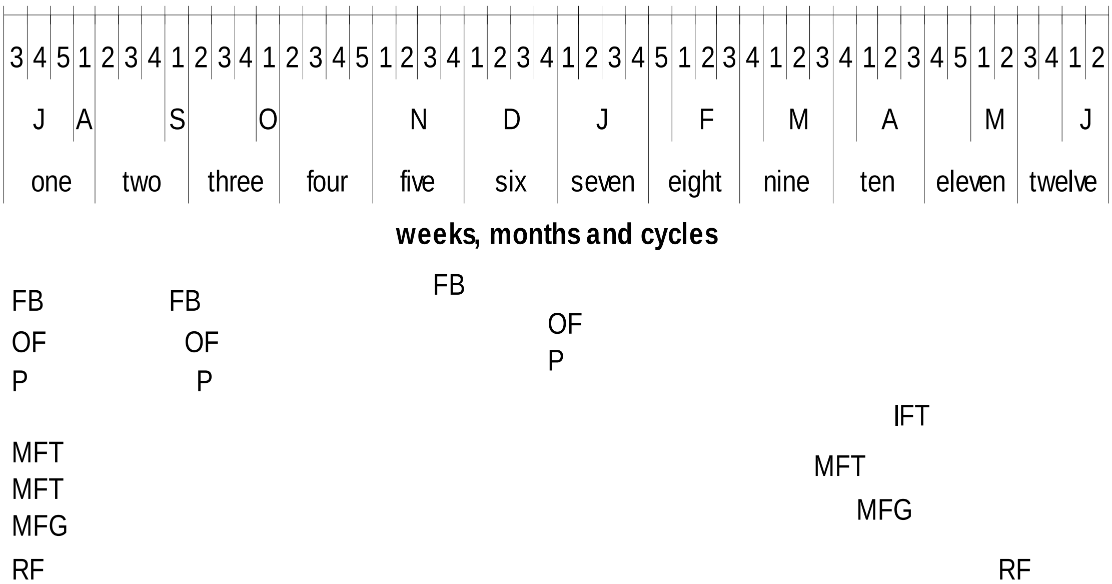

Figure 12: Phenological events of loquat

FB- Flower buds; OF- Open flowers; P- Pollen shedding; IFT- Immature fruits on the tree; SB- Swollen flower bases; IFG- Immature fruits on the ground; MFT- Mature fruits on the tree; MFG- Mature fruits on the ground; RF- Ripen fruits; NFF- Neither fruits nor flowers present.

4.1.9 Soursop

Phenological events of soursop are shown in Figure 13. On soursop trees, immature, mature and ripe fruits were already present before the first week of July. Immature fruits were present up to the third week of September while mature and ripe fruits were available up to the third week of October. Flower buds, open flowers, pollen and swollen flower bases showed up from the third week of October and again from the second week of February which led to the formation of immature fruits from the second week of November to the last week of April. Mature and ripe fruits showed up again from the last week of January and also towards the end of data recording time from the third week of May.

During all fruit ripening time there were also many fruits on the ground under the tree and around the sub-orchard.

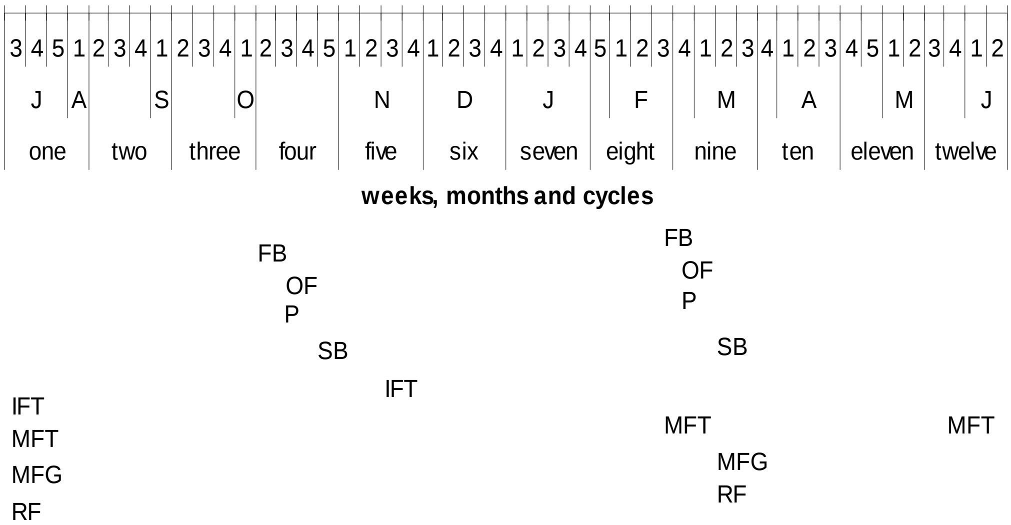

Figure 13: Phenological events of soursop

FB- Flower buds; OF- Open flowers; P- Pollen shedding; IFT- Immature fruits on the tree; SB- Swollen flower bases; IFG- Immature fruits on the ground; MFT- Mature fruits on the tree; MFG- Mature fruits on the ground; RF- Ripen fruits; NFF- Neither fruits nor flowers present.

4.2 Fruit flies trapping

Trapping of fruit flies was done for 48 weeks from the third week of July 2006 to the second week of June 2007 as planned. The attractants, Methyl eugenol, Protein bait and Trimedlure (ME, PB and TM) were used at all times. The attractants were quite specific in their attraction. Only a few untargeted catches were recorded. These were considered accidental, for example the two *B. invadens* flies caught by TM suspended on guava tree (see Table 3).

4.2.1 Population dynamics of B. invadens in the field

The general trend of the population dynamics of *B. invadens* is shown in Figure 14. The overall results show that *B. invadens* population was quite dynamic, with the highest peak at the end of January-mid February 2007. The lowest level of *B. invadens* was observed in September-October 2006. The trend is affected by weather as well as by fruit phenological events. The decreasing population from June to early October correspond to the cool and dry season. The fruit fly population was observed to rise as from mid October 2006 to reach the maximum in January 2007. The period from June to October corresponds to the cool and dry season. Usually from mid October-January the short rainy season is received (Fig. 1 and 2). The predominant fruit phenology stages from June to October included the presence of mature to ripe guava, citrus, loquat and soursop fruits.

The population increase from late October to the end of January corresponds to high temperatures and the short rainy season at the time. High temperature and rainfall have direct effects to the phenology of many fruits including mango, guava and other perennial fruit crops as stated by Samson (1986). From October to March mango fruits were available at immature, mature and ripe stages. Immature guava fruits were also available while mature to ripe guava became available from February to May. From the end of April, mature Citrus fruits became available again. Other fruits like jewplum, starfruit and Papaya were available throughout the year as the phenology Fig. 9 and 10 have shown.

Changes in weather affect fruiting of plants which as a result affect population fluctuations in fruit flies, because the population decreased in February as the short rainy season ended and temperatures decreased. Looking at Fig. 14, the population increased a bit in March along with the onset of the long rainy season but this time the temperatures were decreasing. The effect of temperature is vivid as the numbers of *B. invadens* catches are not as high as during the previous rainy season. Moreover, this may also be explained by the fact that the many plants including that bloomed or had fruits during the onset of the short rainy season had vegetative growth during the long rainy season.

Fruit fly population decreases with decreasing temperatures (Mwatawala *et al.*, 2006b) as well as drought due to its effect on fruiting of plant species (Leweniqila *et al*., 1997). After the long rainy season in May, the fruit fly catches decrease as the cool and dry season begins in June. The surviving fruit flies at this time are probably largely supported by the abundance of various fruits at mature to ripe stages like citrus (Fig. 4 -7), guava (Fig. 8), Loquat (Fig. 12), and annona (Fig. 13) and many other non-seasonal fruits in small quantities.

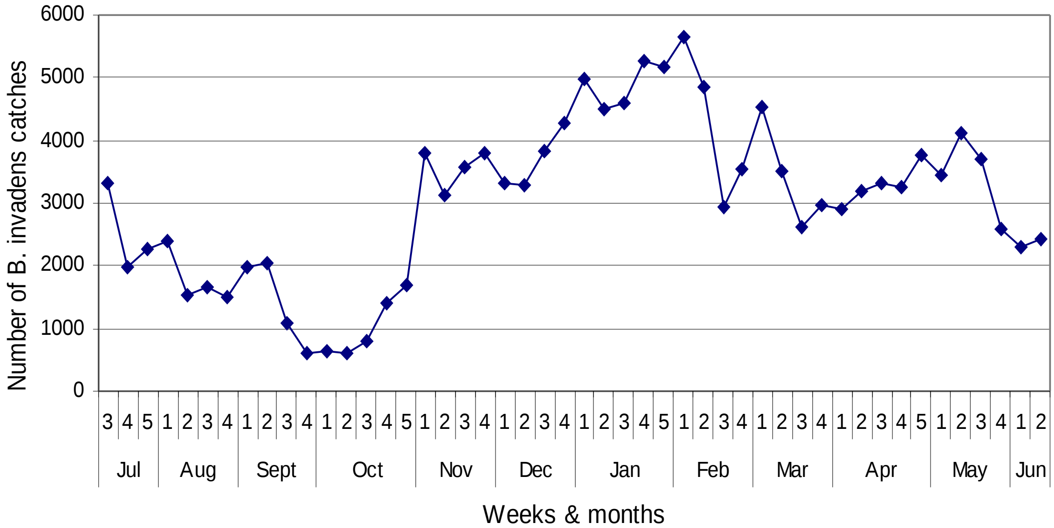

Figure 14: The general trend of *B. invadens* catches during the study period from July 2006 to June 2007

4.2.2 Temporal effects of lure types on *B. invadens* catches

Table 2 shows the results of the Analysis of Variance (ANOVA) performed to determine the statistical differences in means of *B. invadens* catches between the three attractants. The results revealed that there was significant difference (at P= 0.05) between ME catches and the other two attractants. There was no significant difference (at P= 0.05) between PB and TM catches. Mean catches from ME attractants are very high as compared to those from PB and TM. Based on the results, ME attractant becomes the best attractant for *B. invadens*. TM catches on *B.invadens* were expected since it was used as a control.

Table 2: Attractants effect on mean *B. invadens* catches

Attractant	ME	PB	TM
Mean catches	573.2 a	2.9 b	0.0 b

Mean values with the same letters are not significantly different at P= 0.05

Figures 15 and 16 presents the specific trends of fruit fly catches for each orchard and attractant used in the study. The trend in ME catches (Fig. 15) show a declining population as the trapping period began from the third week of July reaching the lowest level in early October. The population decline is the result of the cool and dry season. The population started to increase from the third week of October. This period corresponds to the onset of the short rainy season as shown in figure 19. Temperature at this time was between 30 and 32°C. It is at this time when most of the tropical trees form new flushes of growth. During the cool and dry season from June to September, the rate of growth is usually reduced (Verheij, 1982). According to Pedigo (1996) rainfall affects plant phenology and nutrient quality for insects. Not only that but also rainfall is one of the factors for rapid increase of *Bactrocera* species (Amice and Sales, 1997). Low temperatures appear to have a negative impact on *B. invadens* population as revealed by Mwatawala *et al.* (2006a), who reported on the failure of the invasive fruit fly to dominate other flies in high altitude areas where temperatures are cooler.

The fruit fly population reached its maximum level between January and February, after which it declined slightly, but remaining high above 3000 catches per week up to the beginning of June when it further declined repeating the cycle. The high population at that time is directly linked with the hot and wet season. The season is usually characterised by high temperature, relative humidity and short rains. All of these weather components have a direct effect with fruit flies population. The trend of *B. invadens* catches by ME lure assumes the general trend because it is mostly dominated by ME highest catches. As compared to other attractants, ME catches are perhaps very high because of its characteristic of being a strong attractant, able work within a wide area hence very efficient (White and Elson-Harris, 1992). On the hand, the high numbers give a true reflection of how big the fruit fly problem is.

The trend in PB catches as presented in figure 16, shows a decreasing *B. invadens* population from May to end of August and thereafter an increase that led to the formation of peak during the second week of September. At this time (September) guava, most citrus fruits like sweet orange, lime and grapefruit (Fig. 4 - 6) were available at ripening stage in addition to the non-seasonal fruits which are always present. The peak is further followed by a decline between October and March, when a sudden rise was observed up to April. Protein bait lures are known to work at a shorter distance giving a reflection of the fruit fly population within the nearby surrounding, like within a small orchard. PB catches as shown in Fig. 16 reflects population peaks within the orchards where the trap was.

A number of other tephritids than *B. invadens* were trapped by PB and TM traps. Since PB is not species specific and TM targets fruit flies of the sub-genus Ceratitis (White and Elson-Harris, 1992) it was normal for these lures to catch other fruit flies. Table 3 shows the total number of fruit fly catches by each lure and orchard including number of other tephritids. The table shows clearly the dominance of *B. invadens* as compared to other fruit flies in the area. This can be shown in ME and PB catches. Numbers of catches from ME are very high. *B. invadens* catches from PB which is a non-specific attractant are twice to those of other tephritids. The other tephritids caught from TM attractant shows that the invasive *B. invadens* are more hazardous than the others which include mostly the indigenous fruit flies.

Table 3: Total number of fruit flies trapped by each lure and orchard

Lure	**Orchard**	**Number of traps**	***B. invadens***	**Other tephritids**
ME	Citrus	2	40207	0
	Mango	2	74305	2
	Guava	1	34328	0
PB	Citrus	2	345	171
	Mango	2	247	128
	Guava	1	421	287
TM	Citrus	2	0	223
	Mango	2	0	160
	Guava	1	2	93
Total		**15**	**149855**	**1064**

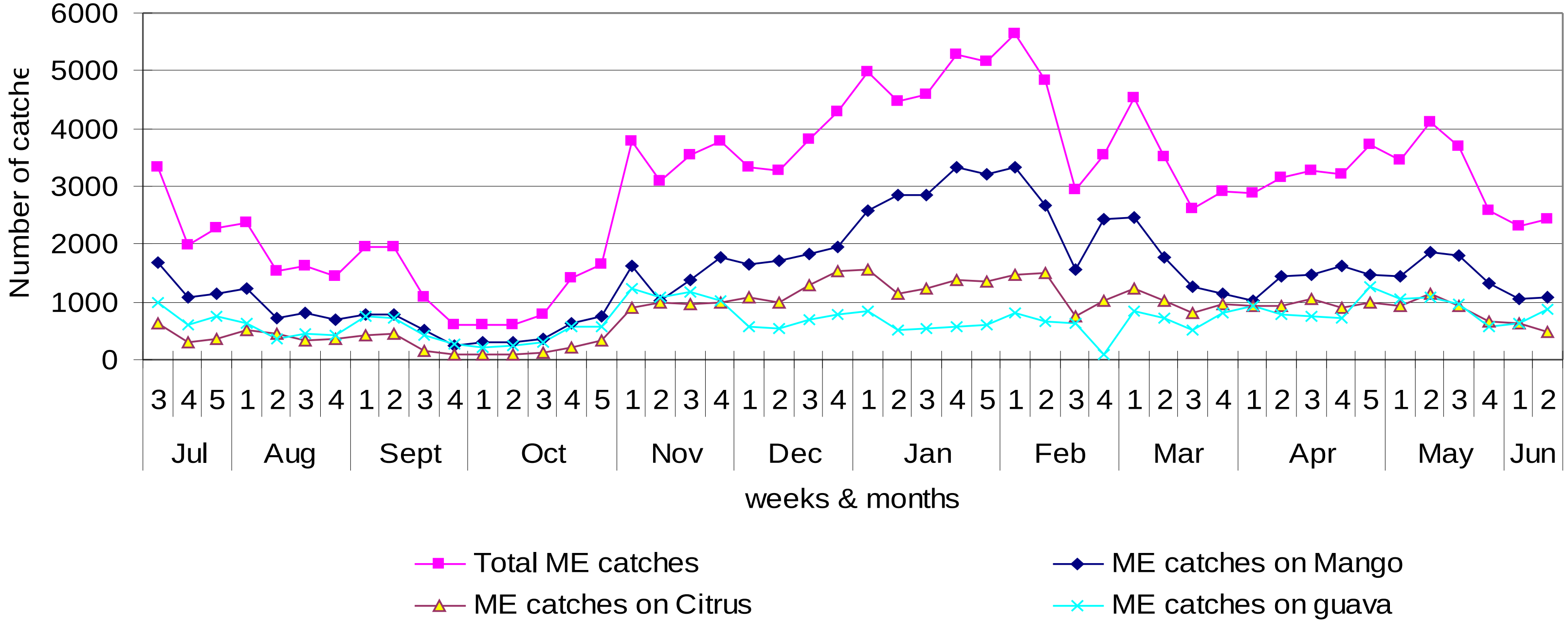

Figure 15: Catches of *B. invadens* from the three orchards by Methyl euginol attractant

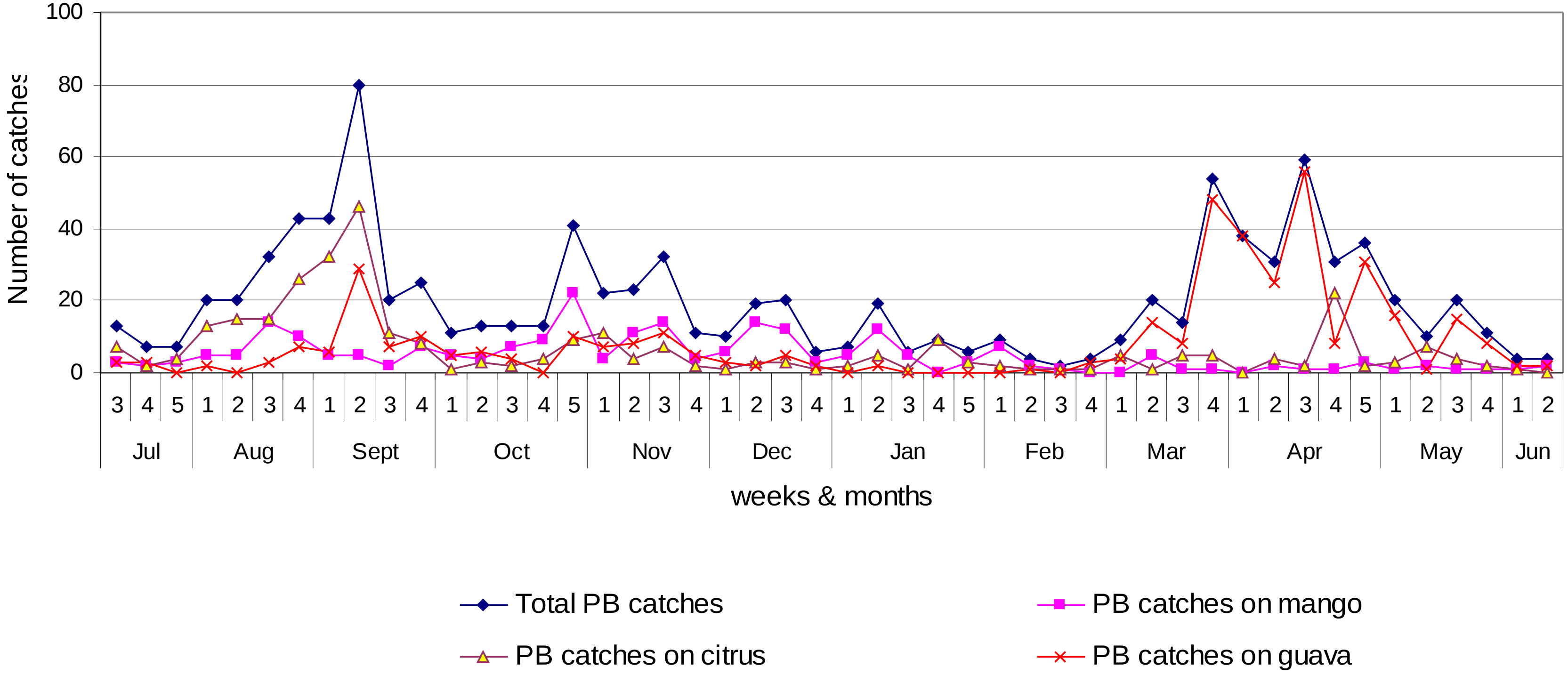

Figure 16: Catches of *B. invadens* from the three orchards by Protein bait

4.2.3 Variations in catches of *B. invadens* between sub-orchards

Figure 17 presents the trend of *B. invadens* catches from the three sub-orchards of mango, citrus and guava. Results (Table 4) showed a significant difference (at P= 0.05) between mango and citrus sub-orchards in the mean numbers of *B. invadens* catches. Mango sub-orchard had the highest catches. Guava was not included in the analysis since the attractants were a single replicate (Table 4).

Table 4: Variations in *B. invadens* mean catches between mango and citrus sub-orchards

Sub-orchard	Mango	Citrus
Mean catches	247.4a	136.7b

Mean values with the same letters are not significantly different at P= 0.05

The trend in mango catches started with a decreasing population that can be associated with a cool and dry season in July. The least population occurred from the last week of September to mid-October. This was followed by a population increase reaching a peak in mid-January to February. The population increase at this time corresponds with the onset of the short rainy season, increasing temperature and relative humidity. This is also the time when mango fruits were available (Fig. 3). The population drop in mid February corresponds to the end of the short rainy season, changes in temperature and also the ending of the mango season. As earlier stated, what counts the most is what weather changes does to plants and then to the insects. It is obvious that the beginning of the long rains in March became responsible for the population increase from the last week of February. The trend shows that the population was maintained in April and slightly increased in May before a decrease in June as a result of the cool and dry season.

The trend in citrus catches also start with a decreasing population from July to the least population at the end of September to mid October. From there the population started to increase following both the short and long rainy seasons. The population peak in citrus catches occurred during the last week of January and the first week of February.

The trend of catches in guava differed from the others by having its peaks during the first week of November and during the last week of April. Another difference is the population increase during the start of the cool and dry season in June. These differences can be linked to the phenological events in guava because the population increased at the time when mature and ripe guava fruits became available as hosts to fruit flies.

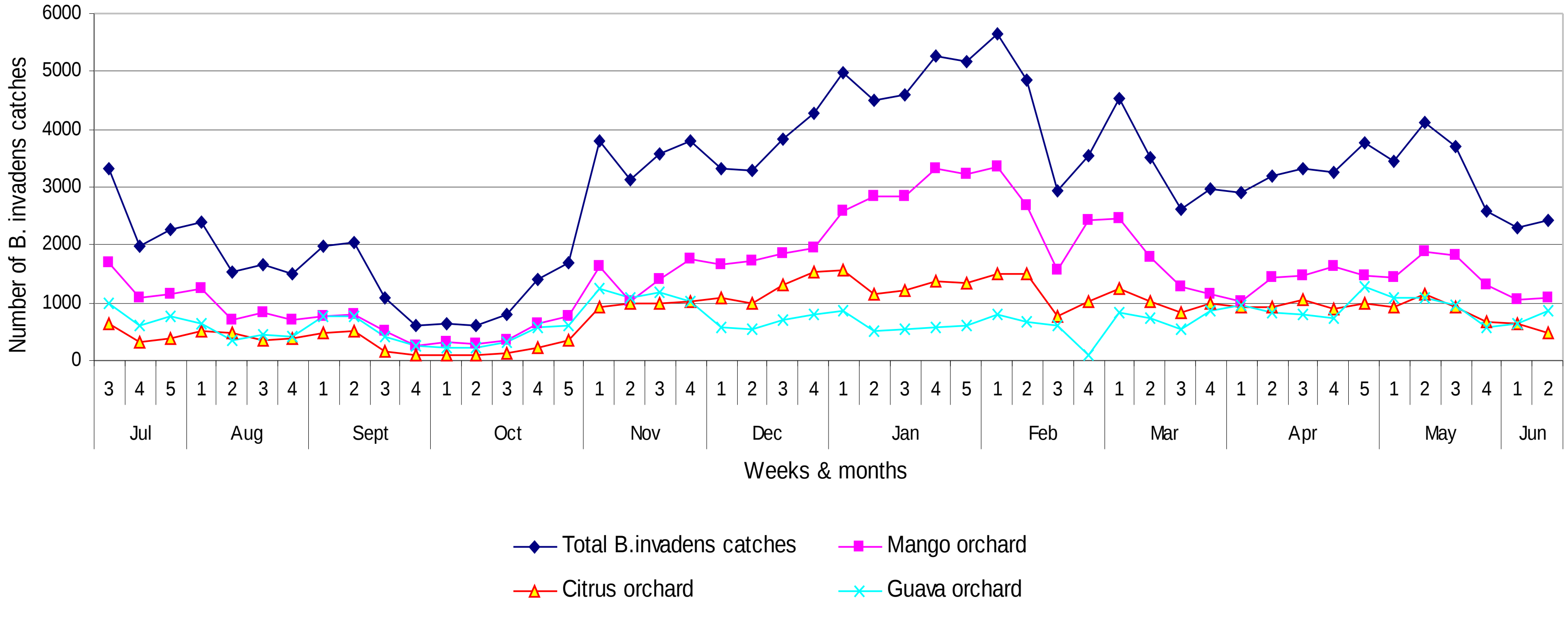

Figure 17: Catches of *B. invadens* from the three orchards

4.2.4 Variations in *B. invadens* catches for the different trapping cycles

The twelve trapping cycles were formed by lure changing dates and their corresponding calendar weeks. ANOVA results of *B. invadens* mean catches for each trapping cycle are presented in Table 5. Results show significant differences (at P= 0.05) between cyclic catches. Cycle seven has the highest catches and placed in the highest rank. Highest catches in cycle seven which fall under the first four weeks of January, can be explained by the weather conditions before and during the season whereby there were short rains at the time, also the presence of many fruits like mango, guava lime and grapefruits to mention a few.

Trapping cycle number seven is followed by cycle eight and six in the second rank. These two trapping cycles are followed by the third rank with cycles five, nine, ten and eleven. The fourth rank carries cycles one, two, four and twelve while the last rank has only trapping cycle number three. Reasons for cycle three to have the least of all mean catches can be linked directly to the dry season that occurred before cycle one in June. The ending of the sweet orange fruits season, leaving only guava available as host at the time may have contributed to the low population of fruit flies, implying that fruit flies host fruits were less abundant.

Trapping cycles would have similar number of catches if there were no effect from weather and plant phenology because for each cycle the lures used are the same as well as the number of traps. Therefore, this analysis is a proof to the fact that fruit fly population dynamics particularly of *B. invadens* are indeed influenced by plant phenology and its impact on host suitability.

Table 5: Variations of *B. invadens* mean catches between trapping cycles

Cycles	Mean catches	Corresponding weeks
One	122.3 d	Third week of July to the first week of August
Two	100.1 d	Second week of August to the first week of September
Three	37.3 e	Second week of September to the first week of October
Four	103.8 d	Second week to the last week of October
Five	207.3 c	All weeks in November
Six	281.4 b	All weeks in December
Seven	361.4 a	First to the fourth week of January
Eight	307.7 b	Last week of January to the third week of February
Nine	226.8 c	Last week of February to the third week of March
Ten	198.8 c	Last week of March to the third week of April
Eleven	226.8 c	Fourth week of April to the second week of May
Twelve	135.9 d	Fourth week of April to the second week of May

Mean values with the same letters are not significantly different at P= 0.05

4.3 Impact of weather (rainfall, relative humidity and temperature) on seasonal abundance of *B. invadens*

4.3.1 Temperature

Figure 18 presents the weekly maximum and minimum temperature and *B. invadens* catches. Minimum temperatures during the study period ranged from 14.1°C to 22.5°C while maximum temperatures ranged from 27.0°C to 35.0°C. As it is always in the tropics, the difference between daily maximum and minimum temperature is higher but the difference between one day and another day is very low. Change in temperature is mostly observed during the cool season from June-September covering seasons one, two, three and twelve. Looking at Figure 18, the number of catches at that time was very low with the least catches in September. The population appear to decrease with decreasing temperature from one trapping cycle to another and increase with increasing temperature.

Temperatures recorded during the study period are higher as compared to the general ten year averages. The higher temperatures are probably due to the effects of global warming. Temperatures were high but the trend of change remained the same as the coolest and the hottest months were the same in both cases. High temperatures are known to affect the fruit fly abundance. According to the observations made by Amice and Sales (1997) high temperature is reported to correspond to fruit fly population peaks. Herms (1997) also observed that early emergence of insects are highly influenced by warm temperatures. Mwatawala *et al.* (2006b) reported that in low-and mid-altitude areas of Morogoro, *B. invadens* was present in higher numbers while in high altitude areas where temperature is low the fly was only present during a short period and in relatively low numbers. Observations from this study and other observations mentioned above clearly explain how fluctuation in temperature influences the population dynamics of fruit flies particularly *B. invadens*.

4.3.2 Rainfall

Figure 19 summarizes rainfall patterns between one trapping cycle to another and their corresponding numbers of fruit fly catches. Trapping cycles with higher rainfall records start from cycle four to eleven (October to May) where by the number of catches are also higher. Peak catches appear at the midst of trapping cycles with the highest rainfall totals which are cycles seven and eight (January and February). Number of catches increases with increasing rainfall amounts and decreases when rainfall amounts decrease.

Rainfall amounts received during the study period were higher as compared to the general ten year averages but the pattern remained the same. The same observations as from this study that periods of high rainfall correspond with high fruit fly population were reported by Amice and Sales (1997) and Vayssieres *et al*. (2005), while Pedigo (1996) found that rainfall affect plant phenology and nutrient quality for insects. All these observations insist on the importance of rainfall as a factor in fruit fly population dynamics.

4.3.3 Relative humidity

Figure 19 also shows the influence of relative humidity on total fruit fly catches for each trapping cycle. Minimum relative humidity ranged from 36% to 66% while maximum relative humidity ranged from 82% to 97%. As the figure shows, decrease and increase in relative humidity is directly related to the trend of the number of catches. According to Samson (1986) atmospheric humidity influences growth and development of plants as low humidity has a drying effect to plants. Fruit flies then depend on those plants for survival. This makes relative humidity too an important factor for fruit fly abundance.

Fruit flies themselves are also affected by low relative humidity as it is commonly known that the lower the relative humidity the lower the water content inside their bodies. This condition affects their ability to survive and reproduce hence decreasing fruit fly population.

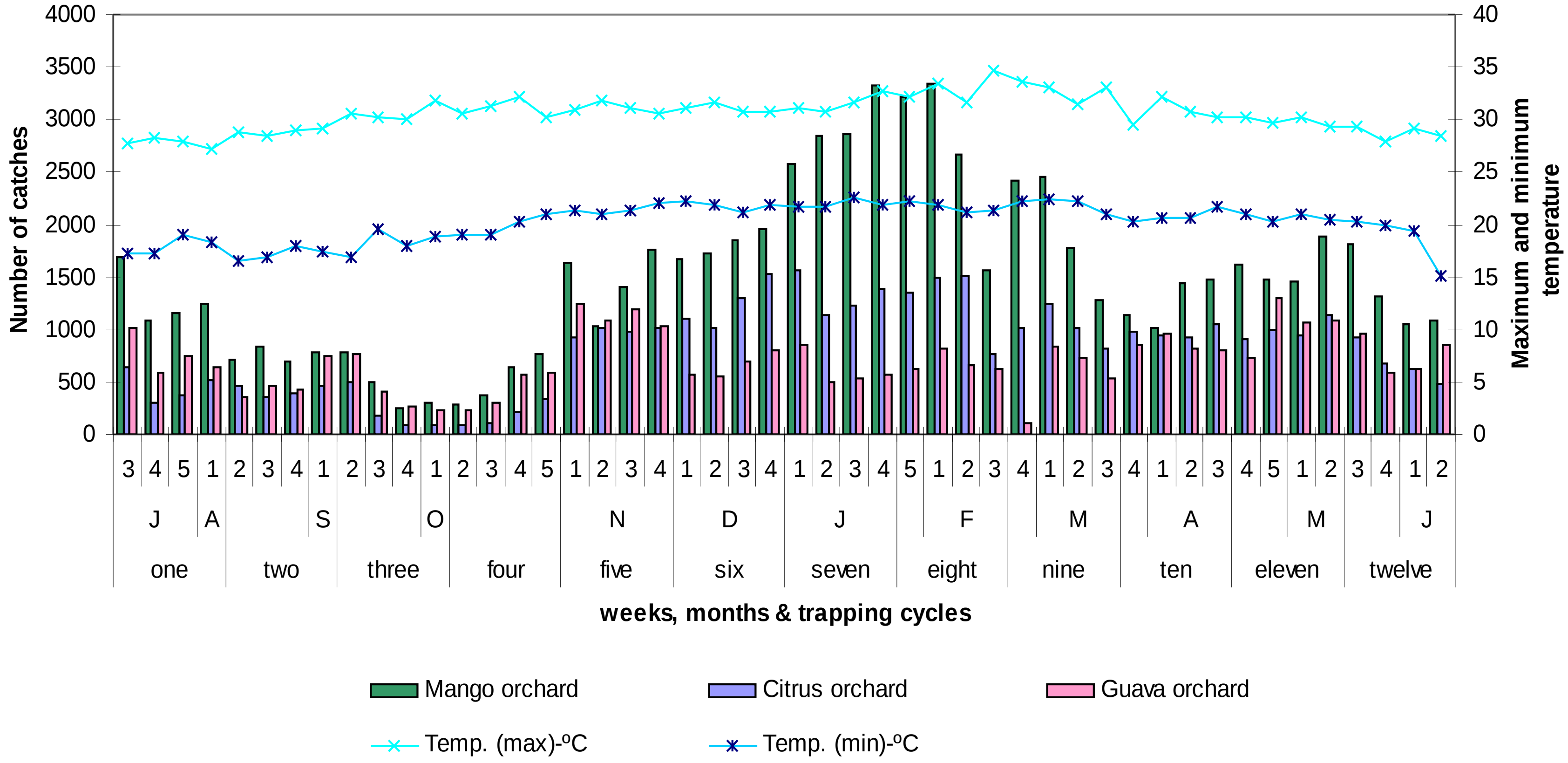

Figure 18: Numbers of trapped *B. invadens* from the three sub-orchards with maximum and minimum weekly temperature averages

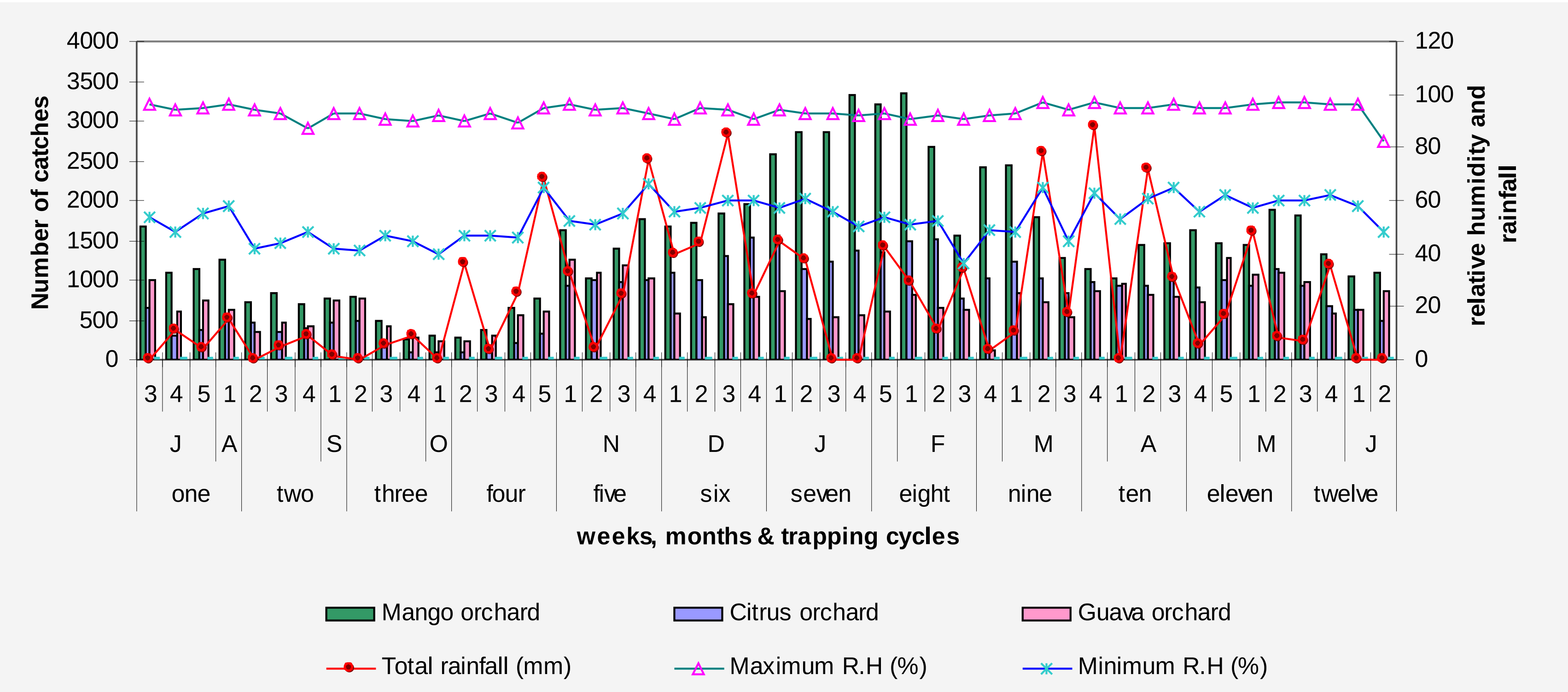

Figure 19: Numbers of trapped *B. invadens* from the three sub-orchards with weekly total rainfall, average maximum and minimum relative humidity

Fruit phenological developments show a direct relationship with weather changes and population dynamics of *B. invadens*. The observation that host availability and abundance are among the factors determining the population fluctuations of *Bactrocera* species, agree with earlier observations by Drew and Hooper (1983), Vargas *et al.* (1990) and Vayssières *et al.* (2005) who reported that population of *B. invadens* increases with rise in temperature and rainfall. According to Samson (1986) the rate of growth in plants is reduced during the cool and dry season from June to August in the tropics. The reduction in growth affects phenological development in fruits and fruit fly abundance.

The influence of the presence of some host fruits on abundance of *B. invadens* can be seen clearly during the time when mango fruits are available in their immature, mature and ripe stages in November to March. The mango fruiting season which is usually characterized by high rainfall, temperature and relative humidity corresponds to the highest catches of *B. invadens*. The high catches are probably contributed to a large extent by those favourable weather conditions during those months, but the influence of mango fruiting on *B. invadens* at the time can not be ignored. Mangoes are available only once in a year but seem to have a pronounced effect on *B. invadens* numbers. Presence of guava fruits also has proved to have an influence on fruit fly abundance since high catches were maintained during the times when mature to ripe guava fruits were available regardless of the prevailing weather conditions. The observation that mango and guava may be the most favourable hosts does not ignore the contribution from other fruits where no traps were hung like from the annona orchard.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The overall objective of this study was to assess the temporal and spatial presences of *B. invadens* in relation to the fruiting of economically important fruit crops species. Phenological development of 21 commercial fruit species/varieties was studied. At the same time *B. invadens* and other fruit flies were trapped using Methyl euginol, Trimedlure and Protein bait (ME, TM and PB respectively) attractants. Findings revealed that phenological development in the studied fruit crops responded very well to weather changes represented by temperature, rainfall and relative humidity components. Analysis of the results with respect to fruit fly trapping revealed that ME was the most efficient attractant of the three.

It has been shown in this study that *Bactrocera invadens* is present throughout the year with its population changing due to changes in weather and presence of various host plants. Their number in comparison to other tephritids, are extremely high. The highest population recorded in October to February was attributed to a combination of high rainfall, rising temperatures and relative humidity which favours at the same time the presence of many seasonal host fruits including mango and non seasonal fruits like guava. Although, only a single trap had been used in the guava orchard, the catches found in it were very high indicating that it is a very important host for *B. invadens*. In this study, the fact that fruit phenology and changes in the weather affect population dynamics and seasonal abundance of fruit flies has been brought to light using *B. invadens* as an example.

5.2 Recommendations

Findings from the study support the recommendation that plant phenology be used as a tool in Integrated Pest Management not only for control of fruit flies, but also for control of other insect pests. In order to reduce fruit losses due to fruit flies, other management methods like orchard sanitation are also strongly recommended. This is because many fruits in their immature, mature, ripe and decaying stages, if they are just left on the ground they play a big role in fruit fly reproduction and development.

From observations made in this study, taking mango fruits as an example, it is hereby suggested that management measures should be applied when young immature mango fruits are formed and drop from the trees. Orchard sanitation in this case by collecting and burying the fruits or by putting the collected fruits in a black plastic bag at weekly intervals is highly recommended. This fruit fly management method is recommended because it is the easiest, cheapest, safest and efficient but mostly feasible in a small orchard. For more effective results the same methods should be done for other fruits in the orchard.

In order to reduce the fruit fly problem to manageable levels or even to elimination all integrated pest management methods should be researched and practised. Focus should also be on wild hosts which also play a major role in fruit fly multiplication as alternative hosts especially when other preferable commercial hosts are off-season. Another research focus can be on management practices using plant phenology information to discover the exact time of using insecticides to control *B. invadens* so as to make an efficient and cost effective management.

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APPENDIX

ANOVA tables

Genstat 4.24 DE Anova Tables

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GenStat Release 4.24DE  (PC/Windows XP)             20 July 2007
12:14:33
Copyright 2005, Lawes Agricultural Trust (Rothamsted Experimental
Station)

The GenStat Discovery Edition can be used for educational or not-for
profit
research purposes in qualifying countries. A list of qualifying countries
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be viewed at http://discovery.genstat.co.uk. Commercial use of the
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                ________________________________________

                GenStat Discovery Edition 2
                GenStat Procedure Library Release PL12.2
                ________________________________________

   1  %CD 'D:/Documents and Settings/Mwatawala/Desktop/Ceratitis paper'
   2  "Data taken from File: \
  -3  D:/Documents and Settings/Mwatawala/Desktop/Lilian/Efficacy ME.xls"
   4  DELETE [Redefine=yes] _stitle_: TEXT _stitle_
   5  READ [print=*;SETNVALUES=yes] _stitle_
   9  PRINT [IPrint=*] _stitle_; Just=Left
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 Data imported from Excel file: D:\Documents and
Settings\Mwatawala\Desktop\Lili
an\Efficacy ME.xls
  on: 20-Jul-2007 12:15:39

  taken from sheet "Sheet1", cells A7:H151



  10  DELETE [redefine=yes]
Season,Attractant,Orchard,Repl,B_invadens_male,\
  11  B_invadens_female,B_invadens_total
  12  FACTOR [modify=yes;nvalues=144;levels=12;labels=!
t('eight','eleven','five',\
  13  'four','nine','one','seven','six','ten','three','twelve','two')]
Season
  14  READ Season; frepresentation=ordinal

    Identifier    Values   Missing    Levels
        Season       144         0        12

  20  FACTOR [modify=yes;nvalues=144;levels=3;labels=!t('ME','PB','TM')\
  21  ] Attractant
  22  READ Attractant; frepresentation=ordinal

    Identifier    Values   Missing    Levels
    Attractant       144         0         3

  27  FACTOR [modify=yes;nvalues=144;levels=2;labels=!
t('citrus','Mango')] Orchard
  28  READ Orchard; frepresentation=ordinal
```

```
    Identifier    Values   Missing    Levels
       Orchard       144         0         2

  33  FACTOR [modify=yes;nvalues=144;levels=4;labels=!t(\
  34  'Citrus var Sweet seedling','Citrus var Tahiti lime','M.indica var
Dodo',\
  35  'M.indica var Sindano nyeusi')] Repl
  36  READ Repl; frepresentation=ordinal

    Identifier    Values   Missing    Levels
          Repl       144         0         4

  41  VARIATE [nvalues=144] B_invadens_male
  42  READ B_invadens_male

    Identifier   Minimum      Mean   Maximum    Values   Missing
B_invadens_male    0.0000     191.3      1620       144         0    Skew

  51  VARIATE [nvalues=144] B_invadens_female
  52  READ B_invadens_female

    Identifier   Minimum      Mean   Maximum    Values   Missing
B_invadens_female    0.0000    0.7795     17.50       144         0
Skew

  59  VARIATE [nvalues=144] B_invadens_total
  60  READ B_invadens_total

    Identifier   Minimum      Mean   Maximum    Values   Missing
```

```
B_invadens_total    0.0000     192.0      1620       144          0
Skew

RESTRICT Season,Attractant,Orchard,Repl,B_invadens_male,B_invadens_female,\
B_invadens_total

"Split-Split-Plot Design."
BLOCK Repl/Season/Attractant/Orchard
TREATMENTS Attractant + Orchard + Attractant.Orchard + Season + Season.Attractant + Season.Orchard + Attractant.Orchard.Season
COVARIATE "No Covariate"
ANOVA [PRINT=aovtable,information,means; FACT=32; FPROB=yes; PSE=diff] B_invadens_total
```

76...

***** Analysis of variance *****

Variate: B_invadens_total

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Repl stratum					
Orchard	1	441090.	441090.	41.11	0.023
Residual	2	21460.	10730.	3.70	
Repl.Season stratum					
Season	11	1207277.	109752.	37.81	<.001
Season.Orchard	11	181967.	16542.	5.70	<.001
Residual	22	63859.	2903.	0.82	
Repl.Season.Attractant stratum					
Attractant	2	10461130.	5230565.	1479.67	<.001
Attractant.Orchard	2	890006.	445003.	125.89	<.001
Season.Attractant	22	2439153.	110871.	31.36	<.001
Season.Attractant.Orchard	22	359386.	16336.	4.62	<.001
Residual	48	169678.	3535.		
Total	143	16235006.			

```
* MESSAGE: the following units have large residuals.

Repl M.indica var Dodo            Season five          51.6   s.e. 21.1
Repl M.indica var Dodo            Season seven        -46.8   s.e. 21.1
Repl M.indica var Sindano nyeusi  Season five         -51.6   s.e. 21.1
Repl M.indica var Sindano nyeusi  Season seven         46.8   s.e. 21.1

Repl Citrus var Sweet seedling    Season six     Attractant ME
                                                         85.4   s.e. 34.3
Repl Citrus var Tahiti lime       Season six     Attractant ME
                                                        -85.4   s.e. 34.3
Repl M.indica var Dodo            Season five    Attractant ME
                                                        135.3   s.e. 34.3
Repl M.indica var Sindano nyeusi  Season five    Attractant ME
                                                       -135.3   s.e. 34.3

***** Tables of means *****
Variate: B_invadens_total

Grand mean  192.0

 Attractant        ME        PB        TM
                573.2       2.9       0.0

  Orchard   citrus    Mango
             136.7    247.4

 Attractant  Orchard   citrus    Mango
         ME             406.7    739.7
         PB               3.4      2.4
```

TM	0.0	0.0

Season	eight	eleven	five	four	nine	one	seven
	307.7	221.6	207.3	103.8	226.8	122.3	361.4

Season	six	ten	three	twelve	two
	281.4	198.8	37.3	135.9	100.1

Season Attractant	ME	PB	TM
eight	922.2	0.9	0.0
eleven	663.5	1.4	0.0
five	618.2	3.6	0.0
four	307.6	3.8	0.0
nine	678.9	1.5	0.0
one	363.8	3.1	0.0
seven	1081.9	2.4	0.0
six	841.4	2.8	0.0
ten	594.4	2.0	0.0
three	109.4	2.6	0.0
twelve	406.8	0.9	0.0
two	290.4	9.9	0.0

Season Orchard	citrus	Mango
eight	198.8	416.7
eleven	167.9	275.3
five	170.5	244.0
four	65.9	141.7
nine	176.3	277.4
one	69.7	174.9
seven	212.5	510.4

six	225.3	337.4
ten	166.3	231.3
three	18.3	56.3
twelve	97.2	174.6
two	71.7	128.6

Attractant		ME		PB		TM	
Season	Orchard	citrus	Mango	citrus	Mango	citrus	Mango
eight		595.8	1248.7	0.5	1.2	0.0	0.0
eleven		501.9	825.1	1.9	0.9	0.0	0.0
five		508.9	727.6	2.8	4.4	0.0	0.0
four		195.3	419.9	2.4	5.2	0.0	0.0
nine		526.6	831.3	2.1	0.9	0.0	0.0
one		204.8	522.8	4.4	1.9	0.0	0.0
seven		635.1	1528.6	2.3	2.5	0.0	0.0
six		674.7	1008.0	1.3	4.2	0.0	0.0
ten		495.3	693.5	3.5	0.5	0.0	0.0
three		52.1	166.6	2.9	2.2	0.0	0.0

twelve	290.4	523.1	1.1	0.6	0.0
0.0					
two	199.4	381.5	15.6	4.2	0.0
0.0					

*** Standard errors of differences of means ***

Table	Attractant	Orchard	Attractant Orchard	Season
rep.	48	72	24	12
s.e.d.	12.14	17.26	22.24	22.00
d.f.	48	2	5.41	22
Except when comparing means with the same level(s) of				
Orchard			17.16	
d.f.			48	

Table	Season Attractant	Season Orchard	Season Attractant Orchard
rep.	4	6	2
s.e.d.	40.77	34.42	59.51
d.f.	69.83	17.51	64.04
Except when comparing means with the same level(s) of			
Orchard		31.11	57.66
d.f.		22	69.83
Attractant.Orchard			57.66
d.f.			69.83
Season	42.04		
d.f.	48		

```
 Season.Orchard                                  59.46
 d.f.                                               48

  77  "Split-Split-Plot Design."
  78  BLOCK Repl/Season/Attractant/Orchard
  79  TREATMENTS Attractant + Orchard + Attractant.Orchard + Season +
Season.Attractant + Season.Orchard + Attractant.Orchard.Season
  80  COVARIATE "No Covariate"
  81  ANOVA [PRINT=aovtable,information,means; FACT=32; FPROB=yes;
PSE=diff,lsd; LSDLEVEL=5]\
  82   B_invadens_total

82.......................................................................
.......

***** Analysis of variance *****

Variate: B_invadens_total

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Repl stratum
Orchard                    1    441090.    441090.   41.11  0.023
Residual                   2     21460.     10730.    3.70

Repl.Season stratum
Season                    11   1207277.    109752.   37.81  <.001
Season.Orchard            11    181967.     16542.    5.70  <.001
Residual                  22     63859.      2903.    0.82
```

```
Repl.Season.Attractant stratum

Attractant                  2  10461130.   5230565. 1479.67  <.001

Attractant.Orchard          2    890006.    445003.  125.89  <.001

Season.Attractant          22   2439153.    110871.   31.36  <.001

Season.Attractant.Orchard

                           22    359386.     16336.    4.62  <.001

Residual                   48    169678.      3535.


Total                     143  16235006.



* MESSAGE: the following units have large residuals.


Repl M.indica var Dodo            Season five           51.6   s.e. 21.1

Repl M.indica var Dodo            Season seven         -46.8   s.e. 21.1

Repl M.indica var Sindano nyeusi  Season five          -51.6   s.e. 21.1

Repl M.indica var Sindano nyeusi  Season seven          46.8   s.e. 21.1


Repl Citrus var Sweet seedling    Season six     Attractant ME

                                                         85.4   s.e. 34.3

Repl Citrus var Tahiti lime       Season six     Attractant ME

                                                        -85.4   s.e. 34.3

Repl M.indica var Dodo            Season five    Attractant ME

                                                        135.3   s.e. 34.3

Repl M.indica var Sindano nyeusi  Season five    Attractant ME

                                                       -135.3   s.e. 34.3



***** Tables of means *****
```

Variate: B_invadens_total

Grand mean 192.0

Attractant	ME	PB	TM
	573.2	2.9	0.0

Orchard	citrus	Mango
	136.7	247.4

Attractant	Orchard	citrus	Mango
ME		406.7	739.7
PB		3.4	2.4
TM		0.0	0.0

Season	eight	eleven	five	four	nine	one	seven
	307.7	221.6	207.3	103.8	226.8	122.3	361.4

Season	six	ten	three	twelve	two
	281.4	198.8	37.3	135.9	100.1

Season	Attractant	ME	PB	TM
eight		922.2	0.9	0.0
eleven		663.5	1.4	0.0
five		618.2	3.6	0.0
four		307.6	3.8	0.0
nine		678.9	1.5	0.0
one		363.8	3.1	0.0
seven		1081.9	2.4	0.0
six		841.4	2.8	0.0

ten	594.4	2.0	0.0
three	109.4	2.6	0.0
twelve	406.8	0.9	0.0
two	290.4	9.9	0.0

Season	Orchard	citrus	Mango
eight		198.8	416.7
eleven		167.9	275.3
five		170.5	244.0
four		65.9	141.7
nine		176.3	277.4
one		69.7	174.9
seven		212.5	510.4
six		225.3	337.4
ten		166.3	231.3
three		18.3	56.3
twelve		97.2	174.6
two		71.7	128.6

	Attractant	ME		PB		TM	
Season	Orchard	citrus	Mango	citrus	Mango	citrus	Mango
eight		595.8	1248.7	0.5	1.2	0.0	0.0
eleven		501.9	825.1	1.9	0.9	0.0	0.0
five		508.9	727.6	2.8	4.4	0.0	0.0
four		195.3	419.9	2.4	5.2	0.0	0.0

nine	526.6	831.3	2.1	0.9	0.0	0.0
one	204.8	522.8	4.4	1.9	0.0	0.0
seven	635.1	1528.6	2.3	2.5	0.0	0.0
six	674.7	1008.0	1.3	4.2	0.0	0.0
ten	495.3	693.5	3.5	0.5	0.0	0.0
three	52.1	166.6	2.9	2.2	0.0	0.0
twelve	290.4	523.1	1.1	0.6	0.0	0.0
two	199.4	381.5	15.6	4.2	0.0	0.0

*** Standard errors of differences of means ***

Table	Attractant	Orchard	Attractant Orchard	Season
rep.	48	72	24	12
s.e.d.	12.14	17.26	22.24	22.00
d.f.	48	2	5.41	22

Except when comparing means with the same level(s) of

Orchard			17.16	
d.f.			48	

Table Season Season Season

	Attractant	Orchard	Attractant Orchard
rep.	4	6	2
s.e.d.	40.77	34.42	59.51
d.f.	69.83	17.51	64.04

Except when comparing means with the same level(s) of

Orchard		31.11	57.66
d.f.		22	69.83
Attractant.Orchard			57.66
d.f.			69.83
Season	42.04		
d.f.	48		
Season.Orchard			59.46
d.f.			48

*** Least significant differences of means (5% level) ***

Table	Attractant	Orchard	Attractant Orchard	Season
rep.	48	72	24	12
l.s.d.	24.40	74.28	55.89	45.61
d.f.	48	2	5.41	22

Except when comparing means with the same level(s) of

Orchard			34.51	
d.f.			48	

Table	Season Attractant	Season Orchard	Season Attractant Orchard
rep.	4	6	2
l.s.d.	81.31	72.47	118.89

d.f.	69.83	17.51	64.04
Except when comparing means with the same level(s) of			
Orchard		64.51	115.00
d.f.		22	69.83
Attractant.Orchard			115.00
d.f.			69.83
Season	84.53		
d.f.	48		
Season.Orchard			119.54
d.f.			48