Assessment of the role and impact of Agroecosystem diversification on maize stemborer, leucaena psyllid and their natural enemies at the Kenyan Coast.

By

Aura Charles Midega
B.Sc. (Hons)
Jomo Kenyatta University of Agriculture and Technology

A thesis submitted in partial fulfilment for the degree of Master of science (Msc) of Kenyatta University.

August 2001

DECLARATION BY CANDIDATE

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

Aura Charles Midega — **Date** 2/5/02

DECLARATION BY SUPERVISORS

This thesis has been submitted with our approval as supervisors.

Dr. Callistus K. P. O. Ogol
Zoology Department
Kenyatta University
P.O. Box 43844,
NAIROBI.

C.K.P.O. Ogol — **Date** 16th May 2002

Dr. William. A. Overholt
The International Centre of Insect
Physiology and Ecology (ICIPE)
P.O.BOX 30772
NAIROBI.

W.A. Overholt. — **Date** 2 MAY 2002

DEDICATION

This work is dedicated to my family who gave me all the support I needed during the course of this study.

ACKNOWLEDGEMENTS

The work reported in this thesis would not have been possible without the help and encouragement provided by many people. First, I gratefully acknowledge the support, expert guidance, encouragement and great patience expressed to me by my supervisors Dr. C.K.P.O. Ogol and Dr. W.A.Overholt throughout this study. Secondly, I wish to acknowledge ICIPE for granting me an opportunity to train in the Dissertation Research Internship Programme (DRIP), ICIPE/WAU stemborer biocontrol project for hosting me during the whole study period and biosystematics unit for assisting with the identification of the recovered stemborer natural enemies. I am also grateful to the field assistant attached to the project John Owuoche Ambajo and the casual workers who in one way or the other made contributions to the success of the study.

I acknowledge the Rockefeller Foundation FORUM on Agricultural Resource Husbandry for funding the study, Kenya Agricultural Research Institute (KARI) Mtwapa for hosting the study through the provision of experimental field and laboratory space. Finally, I give thanks to the staff of Zoology Department Kenyatta University for offering assistance of various kinds during the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Lepidopteran stemborers are a major constraint to the production of cereals in the tropics with *Chilo partellus* (Lepidoptera: Crambidae) being the most serious species. The pest is an exotic species that originated from Asia. Chemical control of the pest is unpractical and can only be effective during a limited period when the first and second larval instars are feeding on the leaf tissues after which they bore into the stem. Classical biological control using parasitoids and predators in an agroecosystem was considered to provide prospects of additional protection to cereals. Leucaena is an essential leguminous agroforestry tree species with several uses besides alley cropping. Leucaena psyllid is threatening the future use of leucaena as an agroforestry tree. Classical biological control using exotic parasitoids has been tried but their establishment and efficacy had not been determined. The current study assessed the role of agroecosystem diversification as a way of promoting the numerical and functional levels of the pests' natural enemies. Studies were conducted at Mtwapa in Coastal Kenya and spanned over a period of 4 cropping seasons. Treatments consisted of hedgerows of leucaena only, gliricidia only, alternating rows of leucaena and gliricidia, and four plots without trees. During the cropping seasons, maize was planted between the hedgerows while a row of cowpea was planted between the rows of maize. Foliar sprays of malathion to control the psyllid were applied on one of the leucaena-only hedgerows. One of the plots without trees was planted with an intercrop of maize and cowpea. The remaining three plots without trees were planted with

maize alone and one of them protected from attack by stemborers by use of Bulldock (betacyfluthrin) granules. The treatments were laid out in a randomised complete block design and replicated four times. Mean rates of egg parasitism were found to be high (>70%) while larval and pupal parasitism rates were low (<10%) for all the treatments. These rates however did not support the enemies hypothesis (neutral response), indicating that the vegetation structures and cultural treatments established in the study did not enhance the activity of the egg, larval and pupal parasitoids. Predation rates were generally low in all the treatments (6.7-13%) with no significant difference among the treatments to support the natural enemies hypothesis. Thus, immigration into, retention and efficacy of predators were not influenced by the vegetation structure. Mean larval and pupal mortality rates were low in all the treatments, ranging from 4.8 to 9.6%. Some of the larvae and pupae under this category had a characteristic common dark coloration on the entire body, suggesting that the mortality factor in this case was associated with microbial agents. These rates however had no significant difference pattern to support the notion that agroecosystem diversification leads to higher natural enemy levels and efficacy. Life table analyses results show no conspicuous natural enemy activity in the more diverse cropping systems as there were no marked variation in intergeneration and mean real generation mortalities among treatments. The main mortality factor was 'disappearance', which represented mortality caused by factors other than parasitoids. Both *Tamarixia leucaenae* and *Psyllaephagus yaseeni* were recovered at every sampling occasion

parasitising the leucaena psyllid, indicating their successful establishment since they are present in the field. The parasitism indices obtained showed that the parasitoids had a significant impact on the pest, though not offering effective control. In spite of this, they certainly contribute towards the overall aim of reducing and keeping under check the pest levels.

CHAPTER ONE

1 GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 General Introduction

Cereal grains form a major staple food source for millions of people in Africa. Sorghum and millets are the traditional staple cereals in most eastern and southern African countries and they used to be the only cereals grown until the introduction of maize about 80 years ago. Maize is now quite extensively grown in the region primarily by the subsistence farmers and provides fodder apart from food. Stemborers constitute one of the major constraints to efficient maize and sorghum production in the developing world (Ampofo, 1986). Most of the stemborer species are native to Africa. These include the noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* (Hampson), the crambids *Chilo orichalcocilliellus* Strand and *Chilo partellus* Swinhoe, and the pyralid *Eldana saccharina* Walker (Ampofo, 1986). *C. partellus* is one of the major stemborer pests in Kenya (Overholt *et al.*, 1994a). The pest was introduced into Africa in the early 1930's (Tams, 1932) from Asia and now occurs throughout the eastern, central and southern parts of the African continent (Harris, 1990). It is the most important stemborer at low and mid elevations in East Africa (Seshu Reddy, 1983).

The species of stemborers infesting maize and sorghum are for the most part, the same, and produce similar symptoms of damage. Newly hatched larvae congregate inside the leaf whorls and feed actively on folded central leaves, causing typical pinhole symptoms (Mathez, 1972). Later on, they feed on the central growing stem of the young

plants, resulting in deadhearts. If the growing point has already moved upwards, only stem tunnelling takes place. The damaged plants become weak and stunted and bear very small cobs/panicles. The stemborer larvae also bore into the maize cobs and feed on the developing seeds (Mathez, 1972, Seshu Reddy, 1983).

Stemborers have a wide range of wild hosts like the numerous wild grasses that serve as reservoirs during non-cropping seasons. It has been suggested that these wild grasses could be destroyed to decrease the survival of stemborers between seasons (Ingram, 1958). This is however less practical due to its being labour intensive. The wild hosts that maintain populations of stemborers between seasons could also indirectly maintain the populations of the natural enemies.

In considering the strategies for the management of maize and sorghum stemborers, it is important and essential to develop Biologically Intensive Integrated Pest Management (BIIPM) strategies that are environmentally safe, economically feasible and acceptable to the resource-limited farmers (Seshu Reddy, 1983). BIIPM fits well into the economy of maize and sorghum cultivation under subsistence farming conditions (Seshu Reddy, 1983). Some useful information has been generated on different methods of controlling the stemborers. These include developing plant resistance to stemborers, cultural control, biological control and botanical control. Supportive tactics include the application of pheromone biology and crop-loss assessment (Dabrowski and Kidiavai, 1983; Omolo, 1983; Ampofo *et al.*, 1986).

1.2 Literature review

1.2.1 Life history and pest status of *Chilo partellus*

Female *C. partellus* moths oviposit eggs in batches of 10-80 eggs on the leaves or stem of maize and sorghum plants (Harris, 1990). The eggs that escape the natural enemies and harsh weather conditions hatch in 4 to 8 days after being oviposited (Berger, 1989), after which the larvae initially feed on the leaf whorl before tunnelling into the stem causing crop damage (Overholt *et al.*, 1994a). Larval development is completed in 2 to 4 weeks and larvae pupate in the damaged stems. The pupal period lasts 5 to 12 days and during the growing season the life cycle is completed in 25 to 50 days (Harris, 1990).

Early instar larvae of *C. partellus* feed initially by scraping in leaf whorls of growing plants, producing characteristic "window-paning" and "pin holes" (Mathez, 1972; Ampofo, 1986). Later, the larvae tunnel into the stems and may kill the central leaves and growing points producing "dead-hearts". The larvae also bore into the maize cobs and feed on the developing seeds/grains (Seshu Reddy, 1998). Plants affected thus have poor growth, reduced yield and are more susceptible to wind damage and secondary infections (Seshu Reddy, 1998).

Yield losses of 18% in maize due to damage caused by *C. partellus* and *C. orichalcocilliellus* has been recorded in Kenya (Warui and Kuria, 1983). Seshu Reddy and Sum (1991) also reported a maximum grain yield reduction and stalk damage in maize (cultivar Quatrain) due to *C. partellus* at 20 days after plant emergence, while there was insignificant larval effect on yield in plants infested at 60 days after emergence. In Uganda a 56% loss of grain yield resulted when sorghum was infested with *C. partellus* 20 days

after plant emergence (Starks, 1969), whereas in Kenya losses have ranged between 2% and 88% (Seshu Reddy, 1988).

1.2.2 Management of stemborers

Methods currently used to manage stemborers include chemical, cultural and biological control (Litsinger and Moody, 1976; Minja, 1990). Several cultural practices have been implicated in stemborer control, mainly in disrupting or slowing down the population build-up (Minja, 1990). These include appropriate disposal of crop residues, time of planting, tillage and mulching, spacing, intercropping, removal and destruction of volunteer and alternative host plants, removal of borer-infested plants, fertilizer application and crop rotation (Minja, 1990). Cultural methods such as intercropping with non-cereals and early planting have been used for quite a long time by farmers (Litsinger and Moody, 1976; Minja, 1990). However, studies have shown that their impact on stemborer populations is limited (Oloo, 1989; Skovgard and Pats, 1996).

Several insecticides have been screened for the control of stemborers in different regions in Africa. These include carbofuran, carbaryl, deltamethrin, endosulfan, trichlorfon and synthetic pyrethroids (Seshu Reddy, 1985; Ajayi, 1989; Minja, 1990; Sithole, 1990; van Rensberg and van den Berg, 1992). Chemical control can effectively reduce stemborer numbers (Mathez, 1972; Warui and Kuria, 1983) but the relatively short time larvae are exposed before they enter the stems makes it necessary to apply pesticides on a regular basis. This is time consuming and expensive and may not be feasible for the small-scale farmer in Africa.

Botanical pesticide extracts have been used traditionally by resource limited small scale farmers to protect crops from ravages of pests. In Tanzania, 4% leaf extracts of *Tephrosia vogelii,* Hook.f. (Fabaceae: Papilionoideae) and *Cassia didymobotrya* (Caesalpionioideae) plants in water were compared with commercial insecticides (Mallya, 1985). The extracts from *T. vogelii* plants gave promising results (Mallya, 1985, 1986; Marandu *et al.*, 1987). In Zambia, *T. vogelii* leaf extracts prevented oviposition by *C. partellus* in maize in addition to being a phagodeterrent (Mugoya and Chinsembu, 1995). The percentage of plants damaged by stemborers in control plots (unsprayed) was almost three times higher than those sprayed with a 15% *T. vogelii* extract (Mugoya and Chinsembu, 1995). Other botanicals include the use of neem seed (*Azadirachta indica*) which is being promoted by the International Centre of Insect Physiology and Ecology (ICIPE). In both maize and sorghum, neem oil extract reduced stemborer attack to the same magnitude as insecticide control (Seshu Reddy, 1998).

The search for alternative control measures that would overcome the drawbacks of insecticides has included research into sex pheromones and how they might be used in stemborer control. These pheromones could be used in population monitoring and control of the pest by mass trapping and mating disruption (Unnithan and Saxena, 1990). These pheromone-baited traps would be very useful for detection of *C. partellus* for monitoring its first emergence, particularly in areas where larval diapause is prevalent during the off-season and for monitoring the flight phenology (Unnithan and Saxena, 1990). It has however been suggested that pheromonal trapping may not be effective in estimating *C. partellus* population density and for mass trapping when the population levels are high.

The use of pheromones has shown promise against stemborers when used only in limited areas/ small-scale (Unnithan and Saxena, 1990).

Host plant resistance is one of the most important and promising ways of reducing stemborer damage and subsequent yield losses in target crops, either by resistance to initial attack, antibiosis once attacked or tolerance to attack (Seshu Reddy, 1998). Research conducted at ICIPE on the evaluation of maize and sorghum lines has shown good levels of resistance/tolerance to stemborer attack (Dabrowski and Kidiavai, 1983; Omolo, 1983; Ampofo et al., 1986). A wide range of mechanisms were involved in *C. partellus* resistance in maize and sorghum, including non-preference for oviposition, reduced feeding, reduced tunnelling, tolerance of plants to leaf damage, deadheart and stem tunnelling and antibiosis. In addition, morphological, physical, chemical and other plant characteristics and non-plant factors including photo- and geotactic stimuli, were involved (Dabrowski and Kidiavai, 1983; Saxena, 1985,1990; Kumar and Saxena, 1992; van Rensburg and Malan, 1992; Kumar, 1993).

1.2.3 Biological control

Several biocontrol agents such as parasitoids, predators and diseases targeting different growth stages of the stemborers have been reported as naturally occurring. A number of parasitoids have been recovered from cereal stemborers in East Africa (Overholt *et al.*, 1994b; Omwega *et al.*, 1995; Bonhof, 2000). Different parasitoid species attack different stages of development of the stemborer. The egg stage is parasitised by *Trichogramma* spp. and *Telonomus* spp. Egg parasitism fluctuates greatly between seasons

and geographical locations, presumably because of different climatic conditions. At the Kenya coast, 92% parasitism of *Chilo* sp. eggs by *Trichogramma* spp. has been recorded (Mathez, 1972). The larval stages of the stemborer are attacked by a great variety of parasitoids. *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) and *Sturmiopsis parasiticae* (Orvan) (Diptera: Tachinidae) are the most widespread and abundant indigenous larval parasitoids in Eastern Africa (Ingram, 1958; Milner, 1967; Mohyuddin and Greathead, 1970; Skovgard and Pats, 1996; Ogol *et al.*, 1998). The exotic parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) was introduced at the Kenya coast in 1993 as part of a biological control program. Since then parasitism has been rising steadily and has become an important mortality factor in some areas (Skovgard and Pats, 1996; Ogol *et al.*, 1998; Overholt, 1998; Zhou, 2001). Larval parasitism was less than 10% at the coast (Skovgard and Pats, 1996; Ogol *et al.*, 1998) and less than 20% in western Kenya (Ogol *et al.*, 1998), with the parasitoid *C. sesamiae* being the most abundant species.

Pupal parasitoids such as *Pediobius furvus* Gahan (Hymenoptera: Eulophidae), *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) and *Psilochalsis soudanensis* Steffan (Hymenoptera: Chalcididae) are widespread in East Africa, but are generally not able to keep the stemborer populations at low levels (Oloo, 1990). Parasitism of pupae, primarily by *P. furvus, D. busseolae and P. soudanensis* was 0-10% at the coast (Skovgard and Pats 1996; Ogol *et al.*, 1998) but upto 58% in west Kenya (Oloo, 1990).

There seems to be a consensus that predators play an important role as mortality agents of cereal stemborers (Mohyuddin and Greathead, 1970; Oloo, 1989; Greathead,

1990; Oloo and Ogeda, 1990; Bonhof, 2000). Eggs are among the most vulnerable life stages of the stemborers and their disappearance is usually attributed to predators. In western Kenya, disappearance of naturally occurring stemborer eggs was 93% (Oloo, 1989). Neonate larvae are vulnerable to predation, especially while migrating from the egg batch to the leaf whorl. Ants are frequently named as predators of all life stages of the stemborer. Spiders, ladybirds and earwigs are also frequently found on agricultural crops in East Africa (Oloo, 1989; Ogol *et al.*, 1998) but they appear to be less numerous and widespread than ants. Earwigs and cockroaches are also predators but occur less frequently (Bonhof, 2000).

1.2.4 Classical Biological control

Chilo partellus is an introduced pest, being native to Asia. A control strategy that has sometimes been successful against such exotic pests is classical biological control. Natural enemies are sought in the region of origin of the pest, collected/imported and introduced into the area where the pest occurs. The major advantage of classical biological control is its sustainability. Once an exotic natural enemy has established in a new environment, it provides a permanent suppression of the pest population without further inputs.

There have been several attempts over the past 50 years to introduce exotic parasitoids for biological control of stemborers. In East Africa, CAB International (formally Commonwealth Institute of Biological Control, CIBC) mounted a 5-year effort against *C. partellus* from 1968-1972 (CIBC, 1968-1972). With the notable exception of

introduction into Madagascar and the Mascarene Islands (Mauritius, Reunion) against *C. sacchariphagus* in sugarcane and *S. calamistis* in maize, exotic parasitoids introduced into Africa have reportedly failed to establish. However, there is recent evidence that *Cotesia flavipes* is already established against *C. partellus* in Kenya (Overholt *et al.*, 1997).

In the long rainy season of 1993 (March-July), *C. flavipes* was released at three locations in the southern coastal region of Kenya over a period of 6-8 weeks (Overholt *et al.*, 1994c). *C. flavipes* successfully located and parasitised stemborers at the three sites during the season of release (Overholt *et al.*, 1994c), and all the three stemborers found at the coast, *C. partellus, C. orichalcocilliellus* and *S. calamistis*, were parasitised (Overholt *et al.*, 1997), confirming the results of previous host suitability studies (Ngi-Song *et al.*, 1995). Data from the 1996 long rains cropping season revealed a significant increase in the abundance of this parasitoid at five sites with average parasitism at one site of 7.1%. In 1997, the number of recoveries increased again and the average parasitism at 15 sites in Kilifi District of coastal Kenya was 15%. The increase in recoveries from 1993-1997 is a clear evidence of the establishment of *C. flavipes* in the coastal Kenya. *C. flavipes* has also been recovered from stemborers in other regions where no releases had been made before, for instance in the former South-Nyanza District (presently Suba, Migori and Homabay districts) of south western Kenya (Omwega *et al.*, 1995). Other areas include northern and central Tanzania (Omwega *et al.*, 1995).

In addition to the releases in Kenya, *C. flavipes* was released in Mozambique in 1996, and in Uganda and Somalia in 1997, and preliminary results from Mozambique indicate that the parasitoid has already colonized maize fields (Overholt, 1998).

1.2.5 Agroforestry and intercropping as low-input crop production technologies

Agroforestry is a polycultural system in which trees are grown along other conventional agricultural crops, while intercropping is a cultural practice of growing two crops in the same field. Both technologies enhance productivity by increasing the vegetational diversity of the agricultural ecosystem.

Agroecosystem diversification is a cultural practice generally thought to increase system stability and decrease the incidence of major insect pests outbreaks often prevelant in monocultures (Perrin, 1977, 1980; Altieri and Letourneau, 1982; Risch, 1983; Risch *et al.*, 1983; Andow, 1991). The ecological basis for reduced insect pest populations in diverse systems has been explained in part by two complementary hypotheses (Root, 1973; Sheehan, 1986; Russel, 1989). The resource concentration hypothesis predicts that monophagous and oligophagous herbivores will locate, remain and increase in concentrated patches of host plants such as monocultures, whereas polyphagous herbivores will tend to disperse out of low diversity patches and into the surrounding vegetational matrix (Root, 1973; Sheehan, 1986; Russel, 1989).

The enemies hypothesis predicts that populations of natural enemies will be greater, and insect pest populations lower, in more diverse habitats due in large part to the availability of alternate prey, suitable microhabitats, and nectar sources (Altieri *et al.*, 1981; Nordland *et al.*, 1988). Thus, the decreased incidence of insect pests often seen in diverse agroecosystems may be caused by a combination of factors including altered patterns of colonization, reproduction, and mortality or dispersal (Perrin and Phillips,

1978). The performance of the natural enemies may also be enhanced by chemical cues from associated plants (Altieri *et al.*, 1981; Nordland *et al.*, 1988). Increasing the vegetational diversity of agroecosystem has been proposed as a means of augmenting entomophagous predators and parasitoids for the control of arthropod pests (Risch, 1983; Herzog and Funderburk, 1986; Russel, 1989; Andow 1991).

Other strategies of agroecosystem diversification have been proposed, the most important being the utilisation of wild gramineous plants for the management of cereal stemborers. Khan *et al.* (1997), demonstrated that the forage grass, *Sorghum vulgare sudanense* (Sudan grass) planted as a trap crop around maize field attracted greater oviposition by stemborers than cultivated maize, resulting in significant increase in maize yield. On the other hand, the non-host forage plant, *Melinis minutiflora* (Molasses grass), when intercropped with maize, repelled gravid stemborer females from ovipositing on maize, resulting in significant reduction in stemborer infestation. Using these attractive and repellent gramineous plant, a novel pest management strategy based on a push-pull or stimulo-detterent diversionary strategy can be developed where stemborers are repelled from the food crop and are simultaneously attracted to a discard or trap crop (Khan *et al.*, 1997).

1.2.6. Stemborer life table studies

Life tables are a means of systematically and numerically describing mortality according to specific age groups or times within a population. It is an account of the survival of an organism as it develops from the egg stage to the adult stage. Life tables

allow the ecological role natural enemies and other mortality factors play in a particular system to be quantified and to determine whether they are a source of regulation contributing to stability (Bellows *et al.*, 1992). Southwood (1978) describes the difference between the two types of life tables. An age-specific (or horizontal) life table is used on the fate of a real cohort; conveniently, the members of a population belonging to a synchronised single generation. The population may be stationery or fluctuating. A time-specific (or vertical) life table is based on the fate of an imaginary cohort found by determining the age structure, at a point of time, of a sample of individuals from what is assumed to be a stationery population with considerable overlapping of generations, i.e. a multi-stage population. Age determination is a prerequisite for time-specific life tables (Southwood 1978).

The construction of a number of life tables is an important component in the understanding of the population dynamics of a species. Deevay (1947) was the first to focus attention of the importance of life tables. Construction of life tables requires careful consideration of sampling interval and procedures to reliably estimate the population density of as many life stages as possible. The total number of individuals that pass through a particular stage in each generation is determined from estimates of stage specific mortality (Southwood 1978). Life table data are most useful when a sequence of life tables during a number of generations are available for the same population. Analysis of such series can reveal major causes of population change and can identify relationships between mortality and the density (Knutson and Gilstrap, 1989a). A key factor analysis introduced by Morris (1959), uses a series of life tables to determine the mortality sources most likely

responsible for the observed changes in population density. This factor is defined as the "key factor". The effect or "killing power" of a mortality factor during each stage is conveniently expressed as a k-value, which is the difference between the logarithms of the population density before and after the mortality acts. Since sources of k-values are assumed to act in sequence, the sum of k-values equals the total generation mortality, K (Varley and Gradwell, 1960, 1968).

Thus:

k-value=logN1-logN2

and total generation mortality=K=k1+k2+k3.....kn

where N1=population density before mortality

N2=population density after mortality

The graphical method of key factor analysis (Varley and Gradwell 1960), plots the individual k-values and total K against time and over as many generations as possible. The age specific mortality (k) is visually compared to determine the k-values that appear to contribute most to variation in total mortality, K. This submortality, expressed by its k-value, is considered to be the key factor (Varley and Gradwell 1960; Southwood 1978).

Podoler and Rogers (1975) proposed a quantitative procedure to identify the key factor for those situations where a visual examination of the plotted k-values fails to clearly define a key factor. The k-values are plotted on the y-axis against the total mortality K on the x-axis and the regression coefficient (b) is calculated. The k-value having the greatest slope (b) is identified as the key factor because it contributes the most to the changes in K. In addition, the relative importance of mortalities other than the key factor can be

determined by comparing the values of their regression coefficients (Podoler and Rogers, 1975).

Census data summarised in life tables can be analysed to describe relationships between the mortality rate and population density. Varley and Gradwell (1970) described four types of interactions between mortality and density. A density-dependent mortality factor kills an increasing proportion of the population as the population density on which it acts increases or there is a proportionate decrease in fecundity or fertility with increasing density. An inverse density-dependent mortality kills a decreasing proportion with increasing population density or there is a proportionate increase in fecundity or fertility with increasing density. There are also delayed density-dependence and density-independent mortality.

Varley and Gradwell (1968) proposed a method of life table analysis that identifies density-dependence, inverse density-dependence, delayed density-dependence and density-independent mortality. The relationship between the rate of a specific mortality factor and population density is determined by regression of its k-value on the logarithm of population density on which the mortality acts. The result is a straight line relationship for the individual mortality factor k described by,

$k=a+b(\log N)$ where

k=k-value factor for the specific mortality

a=intercept

b=slope of the regression and

N=population density on which the mortality factor acts.

A regression coefficient of b=0 indicates density independent mortality. Delayed density dependent mortality is demonstrated graphically by plotting k-values against log host density and serially joining the points. An anticlockwise or spiral graph is a proof of delayed density dependence (Varley and Gradwell, 1970).

1.2.7 Leucaena psyllid, *Heteropsylla cubana*, and its exotic parasitoids at the Kenyan coast

Leucaena, *Leucaena leucocephala*, (Lam) de Wit, is a fast growing leguminous tree with many uses. This tree is native to Central America but has been widely established in the tropics. Of all the tropical legumes, leucaena probably offers the widest assortment of uses. It provides nutritious forage, firewood, timber, a source of organic fertilizer, revegetation, windbreaks, firebreaks, shade and ornamentation (Napompeth, 1994). It is considered a multipurpose tree species (MPTS) in agroforestry programmes. In the 1980s, a tiny insect pest swept across the Asia-Pacific region and caused devastating damage and economic loss (Napompeth, 1990). Although first described in Cuba in 1914, the leucaena psyllid remained relatively unknown and was not regarded as a serious pest of leucaena until an outbreak occurred in Florida, USA in 1983 (Napompeth, 1990). This was immediately followed by its discovery in Hawaii, USA 1984 and the subsequent chain of invasion in the Asia-Pacific region through the mid and late 1980s (Napompeth, 1990). The psyllid was first reported in Africa in 1991 from the Indian ocean Islands of Mauritius and Reunion (Hollis, 1992) and arrived in Kenya and Tanzania in 1992 (Reynolds and Bimbuzi, 1992). Since then it has spread to most of eastern, central and southern Africa

(Ogol and Spence, 1997). The psyllid is native to Central and South America, which is also the natural range of leucaena.

From the egg stage, *H. cubana* undergoes five nymphal instars to reach the adult stage. The life cycle takes 10–20 days and therefore produces several generations in a season (multivoltine). Both nymphs and adults feed on leucaena terminal shoots by sucking plant sap (Napompeth, 1990; Napompeth, 1994). Young flowers are also infested but less frequently whereas older leaves are in most cases not attacked. Feeding results in terminal shoots that may be desiccated and consequently growth is stunted (Napompeth, 1990). High psyllid populations produce copious amounts of honeydew which gives rise to sticky black sooty mould coating terminal shoots and leaflets. In case of heavy infestations, complete defoliation is not uncommon. Although plants recover in most cases death of damaged plants has been known to occur (Napompeth, 1990).

In view of the psyllid damage to leucaena in the Asia-Pacific region, it has been unanimously concluded that pesticides could provide an effective control against the psyllid but these are neither economically feasible nor ecologically desirable with the exception of seedlings and nurseries (Heydon and Affonso, 1989; Napompeth, 1994; FAO, 1994).

From Asia, two control strategies are generally recognised as offering a solution to the problem; resistant varieties and biological control (Heydon and Affonso, 1989; Napompeth, 1990; USAID, 1991; FAO, 1994). With respect to biological control, the establishment of the exotic biocontrol agents from the tropical American region of origin of the pest has always been the desirable and particularly promising approach (Napompeth,

1994). *H. cubana* does not attain its population levels in tropical America that have been observed in areas where the pest has been introduced possibly due, in part, to its diverse indigenous complex of natural enemies. Where successful, classical biological control, has the advantage of continuous control at no recurrent cost (Napompeth, 1994). Classical biological control of the leucaena psyllid has been implemented in many countries in Asia and Pacific regions. In Kenya, the introduction of the exotic parasitoids was executed in 1996 by the International Institute of Biological Control with funding from FAO. During this time, two parasitoids, *Tamarixia leucaenae* Boucek (Hymenoptera: Eupelmidae) and *Psyllaephagus yaseeni* Noyes (Hymenoptera: Encyrtidae), were released at the Kenyan coast. However there was no information on their establishment and /or efficacy and hence the need to carry out research in this area.

1.2.8 Rationale of the Study

Stem borers constitute one of the major constraints to efficient maize and sorghum production in the developing world. They are however protected from chemical control due to their boring activity. There is thus a need for an approach that would be more environmentally safe, cost effective, and sustainable and yet provide greater level of protection against the stemborers for tropical Africa.

Studies have been conducted on the effects of agroforestry on pest management and have revealed that increasing vegetational diversity in agroecosystems increases system stability and decreases the incidence of major insect pest outbreaks observed in some monocultures. But there is shortage of information on the nature and role of various

mortality factors associated with the decrease in the incidence of the major pests in agroecosystems. There was thus a need to closely monitor the population of the stemborers through intensive sampling and construction of life tables and key factor analysis to assist understand how the mortality factors interact to lower the pest incidences.

Leucaena, an essential agroforestry tree, is in danger of serious damage by the leucaena psyllid. There was thus a need to seek cheap and sustainable ways of managing this pest. One of these methods was tried in 1996 when two exotic parasitoids *Tamarixia leucaenae* and *Psyllaephagus yaseeni* were released against the pest at the Kenyan coast. However, there was no information on the establishment and/efficacy of these parasitoids and thus the need for the study.

1.2.9 Hypotheses

•Increasing the vegetational diversity increases the population and activity of the natural enemies and subsequently leads to a decrease in the population of maize stemborers i.e. the enemies hypothesis holds.

•The exotic parasitoids *Tamarixia leucaenae* and *Psyllaephagus yaseeni* have established at the Kenyan coast and have had a negative impact on the psyllid.

1.2.10 General objective

To establish the potentials of agroforestry and intercropping in pest management through enhanced natural enemy abundance and activity levels in the maize cropping systems of coastal Kenya.

Specific objectives

- To assess the role of *Cotesia flavipes* and other indigenous parasitoids in the regulation of maize stem borer populations.
- To investigate the establishment, impact and population dynamics of the exotic parasitoids *Tamarixia leucaenae* and *Psyllaephagus yaseeni* against leucaena psyllid in Kenya.

CHAPTER TWO

2. ABUNDANCE AND ACTIVITY OF NATURAL ENEMIES OF MAIZE STEMBORERS.

2.1 Introduction.

Lepidopteran stemborers are major pests of maize and sorghum in Africa (Youdeowei, 1989). The most abundant and widespread species in the warmer and lowland areas of eastern, central and southern Africa is *Chilo partellus* Swinhoe (Lepidoptera:crambidae). This is a species that was accidentally introduced from Asia into Africa around 1930 (Tams, 1932).

Estimates of yield losses due to stemborers range from 4 to 73% of the potential yield (Seshu Reddy and Walker, 1990). Control strategies are numerous but often not practicable for small-scale subsistence farmers, while the effectiveness of some cultural methods are questionable (van den Berg *et al.*, 1998). As a result, a large number of farmers do not actively control stemborers (Chitere and Omolo, 1993; Grisley, 1997). However, indigenous natural enemies may be able to reduce stemborer populations in the fields of subsistence farmers in the eastern, central and southern Africa (Bonhof, 2000). Understanding the role of natural enemies in suppressing stemborer populations is essential for developing sustainable management practices.

Eggs are among the most vulnerable life stages of stemborers because of their relatively small size, their immobility, and their location. *C. partellus*, just like most other

crambidae, deposit their eggs on leaves and stems, where they are highly exposed to natural enemies and unfavourable weather. Studies conducted by several authors have revealed that the natural mortality of stemborers in the field can be very high (Mathez, 1972; Oloo, 1989; Skovgard and Pats, 1996; Ogol *et al.*, 1998; Bonhof, 2000). Mathez (1972) estimated that only about 5% of eggs hatch into moths that survive to die of old age. Similarly, a study in west Kenya by Oloo (1989) showed that only a small proportion of *Chilo* eggs reached adult stage. Egg disappearance is usually attributed to predators. In another research, larval parasitism was found to be less than 10% at the Kenyan coast (Skovgard and Pats, 1996; Ogol *et al.*, 1998) and less than 20% in western Kenya (Ogol *et al.*, 1998). Parasitism of pupae ranged from 0-10% at the Kenyan coast (Skovgard and Pats, 1996; and Ogol *et al.*, 1998) while in western Kenya it was 58% (Oloo, 1989). Stemborer mortality due to pathogens appears to be negligible (Odindo *et al.*, 1989). Based on the reported and other similar observations, it appears that there is room for improving natural enemy abundance and impact against the stemborers, probably by agroecosystem diversification through agroforestry and intercropping (Ogol *et al.*, 1998).

Increasing the vegetational diversity of agroecosystems has been proposed as a means of augmenting/enhancing the activity of entomophagous predators and parasitoids for the control of the arthropod pests (Risch, 1983; Herzog and Funderburk, 1986; Russel, 1989; Andow, 1991). Many experimental evaluations of the enemies hypothesis have yielded positive, negative and in some instances, neutral responses to the concept that increased vegetational diversity can increase the abundance and effectiveness of natural enemies (Russel, 1989; Andow, 1991). This reflects the complex nature of tritrophic interactions

among plants, herbivores, and natural enemies, and shows that there is no general rule that supports the pest management benefits of agroecosystem diversification. Thus, there is a need to evaluate each system individually (Nordland *et al.*, 1984: Ogol *et al.*, 1998).

Although agroforestry is increasingly gaining ground in pest management strategies, especially in the tropics, more research should be undertaken to help understand how the natural enemies respond to the vegetational diversity in agroecosystems. Consequently, this could explain the observed overall low pest incidence in polycultures. These studies were therefore conducted to test the natural enemies hypothesis at the egg, larval and pupal stages of the stemborer in agroforestry and intercropping systems involving alley cropping of maize and cowpea and the tree species *L. leucocephala* (Lam.) de Wit and *G. sepium*.

2.2 Materials and methods

2.2.1 General materials and methods

2.2.1.1 Study site

The studies were conducted at the Kenya Agricultural Research Institute (KARI) Regional Research Centre at Mtwapa, Coast Province, Kenya (3°56' S, 39° 44' E and 15m above sea level). The average rainfall is about 1200mm per year, and tends to decrease towards the north and interior. Rainfall is bimodal allowing the cultivation of two crops annually during the months of April to August and September to December. Temperatures are generally high (25-30°c) throughout the year (Warui and Kuria, 1983). Agriculture in the coastal strip is characterised by predominantly tree-based systems in which trees such

as coconut palms, cashew nut trees and mangoes are intercropped with cassava and/or maize with or without livestock grazing.

2.2.1.2 Experimental design and plot layout

Five month old seedlings of *L. leucocephala* and *G. sepium* were planted in hedgerows at Mtwapa during the long rains (April to August) of 1999. Plots measured 16 by 13m and separated by 4m buffer strips. Trees were spaced 3.2m between and 0.65m within hedgerows. Hedgerows consisted of plots of leaucaena only, gliricidia only, plots of alternating rows of leucaena and gliricidia, and four plots without trees. This gave a total of nine treatments, which were laid out in a randomised complete block design and replicated four times. A foliar spray of Malathion was applied to the leucaena in leucaena-only hedgerows to control the leucaena psyllid. During the long and short cropping seasons of 1999 and 2000, maize (cultivar Pwani 4 hybrid) was planted between the hedgerows at a spacing of 30cm within rows, 80cm between rows and 80cm between rows of maize and the tree hedgerows. In two of the leucaena-gliricidia hedgerows plots, a row of cowpea (cultivar k80) was planted between the rows of maize (and not between the maize and trees) at an intra-row spacing of 10cm. Three of the plots without trees were planted with maize alone while the other was had an intercrop of maize and cowpea. Two days before planting of maize and cowpea, the leucaena and gliricidia trees were pruned to 30cm above the ground level and all foliage for respective plant species weighed per plot, and applied as mulch on respective plots. Foliage from a separately developed tree plantation was used to mulch plots without trees, except for one of the maize monocrop plots. Maize plants in

one of the two mulched maize monocrop plots and one of the two leucaena-maize plots were chemically protected from stemborer attack by weekly application of insecticide application of Bulldock (betacyfluthrin) granules from one week after plant emergence to crop maturity (Tables 1 and 2). Plots were hand-weeded three times during each cropping season (See attached plots layout).

Table 1. Summary of treatments

Hedgerow type	Crops between hedgerows
Leucaena	Maize
Gliricidia	Maize
Alternating rows of gliricidia and leucaena	Maize,cowpea
Alternating rows of gliricidia and leucaena	Maize
Non	Maize,cowpea
Non	Maize
Non	Maize,pesticide
Non	Maize
Leucaena	Maize, pesticide

Table 2: Experimental plot layout.

7A	6B	4C	7D
1A	5B	8C	4D
8A	9B	1C	9D
5A	8B	2C	8D
2A	3B	6C	3D
4A	1B	5C	6D
3A	4B	7C	2D
6A	7B	9C	5D
9A	2B	3C	1D

Key:

1 (A-D)-Maize/leucaena

2 (A-D)-Maize/gliricidia

3 (A-D)-Maize/cowpea/leucaena/gliricidia

4 (A-D)-Maize/leucaena/gliricidia

5 (A-D)-Maize/cowpea

6 (A-D)-Maize/mulch

7 (A-D)-Maize/pesticide

8 (A-D)-Maize/no mulch

9 (A-D)-Maize/leucaena/pesticide

2.2.2 Stemborer parasitism and predation studies

2.2.2.1 Egg parasitism and predation.

During the short cropping season of 1999 and the long and short cropping seasons of 2000, a method adapted from Ogol *et al* (1998) was employed for these studies. The foliage of all maize plants was carefully inspected for newly laid stemborer egg batches and counted. All plants bearing egg batches were marked by a wooden peg in the soil. All unmarked plants were inspected again 24 hours later. Ten egg batches of such eggs, each from a single plant, were selected, and marked using tags. The location of each egg batch was marked with a permanent marker on the opposite leaf surface. On the third day, each egg batch was inspected and its condition recorded as healthy, partially eaten, or missing. The ones missing or eaten were presumed as having been depredated. The data were expressed as percentage of eggs predated per plot. All healthy and partially eaten eggs were cut out with some portion of the leaf, taken to the laboratory and the eggs counted under a dissecting microscope. They were then placed in labelled vials and observed for a period of two weeks for hatchability, parasitoid emergence, or failure to hatch. Data obtained were expressed as percentage of eggs parasitized per plot. The procedure was repeated biweekly for 8 weeks.

2.2.2.2 Larval and pupal parasitism.

Weekly sampling for the larval and pupal stages started soon after plant emergence and continued until harvest during the long and short cropping seasons of 1999 and 2000. Ten maize plants were randomly sampled from each plot. The stalks were then dissected to

recover the immature stages of the borer. Both dead and live larvae and pupae were recovered. Live larvae were placed individually in vials with natural diet and taken to the rearing laboratory and observed until they pupated or died. Similarly, pupae were kept until adults emerged or died. The samples were checked daily for any parasitoid emergence. The parasitoids were then preserved in 70% alcohol and representative samples sent to the International Centre of Insect Physiology and Ecology (ICIPE) for identification.

2.2.2.3 Larval and pupal mortality.

Dead larvae and pupae obtained from the same sampling program and those that died while being held in the laboratory (see larval and pupal parasitism) were also counted (the parasitised ones were excluded from this category). These were used to test for the possibility that the action of other mortality factors such as predators and microbial agents (other than parasitism) might have been affected by the vegetation pattern. No further attempts were made to identify the cause of death due to the complexity of the process and inadequacy of the facilities required.

2.3 Data analysis.

Data collected were averaged for individual plots during each cropping season. Data were subjected to arcsine transformation in order to conform to the assumptions of analysis of variance (ANOVA) as indicated by tests of normality (PROC UNIVARIATE, SAS Institute, 1985), and analysed by two-way (treatment x seasons) ANOVA (PROC GLM,

SAS Institute, 1985). Thereafter, pre-planned orthogonal contrasts were used to test for the effects of mulching, intercropping, agroforestry, tree species, multiple trees and pesticide on natural enemy activity levels as follows;

Table 3. Performed contrasts

Variable	Contrasts
Mulching	m vs mmu
Intercropping	mmu vs mcmu
Individual trees	mmu vs lmmu, gmmu
Multiple trees	lgmmu vs lmmu, gmmu
Intercrop in agroforestry	lgcmmu vs lgmmu
Pesticide	mmu vs mpmu

Key:
lmmu- leucaena, maize, mulch
gmmu- gliricidia, maize, mulch
lgmcmu- leuceana, gliricidia, cowpea, maize, mulch
lgmmu- leucaena, gliricidia, maize, mulch
mcmu- maize, cowpea, mulch
mmu- maize monocrop, mulch
mpmu- maize monocrop, pesticide, mulch
m- maize monocrop

2.4 Results.

2.4.1 Egg parasitism and predation.

The egg parasitoids recovered included *Trichogramma* and *Telenomus* species. The proportion of eggs parasitised was generally high (71.6-79.9%) for all the treatments during the three cropping seasons (Table 4). From visual observation, a wide range of

factors was found responsible for the stemborer egg disappearance believed to have been brought about by predators. Some notable predators included ants (Hymenoptera: Formicidae), ladybirds (Coleoptera: Coccinellidae), earwigs (Dermaptera: Forficulidae) and spiders (Araneidae: Philodromidae). Predation rates were generally low in all the treatments (5.7-11.6%) (Table 4). The ANOVA however indicated no significant differences among treatments with regards to parasitism and predation rates ($p=0.455$ and 0.366 respectively). The pre-planned orthogonal contrasts did not show any statistical differences between treatments implying that agroforestry and cultural systems established in the study did not enhance the numerical and efficacy levels of the egg parasitoids and predators (Table 5).

2.4.2 Larval and pupal parasitism.

The larval parasitoids encountered were *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae), *C. flavipes* Cameron (Hymenoptera: Braconidae), and *Goniozus indicus* Ashmead (Hymenoptera: Bethylidae) and pupal parasitoid *Pediobius furvus* Gahan (Hymenoptera: Eulophidae). Hyperparasitoids recovered were *Aphanogmus fijiensis* (Ferriere), (Hymenoptera: Ceraphronidae) and *Exoristobia* sp. (Hymenoptera: Encytridae). Larval and pupal parasitism rates were generally low (6.0-8.1%) in all the treatments (Table 4). Analysis of the data indicated that there were no significant differences among treatments ($p=0.558$). Parasitism rates were relatively higher in plots comprising individual and multiple tree species than in maize monocropped plots, although the differences were not significant (Table 5).

2.4.3 Larval and pupal mortality.

Mean larval and pupal mortality rates were low in all the treatments (7.8-9.6%) during the four cropping seasons (Table 4). Some of the larvae and pupae under this category had a characteristic common dark coloration of the entire body, suggesting that the mortality factor in this case was associated with microbial agents. ANOVA ($p=0.511$) and pre-planned contrasts (Table 4), showed no statistical differences indicating that the activity of the microbial mortality factors was not affected by the vegetation structures and cultural treatments in the study.

Table 4. Mean (±SE) percentage of stemborer eggs, larvae and pupae preyed upon, parasitised and dead per plot during the long and short rainy seasons of 1999 and 2000. Means represent treatment averages over four cropping seasons.

Activity	**Treatments**								
	Lmmu	**gmmu**	**lgcmmu**	**lgmmu**	**mcmu**	**mmu**	**mpmu**	**mlp**	**mmu__**
Egg parasitism	75.1±3.0	71.6±3.1	76.9±2.4	76.6±2.1	79.9±1.5	73.7±4.6	71.3±4.8	74.1±2.7	77.4±2.6
Egg predation	11.6±2.5	12.4±2.5	8.9±2	7.3±0.5	6.7±1.4	13±3.4	5.7±1.7	9.1±1.6	7.8±1.7
Larval and pupal parasitism	7.3±0.9	6.6±0.9	6±0.4	8.1±0.7	7.7±1.1	6.9±0.5	*	6.2±0.9	*
Larval and pupal mortality	9.6±0.9	9.6±0.8	7.8±1.2	8.9±1.2	7.8±0.8	9.3±1	*	8.6±0.8	*

*Means within a row are not statistically different.

Key:
lmmu- leucaena, maize, mulch
gmmu- gliricidia, maize, mulch
lgmcmu- leuceana, gliricidia, cowpea, maize, mulch
lgmmu- leucaena, gliricidia, maize, mulch
mcmu- maize, cowpea, mulch
mmu- maize monocrop, mulch
m- maize monocrop
mpmu- maize monocrop, pesticide, mulch
m- maize monocrop
lpmmu- leucaena, pesticide, maize, mulch

Table 5. Probabilities of orthogonal contrasts for pooled data on stemborer egg parasitism and predation, larval and pupal parasitism, and larval and pupal mortality for four cropping seasons.
* Lack of larvae and pupae for analysis due to effect of pesticide.

Activity	**Treatment contrasts (p values)**								
	m vs mmu	**mmu /mcmu**	**mmu/ gmmu**	**mmu/ lmmu**	**lgmmu/ gmmu**	**lgmmu /lmmu**	**lgcmmu /lgmmu**	**mmu /mpmu**	**mmu/ lpmmu**
Egg parasitism	0.791	0.1932	0.942	0.381	0.343	0.202	0.741	0.934	0.424
Egg predation	0.093	0.019	0.166	0.685	0.309	0.222	0.914	0.914	0.072
Larval and pupal parasitism	0.308	0.837	0.777	0.503	0.361	0.114	0.561	0.133	*
Larval and pupal mortality	0.633	0.252	0.797	0.754	0.969	0.492	0.543	0.133	*

Key:
lmmu- leucaena, maize, mulch
gmmu- gliricidia, maize, mulch
lgmcmu- leuceana, gliricidia, maize, cowpea, mulch
lgmmu- leucaena, gliricidia, maize, mulch
mcmu- maize, cowpea, mulch
mmu- maize monocrop, mulch
mpmu- maize monocrop, pesticide, mulch
m- maize monocrop
lpmmu- leucaena, pesticide, maize, mulch

2.5 Discussion

Mean rates of egg parasitism were higher than those for larval and pupal parasitism in all the treatments during the whole sampling period. However, there were no significant differences among treatments, indicating that agroforestry and intercropping in the study did not promote colonisation and activity of the stemborer parasitoids. Similar results were obtained by Ogol *et al.* (1998), who reported higher parasitism rates on maize stemborer eggs (>75%) and lower larval and pupal parasitism rates (<10%) at the Kenyan coast. In addition, there were no significant differences among the monocropped, weeded and unweeded and leucaena-maize intercrop. Studies by Skovgard and Pats (1996) at the Kenyan coast also revealed that intercropping maize with cowpea did not consistently yield any significant abundance or activity of the natural enemies of the spotted maize stemborer, *C. partellus*. Pavuk and Barret (1993) reported a neutral response to agroecosystem diversification by larval parasitoids of the green cloverworm.

The results in the current study indicate neutral response to agroecosystem diversification by the parasitoid species encountered. As explained by Russel (1989), Bonhof (2000) and Zhou *et al.* (2001), the impact of natural enemies is dependent not only on the resources available, but also on the other biotic (e.g. associated living organisms) and abiotic (e.g. weather) components of the agroecosystem as these directly determine the suitability of the available resources. Most studies that consistently supported the natural enemies hypothesis involved mainly the generalist natural enemies (Sheehan, 1986; Russel, 1989). As it has been suggested by Sheehan (1986), the impact of specialist natural enemies like parasitoids could be diminished in diverse agroecosystems due partly to

disrupted host-plant and patch-olfactory cues or lowered host abundance. These are partly dependent on the abiotic components like seasonal variations in the weather, thus yielding seasonal disparities in the abundance and activity of the specialist natural enemies. Furthermore, the provision of alternate food and microhabitats associated with diverse vegetation are more relevant to enemies with broad feeding ranges than to specialist enemies (Sheehan, 1986).

Predation rates were generally low in all the treatments with no significant difference among the treatments to support the natural enemies hypothesis. Thus, immigration into, retention and efficacy of predators were not enhanced by the more diverse vegetational matrix comprising of maize-cowpea-leucaena-gliricidia. Pollard (1971) suggested that highly mobile predators are not likely to be enhanced by the presence of alternate vegetation in a diverse agroecosystem. Some of the predators encountered in this study but not sampled due to complexity of the procedures and time included ants (Hymenoptera: Formicidae), ladybirds (Coleoptera: Coccinellidae), earwigs (Dermaptera: Forficulidae) and spiders (Araneidae: Philodromidae). These are known to exhibit high mobility (Pollard 1971). It is thus apparent that they were capable of easily traversing plots and buffer strips in the agroforestry and intercropping systems established in this study. Sheehan (1986) advanced the same reasoning for the failure of the natural enemies of green cloverworm to respond to the soybean intercropped with sorghum.

Bugg *et al.* (1987) found that, for most crops there was no increase in predation when they were interplanted with common knotweed despite the high abundance of natural enemies on this plant. They argued that, given the abundance of resources on knotweed,

predators may not have been inclined to move from the knotweed to forage on the adjacent vegetation. Similarly, Perrin (1975) suggested that aphids on the perennial stinging nettle may act as a 'diversionary prey' for natural enemies, thereby decreasing their presence on neighboring crops. Ogol *et al.* (1998) observed that predation on stemborer eggs at the Kenyan coast was significantly lower in the leucaena-maize intercrop (more diverse) than in the maize monocrop. Thus, it is not clear whether vegetation that provides abundant resources will act as a 'source' or a 'sink' of natural enemies in agroecosystems. Moreover, a review of the natural enemies hypothesis reported that 9.3% of the predator species studied had lower densities in polycultures, whereas 13.2% did not show any difference (Andow, 1991) indicating that there is no rule of thumb about the response of natural enemies to agroecosystem diversification. Furthermore, some of the agroforestry tree species have their herbivores that the natural enemies might have found relatively abundant and accessible than the stemborer eggs. Leucaena and gliricidia have pests, the leucaena psyllid and aphids respectively, that the predators may have found more abundant, accessible and predictable than the stemborer eggs and this might have diminished their effectiveness as predators (Ogol *et al.*, 1998).

Although attempts were not made to identify the mortality factors responsible for the larval and pupal mortality due to the complexity in terms of facilities required, it is evident that the vegetation structure and cultural treatments in the study did not exhibit any influence on the abundance and activity of these mortality factors. These results are consistent with those of Ogol *et al.* (1998) who found that alley cropping involving leucaena and maize did not influence the activity of microbial agents against maize

stemborer. Williams *et al.* (1995) also reported that the incidence of the entomopathogenic fungus *Nomuraea riley* (Farlow) Sampson was not significantly different between green cloverworms in a monocropped soybean and those in soybean intercropped with sorghum. It has been advanced by Ogol *et al.* (1998) that the larvae and pupae spend most of their life concealed in the stem where climatic variables like temperature and humidity would be minimally affected by the microclimatic conditions created by the vegetational diversification and so the incidence of microbial agents are expected to remain fairly uniform in any cropping system.

It is evident that herbivore populations are controlled by enemies and by their ability to find and stay on host plants. The relevant course of action should be on how to enhance both and achieve maximum control. As suggested by Nordland *et al* (1984) and Ogol *et al.* (1998), each case of agroecosystem diversification needs to be considered on an individual basis before any useful generalisation can be made. In every consideration, factors that need focus include the origin of the various agroforestry tree species as this could affect their contribution to the enemies hypothesis and biotic and abiotic components of the created agroecosystems. Probably the fact that leucaena and gliricidia used in this study are exotic, might have had a significant effect thus accounting for the results obtained (Ogol *et al.*, 1998). The information generated can therefore be used to predict and test the relative importance of various factors that control enemy effectiveness and response to vegetational patterns. As suggested by Ogol *et al.*, (1998), this should allow us to move into a more predictive theory of enemy activity in diverse systems.

CHAPTER THREE

3. LIFE TABLES, KEY FACTOR ANALYSIS AND DENSITY RELATIONS OF NATURAL POPULATIONS OF MAIZE STEMBORER UNDER DIFFERENT CROPPING SYSTEMS.

3.1 Introduction

Cotesia sesamiae which is an indigenous larval parasitoid of the stemborers has not been able to maintain the pest's population density at a level acceptable to farmers (Oloo, 1989; Overholt, 1994a). *Cotesia flavipes*, which has now been used successfully in other parts of the world, was introduced into Kenya from Pakistan in 1993 in an attempt to reduce the severity of *C. partellus* (Overholt, 1994b). Establishment of this parasitoid has been reported (Omwega *et al.*, 1995). However its impact alongside other indigenous natural enemies under different cropping systems has not been evaluated.

Bellows *et al.* (1992) described a method for evaluating the impact of natural enemies on their hosts. This category involves the construction and analysis of life tables for the affected populations. Here the mortality caused by an agent may be compared with other sources of mortality acting on the population and contributions of contemporaneous factors separately quantified. Life tables are one of the most useful tools in the study of insect population dynamics (Harcourt, 1969; Southwood, 1978). They also allow the ecological role a natural enemy plays in a particular system to be determined, i.e. whether it is a source of regulation contributing to stability or not. Life studies by Oloo (1989),

Oloo and Ogeda (1990) and Ogeda (1999) reported significant activity of natural mortality causes in lowering stemborer incidences in western Kenya. They observed that less than 10% of the immature stages (larvae) reached adult stage. These studies were however restricted to maize monocrop system.

Studies on agroecosystem diversification as a pest management strategy revealed that increasing the vegetational diversity of agroecosystems may increase system stability and decrease the incidence of major insect pest outbreaks observed in some monocultures. However, there was shortage of information on the nature and role of various mortality factors associated with the decrease in the incidence of the major insect pests in agroecosystems. These studies were thus conducted to closely monitor the populations of the stemborers through intensive sampling and construction of life tables and key factor analysis to understand how the mortality factors interact to lower incidences of maize stem borers under polycultural crop production systems.

3.2 Materials and Methods

The studies were conducted in the same treatments described in chapter two under experimental design and plots layout (2.2.1.2). Sampling at weekly intervals for the larval and pupal stages of the borers started soon after plant emergence and continued until harvest. During each sampling occasion, 10 plants were chosen at random per plot. These plants were uprooted and checked for stemborer eggs and then dissected to recover the immature stages of the borer. The stage of the plant, the stemborer life stage, the location of the stemborer in the plant and the health status of the stemborer at the time of collection

were all recorded during the dissections. Both dead and live larvae and pupae were recovered. Live borers were placed individually in vials with natural diet and held in the laboratory for possible parasitoid emergence. The parasitoids were preserved in 70% alcohol and representative samples sent to ICIPE for identification. A list of all the natural enemies encountered in the plots was compiled.

The field samples did not yield sufficient number of eggs to account for the number of larvae and pupae recovered during sampling occasions and therefore the egg data were not used in the life table analysis. In addition, it was not easy to separate the various larval instars. Consequently, the data was pooled into four-age categories; small (first and second instars), medium (third instar), large (fourth and fifth instars) and pupal stages.

The number of individuals entering a specific stage (lx) were determined using the graphical method of Southwood and Jepson (1962). The density of each life stage was plotted against sample occasion for successive census data. The area beneath the curve represented the total number of population estimates of the particular stage. Due to the variations in different life stages and also due to other mortality factors, it was necessary to standardise population estimates that were obtained by dividing the estimated area under the curve by the developmental time (days) of the stemborer life stage obtained at 25 degrees centigrade under laboratory conditions.

To determine the impact of *C. flavipes* and indigenous parasitoids and predators on *C. partellus* populations, partial ecological life tables for each season and each treatment were constructed for the first generation of the dominant borer according to the method described by Morris and Miller (1954). Each mortality factor was treated as a

percent proportion of the population estimate of the stage at which it acted (apparent mortality) and percent proportion of the population estimate at the beginning of the generation/cohort (real mortality). In both cases, the total mortality for every stemborer stage was obtained by adding the proportions contributed by each mortality factor at that stage. Life tables were constructed for the first generation as this is the generation reported by earlier workers to be the most damaging to maize and sorghum in East Africa (Whitney, 1977). Moreover the first generation is more or less discrete whereas overlap occurs between successive generations (Stark, 1969). Mortality factors (dxF) was partitioned into two causes; parasitism, whereby the parasitoids were identified, and disappearance, which covered all other undetermined losses which included predators, dispersal, disease or abiotic factors. Mortality estimates (dx) were obtained by dividing the population estimates of the parasitoids (obtained as the stemborer life stage estimates described above) i.e. dividing the area under the curve by the developmental time (days) in the host. For disappearance, the estimates were obtained by subtracting the population estimates of the succeeding life stage from the difference of the life stage on which the mortality factor acted and the mortality due to parasitism. Mortality occurring in each instar (apparent mortality, 100qx) was obtained by dividing dx by the corresponding dx, while mortality in relation to the original population at the beginning of the generation (real mortality, 100rx) was obtained by dividing all the dx values by lx at the beginning of the generation. Key factor analysis (Varley and Gradwell, 1960) was used to compare the relative importance of each stage-specific mortality to overall generation mortality. The intensity or 'killing power' of mortality during each stage was expressed as a k value equal to the difference

between the logarithms of the stage density (lx) before and after mortality. The sum of all successive mortality factors (ki) equals total generation mortality (K). Podoler and Rogers (1975) suggest that key mortality factors be identified from regressions for each of the k values with K as the independent variable. Positive correlation with K indicate that the mortality factor(s) contribute to population regulation while negative correlation indicate that the mortality factor(s) have no contribution to population regulation. Such regressions with the greatest positive slope indicate submortalities (k_i) acting as key factors. This method was used to identify individual mortality factors (k-values) most closely associated with variations in generation mortality (K).

In order to detect possible density dependence, individual k-values were regressed on the log 10 densities upon which they acted. Where a relationship appeared to exist, a proof of density dependence test was carried out to ascertain whether density dependence was real or spurious (Southwood, 1967; Varley and Gradwell, 1968; Luck, 1971).

3.3 Results.

3.3.1 Life table analysis

Life tables for *C. partellus* populations during the long and short cropping seasons of 1999 and 2000 under the various cropping systems are presented in appendices 1-7. The real generation mortalities for each age category are summarised in tables 6-12. In all cases, lowest mean mortality occurred during the pupal stage with a range of 3.3% in unmulched maize monocrop to 8.9% in maize/leucaena/gliricidia (Tables 6-12).

There was little variation in the total inter-generation mortality expressed as total 100rx in all the cropping systems (Tables 6-12). The mean mortality values were generally high and varied only slightly from 90.6% in maize/leucaena to 97% in gliricidia/maize/mulch.

3.3.2 Key factor analysis and density relationships.

The life table data were used to construct partial mortality budgets from which the various k values were calculated for each cropping system. These results are summarized in tables 13-19. On visual examination, k4, which represented mortality due to disappearance of the medium larvae stage, showed a similar trend to change in K in maize/leucaena, mulched maize and unmulched maize cropping systems. k6 which represented disappearance of large larvae showed a similar trend of change in K in maize/gliricidia, maize/gliricidia/leucaena/cowpea, maize/leucaena/gliricidia and maize cowpea cropping systems. k4 and k6 were thus the key mortality factors associated with population changes in the various cropping systems. Mortality due to parasitism at the medium larvae stage (k3a and k3b) were minimal, ranging from 0-0.1 (Tables 13-19), in all the systems, indicating that the larval parasitoids *C. sesamiae* and *C. flavipes* contributed minimally to the changes in *C. partellus* populations in all the cropping systems studied.

Results from regressions (Tables 20-26) showed k values with positive regression coefficients. They indicate that k4 and k6 had higher regression coefficients and so are the key mortality factors in the respective cropping systems. The regression of kx on log

density for each lx interval was also computed to determine the relationship between the stage-specific mortality and *C. partellus* density (test of density dependence). The results show that only k3a (mortality due to *C. sesamiae*) under maize/gliricidia was significant (b=-0.08; p=0.02). It was this factor under the cropping system that acted in an inverse density dependent manner, meaning that the activity of the mortality factor decreased with an increase in stemborer population. Since the other regressions although positive, were not significant, no density dependence could be suspected. Density dependent mortality factors must yield regression coefficients that are statistically significant. The mortality factors thus acted in a density independent manner (Table 27).

3.4 Discussion.

There was no conspicuous evidence of enhanced activity/effectiveness of natural mortality factors noted in the agroforested and intercropped systems when compared to the maize monocropped system. There was very little variation in total intergeneration and mean real generation mortalities within and among the various cropping systems.

Observations on mortality factors and their role in population regulation presented in the life tables showed that the highest mortality occurred in the medium (third instar) larval stage in all the cropping systems studied. This mortality was attributable to 'disappearance', which represented mortality due to predation, disease, emigration and other unknown biotic and abiotic factors. The small (instars 1 and 2) larvae also registered high mortality attributable to disappearance. It has been reported that these early stages (small and medium) of *C. partellus*, remain exposed before the larvae enter the stem of the

host plants. This exposure predisposes them to the natural enemies and other biotic and abiotic mortality factors thus explaining the results.

The mean total real generation mortality ranged from 90.6% in maize/leucaena to 95.7% in maize/leucaena/gliricidia, implying that from the initial cohort of small larvae, less than 10% *C. partellus* survived to the adult stage under field conditions in all the cropping systems studied. These results coincide with those of Ogeda (1999) who found that on the average, less than 10% of the first and second *C. partellus* larvae survived to adult stage under natural conditions in western Kenya. Similarly, life table studies by Oloo, (1989) and Oloo and Ogeda (1990) in west Kenya reported that only 5% of *C. partellus* eggs produced moths under natural conditions. The mortality occurring in each instar (apparent mortality) and the mortality in relation to the original population at the beginning of the generation (real mortality) indicated that the lowest mortality occurred at the pupal stage in all the cropping systems in the study. These findings conform to those of Mathez (1972), Oloo (1989), Oloo and Ogeda (1990) and Ogeda (1999) who reported high egg and small larvae mortality (up to 90% for both) and much lower pupal mortality (<10%) in natural populations of *C. partellus*. This suggests that the relative inactivity, immobility, pupal case covering and the fact that pupae are covered/burrowed in the stems of host plants greatly reduces their predisposition to the natural enemies and other biotic and abiotic mortality factors.

The Podoler and Rogers (1975) method of key factor analysis was also performed to confirm the key mortality factors. It should be noted that the identification of a key factor does not necessarily point to the factor(s) that may regulate the population density

(Southwood, 1967; De Bach *et al.,* 1976). Furthermore, it does not identify which factors were primarily responsible for maintaining the characteristic density of the population, or what the density would be if a particular factor were removed. k3a and k3b which represented mortality at the medium larval stage by *Cotesia sesamiae* and *C. flavipes* respectively were found to be very minimal, indicating that the parasitoids contributed little to the total generation mortality and thus are not important mortality factors of *C. partellus* at the Kenyan coast. However the impact of natural enemies is not necessarily related to their status as key factors. Many natural enemies do not appear as key factors in life tables of their host populations (Bellows *et al.,* 1992). This observation agrees with the view of some authors (Knutson and Gilstrap, 1990; Ogeda, 1999) on the role of parasitoids in population regulation of insects. However, since any attack by parasitoids usually leads to death of the host and not normally easy to count directly, estimation of parasitised hosts may be lower than those attacked, resulting in an under-estimation of the effect of parasitism on population regulation (Cock, 1986). Thus, the results on parasitism of *C. partellus* found under the various cropping systems in this study may have been an underestimate of the role of these mortality agents in the regulation of the pest's population density.

An important component in the life table analysis was to test whether any of the mortality factors acted in a density dependent manner and thus contributed to population stability of *C. partellus* under the various cropping systems. The results indicated that it was only k3a (mortality due to parasitism by the larval parasitoid *C. sesamiae*) under maize/gliricidia cropping system that acted in an inverse density dependent manner. This

shows that mortality due to *C. sesamiae* decreases with increasing population density of *C. partellus*, which has a destabilizing effect on the population. All the other mortality factors acted in a density independent manner in all the cropping systems in the study, they thus acted irrespective of population density of *C. partellus*. These results are consistent with other field studies (Knutson and Gilstrap, 1989a,b; Knutson and Gilstrap, 1990) that showed that factors commonly responsible for density-dependent mortality (including predators, parasites, pathogens, and competition) were uncommon during the first generation. The observed inverse density dependent relationship has no apparent biological explanation. However as indicated in table 29, the positive correlations between the various mortality factors and log densities of the stages on which they acted indicate the extent of contribution of the factors to stabilization of the population densities of the pest under the various cropping systems considered in this study. The closer the regression coefficient to 1, the more the stabilizing effect on the population. k2 (disappearance at the small larvae stage) had regression coefficients (b values) of 0.27 and 0.76 under mulched maize monocrop and unmulched maize cropping systems respectively. k4 (disappearance at the medium larvae stage) had the highest b values of 0.79 in the maize/leucaena and maize/cowpea/leucaena/gliricidia cropping systems. k6 (disappearance at the large larvae stage) had b value of 0.45, in maize/gliricidia. k8 (disappearance at the pupae stage) had b value of 0.68 under maize/leucaena/gliricidia system. Both k7 (parasitism of the pupae by *Pediobius furvus*) and k8 had a b value of 0.39 under maize/cowpea cropping system. The mortality factors k2, k4, k6, k7 and k8 were thus the main stabilizing factors of *C. partellus* populations in the various cropping systems.

The demonstration of density dependence is fraught with many difficulties; in particular, failure to detect it in no way proves its absence (Southwood, 1978). Precise studies on individual cohorts and experimental work with particular components of the population system would seem to be profitable ways of investigating its role in population dynamics. Otherwise from this study it was evident that the mortality sources varied from one cropping system to the other, in a density independent manner. It was noted that the main mortality factor is disappearance, which covers the aspects of predation, emigration, weather, other biotic and abiotic, with the specialised natural enemies, parasitoids, only providing minimal contribution to the total generation mortality. Their numerical and efficacy levels were thus not affected by the vegetation structure and cultural systems established in the study. The main mortality factor was disappearance while parasitism by parasitoids contributed minimally to *C. partellus* population regulation in all the cropping systems in the study. This however does not mean absence of positive contribution of agroforestry and intercropping in enhancing the numerical and/or functional response of the *C. partellus* natural enemies since the life table data are population estimates and not the actual parasitism, predation or disappearance measures. Thus, more detailed studies are desirable that would incorporate all the life stages as response to agroecosystem diversification by the natural enemies of various life stages vary. For example the egg stage is known to be very vulnerable to the natural mortality factors since they are exposed after oviposition, immobile, minute and pale whitish in colour. They are therefore more vulnerable to both biotic and abiotic natural mortality factors and so may give better results.

Table 6. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* UNDER MAIZE-LEUCAENA CROPPING SYSTEM

	Generations					
Stage	1	2	3	4	Mean	S.E.
Small larvae	45	29.6	25	31.8	32.8	4.29
Medium larvae	30	55.6	25	18.2	32.2	8.17
Large larvae	10	11.1	41.7	27.3	22.5	7.52
Pupae	0	0	0	13.6	3.4	3.4
Total	85	96.3	91.7	90.9	90.9	

Table 7. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* UNDER MAIZE-GLIRICIDIA CROPPING SYSTEM

	Generations					
Stage	1	2	3	4	Mean	S.E.
Small larvae	37	10	47.8	13	26.9	9.21
Medium larvae	44.4	70	30.4	17.4	40.5	11.26
Large larvae	7.4	20	13	56.5	24.2	11.06
Pupae	0	0	8.7	13	5.4	3.25
Total	88.8	100	99.9	99.9	97	

Table 8. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* UNDER MAIZE-COWPEA-LEUCAENA-GLIRICIDIA CROPPING SYSTEM

	Generations					
Stage	1	2	3	4	Mean	S.E.
Small larvae	28.5	58.3	41.6	22.2	37.6	7.98
Medium larvae	47.6	29.2	16.7	11.1	26.1	8.09
Large larvae	14.3	12.5	25	55.5	26.8	9.95
Pupae	0	0	8.3	5.5	3.4	2.07
Total	90.4	100	91.6	94.3	93.9	

Table 9. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* UNDER MAIZE-LEUCAENA-GLIRICIDIA CROPPING SYSTEM

	Generations					
Stage	1	2	3	4	Mean	S.E.
Small larvae	37.9	36.8	8.3	23.1	26.5	6.94
Medium larvae	37.9	36.8	33.3	23.1	32.8	3.37
Large larvae	17.2	26.3	33.3	30.8	26.9	3.54
Pupae	3.4	0	16.7	15.4	8.9	4.21
Total	96.4	99.9	91.6	92.4	95.1	

Table 10. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* UNDER MAIZE-COWPEA INTERCROPPING SYSTEM

	Generations					
Stage	1	2	3	4	Mean	S.E.
Small larvae	19.3	21.4	46.4	38.5	31.4	6.59
Medium larvae	61.3	47.1	28.6	23	40	8.77
Large larvae	12.9	21.4	14.3	30.8	19.8	4.09
Pupae	3.2	0	7.1	7.7	4.5	1.8
Total	96.7	89.9	96.4	100	95.7	

Table 11. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* UNDER MULCHED MAIZE MONOCROP SYSTEM

	Generations					
Stage	1	2	3	4	Mean	S.E.
Small larvae	15.4	20	26	44	26.3	6.27
Medium larvae	50	40	21.7	24	33.9	6.73
Large larvae	26.9	40	30.4	12	27.3	5.81
Pupae	3.8	0	8.7	8	5.1	2.02
Total	96.1	100	86.8	88	92.6	

Table 12. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* UNDER UNMULCHED MAIZE MONOCROP SYSTEM

	Generations					
Stage	1	2	3	4	Mean	S.E.
Small larvae	26	14.3	58.8	50	37.3	10.33
Medium larvae	34.8	71.4	11.8	31.2	37.3	12.44
Large larvae	21.7	14.3	17.6	12.5	16.5	2.02
Pupae	4.3	0	8.8	0	3.3	2.1
Total	86.8	100	97	93.7	94.4	

Table 13. Summary of k-values obtained from the partial budgets of *Chilo partellus* under maize-leucaena cropping system.

		Generations			
Life stage	Mortality factor	1	2	3	4
Small larvae	*k1* parasitism	0	0	0	0
	k2 disappearence	0.26	0.15	0.12	0.17
Medium larvae	*k3a Cotesia sesamiae*	0	0	0	0.1
	k3b C. flavipes	0	0.02	0	0
	k4 disappearence	0.26	0.58	0.18	0.03
Large larvae	*k5* parasitism	0	0	0	0
	k6 disappearence	0.22	0.6	0.78	0.34
Pupae	*k7* parasitism	0	0	0	0
	k8 disappearence	0	0	0	0.4
TOTAL (*K*)		0.74	1.35	1.08	1.04

Table 14. Summary of k-values obtained from the partial budgets of *Chilo partellus* under maize-gliricidia cropping system

		Generations			
Life stage	Mortality factor	1	2	3	4
Small larvae	*k2* disappearence	0.2	0.05	0.22	0.06
Medium larvae	*k3a Cotesia sesamiae*	0.03	0.05	0.03	0.02
	k4 disappearence	0.45	0.48	0.24	0.07
Large larvae	*k6* disappearence	0.22	0.3	0.24	0.73
Pupae	*k7 Pediobius furvus*	0	0	0	0.18
	k8 disappearence	0	0	0.3	0.48
TOTAL (*K*)		0.9	0.88	1.03	1.54

Table 15. Summary of k-values obtained from the partial budgets of *Chilo partellus* under maize-cowpea-leucaena-gliricidia cropping system

		Generations			
Life stage	Mortality factor	1	2	3	4
Small larvae	*k2* disappearence	0.15	0.38	0.23	0.11
Medium larvae	*k3a Cotesia sesamiae*	0	0.09	0.07	0.03
	k3b C. flavipes	0	0.05	0.07	0.03
	k4 disappearence	0.48	0.22	0	0
Large larvae	*k6* disappearence	0.4	0.48	0.4	0.78
Pupae	*k8* disappearence	0	0	0.3	0.3
TOTAL (*K*)		1.03	1.22	1.07	1.25

Table 16. Summary of k-values obtained from the partial budgets of *Chilo partellus* under maize-leucaena-gliricidia system.

		Generations			
Life stage	Mortality factor	1	2	3	4
Small larvae	*k2* disappearence	0.21	0.2	0.04	0.11
Medium larvae	*k3a Cotesia sesamiae*	0.02	0	0	0.05
	k3b C. flavipes	0	0	0	0.05
	k4 disappearence	0.35	0.38	0.2	0.05
Large larvae	*k6* disappearence	0.54	0.7	0.37	0.37
Pupae	*k7* parasitism	0	0	0	0.18
	k8 disappearence	0.3	0	0.48	0.18
TOTAL (*K*)		1.42	1.28	1.09	0.99

Table 17. Summary of k-values obtained from the partial budgets of *Chilo partellus* under maize-cowpea intercropping system

		Generations			
Life stage	Mortality factor	1	2	3	4
Small larvae	*k2* disappearence	0.09	0.1	0.33	0.21
Medium larvae	*k3a Cotesia sesamiae*	0	0	0.03	0.09
	k4 disappearence	0.62	0.56	0.27	0.09
Large larvae	*k6* disappearence	0.48	0.48	0.37	0.7
Pupae	*k7 P. furvus*	0.3	0	0.18	0
	k8 disappearence	0	0	0.18	0.3
TOTAL (*K*)		1.49	1.14	1.36	1.39

Table 18. Summary of k-values obtained from the partial budgets of *Chilo partellus* under mulched maize monocrop system

		Generations			
Life stage	Mortality factor	1	2	3	4
Small larvae	*k2* disappearence	0.07	0.09	0.13	0.25
Medium larvae	*k3a Cotesia sesamiae*	0.02	0	0.03	0.07
	k3b C. flavipes	0	0	0.05	0.07
	k4 disappearence	0.34	0.3	0.05	0.07
Large larvae	*k6* disappearence	0.65	0.78	0.38	0.2
Pupae	*k8* disappearence	0.3	0	0.22	0.22
TOTAL (*K*)		1.38	1.17	0.86	0.88

Table 19. Summary of k-values obtained from the partial budgets of *Chilo partellus* under unmulched maize monocrop system

		Generations			
Life stage	Mortality factor	1	2	3	4
Small larvae	*k2* disappearence	0.13	0.07	0.38	0.3
Medium larvae	*k3a Cotesia sesamiae*	0	0.04	0.1	0.06
	k3b C. flavipes	0	0	0.03	0.06
	k4 disappearence	0.28	1.31	0	0.2
Large larvae	*k6* disappearence	0.35	0.3	0.4	0.48
Pupae	*k8* disappearence	0.12	0	0.6	0
TOTAL (*K*)		0.88	1.72	1.51	1.1

Table 20. Key factor analysis under maize/leucaena system. Podoler and Rogers method (1975). Submortalities (k_i) with the greatest positive slope contribute most to total mortality (K).

Stage	k_i	R^2	p	Slope
Small larvae	k2	0.62	0.215 -	0.9
Medium larvae	k3a	0.001	0.996	-0.007
	k3b	0.63	0.206	0.032
	k4	0.304	0.449	0.512
Large larvae	k6	0.46	0.329	0.679
Pupae	k8	0.001	0.967	-0.027

Table 21. Key factor analysis under maize/gliricidia system. Podoler and Rogers method (1975). Submortalities (k_i) with the greatest positive slope contribute most to total mortality (K).

Stage	k_i	R^2	p	Slope
Small larvae	k2	0.16	0.599	-0.116
Medium larvae	k3a	0.55	0.256	-0.03
	k4	0.87	0.068	-0.58
Large larvae	k6	0.912	0.045	0.744
Pupae	k7	0.954	0.023	0.285
	k8	0.83	0.089	0.698

Table 22. Key factor analysis under maize/cowpea/leucaena/gliricidia system. Podoler and Rogers method (1975). Submortalities (k_i) with the greatest positive slope contribute most to total mortality (K).

Stage	k_i	R^2	p	Slope
Small larvae	k2	0.394	0.802	0.218
Medium larvae	k3a	0.152	0.610	0.144
	k3b	0.043	0.792	0.057
	k4	0.246	0.504	-1.04
Large larvae	k6	0.637	0.202	1.326
Pupae	k8	0.034	0.814	0.296

Table 23. Key factor analysis under maize/leucaena/gliricidia system. Podoler and Rogers method (1975). Submortalities (k_i) with the greatest positive slope contribute most to total mortality (K).

Stage	k_i	R^2	p	Slope
Small larvae	k2	0.654	0.192	0.338
Medium larvae	k3a	0.178	0.578	-0.052
	k3b	0.505	0.289	-0.092
	k4	0.829	0.089	0.719
Large larvae	k6	0.526	0.275	0.598
Pupae	k8	0.029	0.830	-0.178

Table 24. Key factor analysis under maize/cowpea system. Podoler and Rogers method (1975). Submortalities (k_i) with the greatest positive slope contribute most to total mortality (K).

Stage	k_i	R^2	p	Slope
Small larvae	k2	0.019	0.860	0.106
Medium larvae	k3a	0.057	0.760	0.069
	k4	0.023	0.848	-0.257
Large larvae	k6	0.018	0.865	0.126
Pupae	k7	0.504	0.289	0.708
	k8	0.062	0.751	0.248

Table 25. Key factor analysis under mulched maize system. Podoler and Rogers method (1975). Submortalities (k_i) with the greatest positive slope contribute most to total mortality (K).

Stage	k_i	R^2	p	Slope
Small larvae	k2	0.569	0.246	-0.244
Medium larvae	k3a	0.388	0.378	-0.074
	k3b	0.821	0.094	-0.129
	k4	0.942	0.029	0.589
Large larvae	k6	0.642	0.199	0.841
Pupae	k8	0.001	0.967	0.017

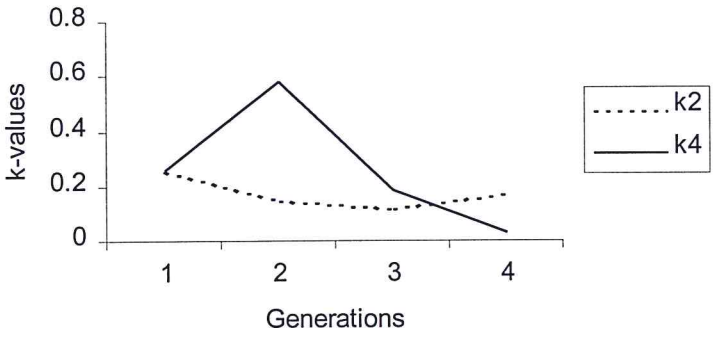
Table 26. Key factor analysis under unmulched maize system. Podoler and Rogers method (1975). Submortalities (k_i) with the greatest positive slope contribute most to total mortality (K).

Stage	k_i	R^2	p	Slope
Small larvae	k2	0.002	0.954	-0.0.17
Medium larvae	k3a	0.282	0.469	0.058
	k3b	0.033	0.819	-0.014
	k4	0.334	0.422	0.888
Large larvae	k6	0.176	0.581	-0.084
Pupae	k8	0.051	0.774	0.169

Table 27. Regression analysis and density relationships of *C. partellus* under various cropping systems.

	Mortality factors						
Cropping systems	k2	k3a	k3b	k4	k6	k7	k8
Maize/leucaena	b=0.13	0.11	0.05	0.79	-0.35	_	-0.28
	p=0.678	0.693	0.237	0.499	0.739	_	0.667
Maize/gliricidia	b=0.3	-0.08	_	-0.86	0.45	0.08	0.5
	p=0.334	0.024	_	0.326	0.302	0.775	0.438
Maize/cowpea/ leucaena/gliricidia	b=0.26	-0.21	-0.18	0.79	0.58	_	0.67
	p=0.715	0.208	0.064	0.473	0.198	_	0.423
Maize/leucaena/ gliricidia	b=0.4	-0.04	-0.12	0.64	-1.82	0.19	0.68
	p=0.109	0.822	0.448	0.553	0.137	0.514	0.239
Maize/cowpea	b=0.28	-0.02	0.13	0.32	0.29	0.39	0.39
	p=0.615	0.936	_	0.808	0.548	0.467	0.467
Maize/mulch	b=0.27	0.01	-0.05	0.25	-1.04	_	0.24
	p=0.636	0.979	0.832	0.811	0.58	_	0.366
Maize/no mulch	b=0.76	-0.22	0.13	-6.678	0.12	_	0.65
	p=0.071	0.658	0.708	0.254	0.484	_	0.342

Figure 1. Key factor analysis under maize-leucaena system. Varley and Gradwell method (1960).



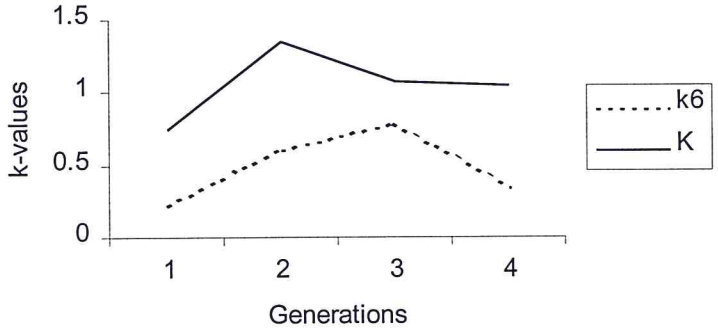
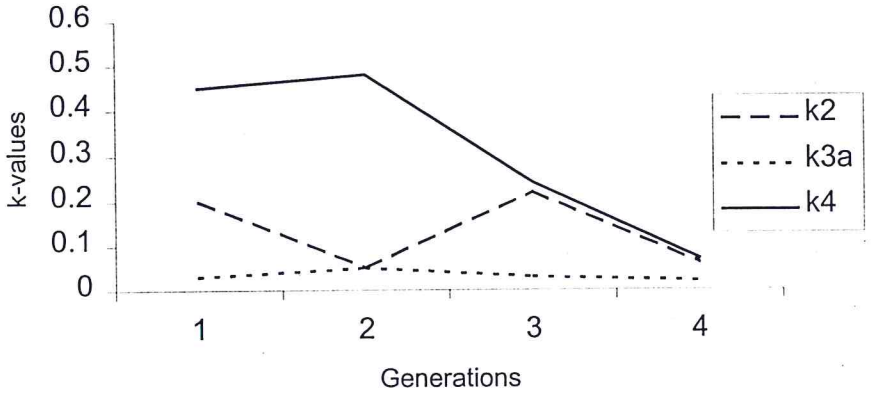


Figure 2. Key factor analysis under maize-gliricidia. Varley and Gradwell method (1960).



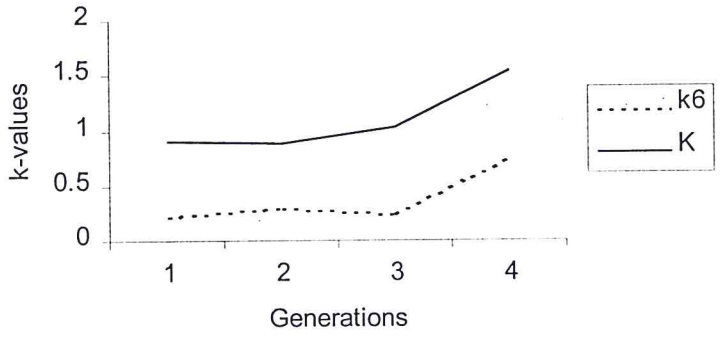
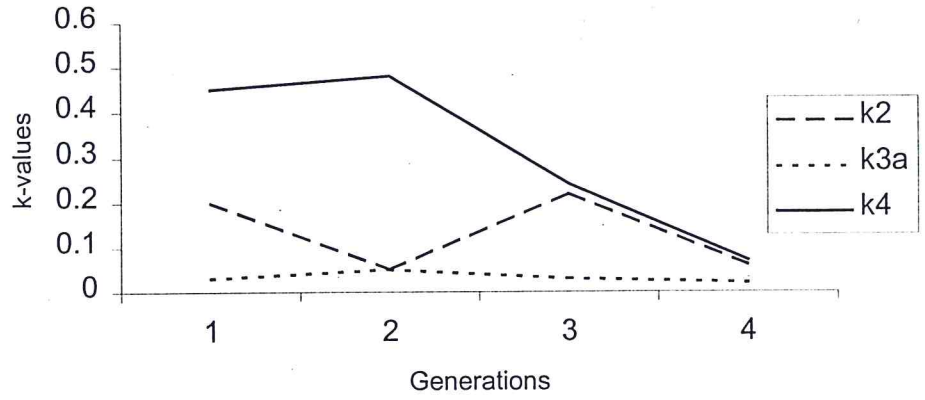


Figure 3. Key factor analysis under maize-cowpea-leucaena-gliricidia system. Varley and Gradwell method (1960).



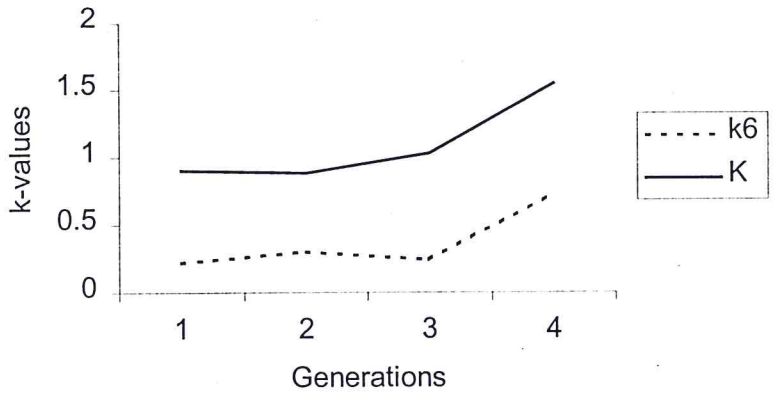


Figure 4. Key factor analysis under maize-leucaena-gliricidia system. Varley and Gradwell method (1960).

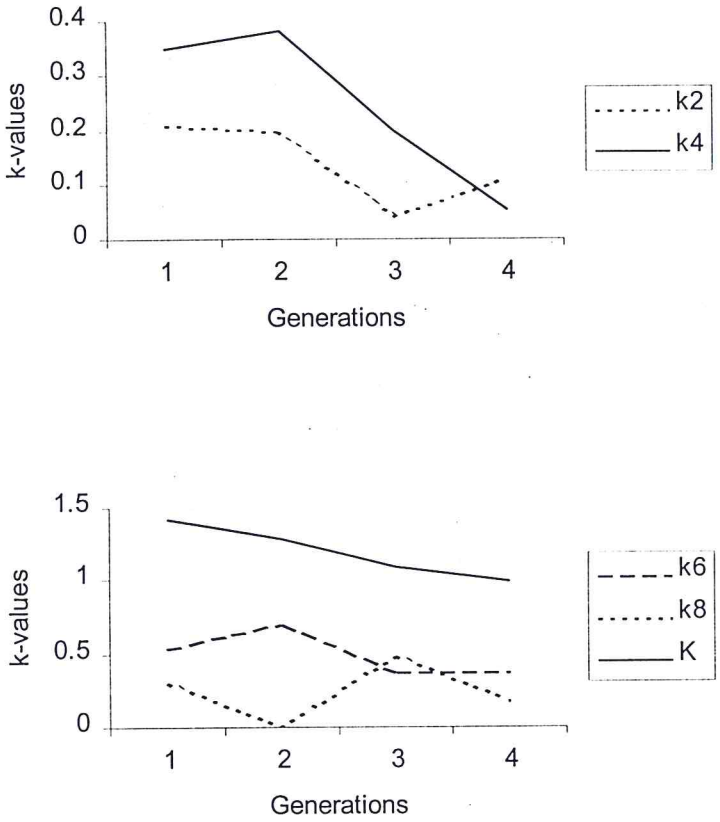


Figure 5. Key factor analysis under maize-cowpea intercrop. Varley and Gradwell method (1960).

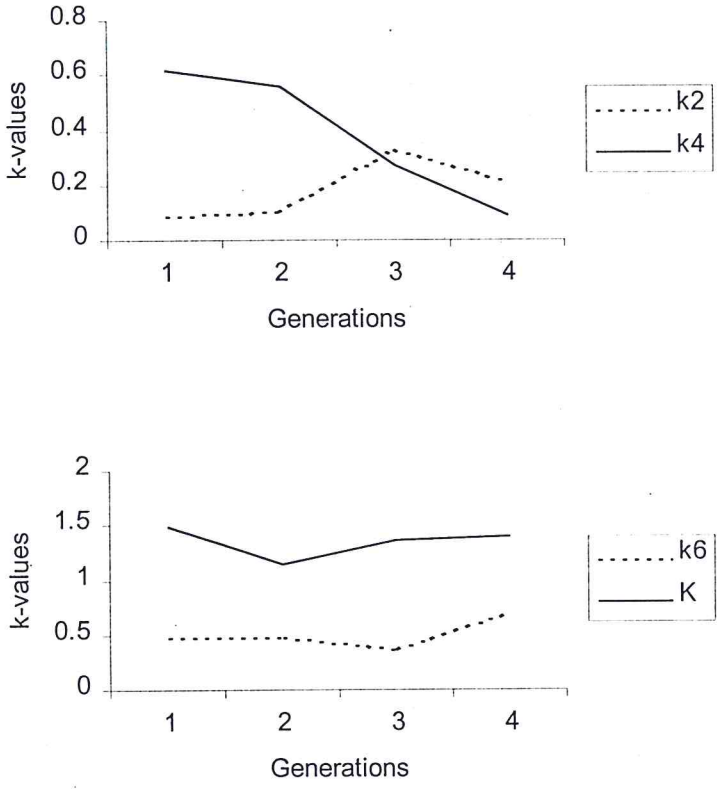


Figure 6. Key factor analysis under mulched maize monocrop. Varley and Gradwell method (1960).

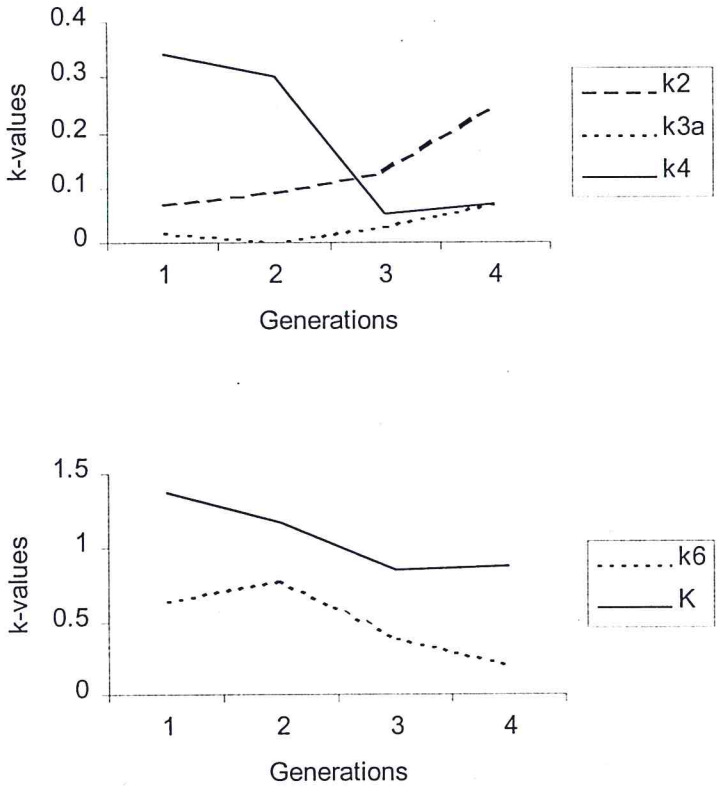
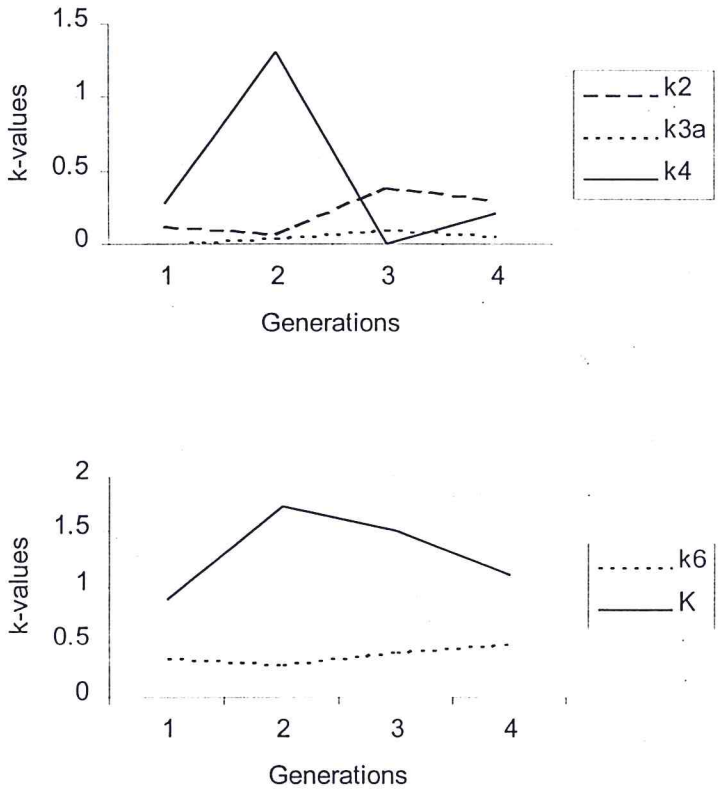


Figure 7. Key factor analysis under unmulched maize monocrop. Varley and Gradwell (1960).



CHAPTER FOUR

4. ESTABLISHMENT AND EFFICACY OF *TAMARIXIA LEUCAENAE* BOUCEK (HYMENOPTERA:EUPELMIDAE) AND *PSYLLAPHAEGUS YASEENI* NOYES (HYMENOPTERA:ENCYRTIDAE) AGAINST THE LEUCAENA PSYLLID.

4.1 Introduction

Leucaena leucocephala is a leguminous multipurpose tree species native to areas of Mexico and Central America. From these areas it has spread over much of the tropical regions of the world where it has become an important component of many farming systems.

In 1991, the leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), as earlier predicted, arrived in Africa from the islands of Mauritius and Reunion (Hollis, 1992) and was first reported in Kenya in 1992 at the coastal region (Reynolds and Bimbuzi, 1992). It has since spread to most of eastern, central and southern Africa (Ogol and Spence, 1997). Both nymphs and adults feed on the developing shoots of the host plant by sucking the sap (Napompeth 1994) causing stunting and rosetting of new growths. Repeated attacks lead to severe defoliation. Additionally, their excessive sucking of plant sap results in the excretion of copious amounts of honeydew that sticks on the terminals and falls onto lower older leaves, encouraging growth of sooty moulds. Although plants recover in most cases, death of damaged plants has been known to occur.

Two control strategies are generally recognised as offering effective solution to the problem; resistant varieties and biological control (Heydon and Affonso, 1989;

Napompeth, 1990; USAID, 1991; FAO, 1994). Classical control of the leucaena psyllid (the introduction of specialised and safe exotic control agents from a pest's native region) has been implemented in many countries in Asia and Pacific regions. In Kenya, the introduction of the exotic parasitoids was executed by CAB International Institute of Biological Control. In 1996, two parasitoids, *Tamarixia leucaenae* Boucek (Hymenoptera:Eupelmidae) and *Psyllaphaegus yaseeni* Noyes (Hymenoptera:Encyrtidae) were released. The first releases were made at Machakos, eastern Kenya, and subsequently at Mtwapa in the coastal region and the establishment of the parasitoids is reported here. The objective of the present study was to determine whether the two parasitoids released against the psyllid had established and the impact they had on the target pest.

4.2 Materials and methods

4.2.1 Monitoring establishment and impact of the parasitoids

To monitor the establishment and any possible impact of the parasitoids, three types of data were collected: psyllid populations, leucaena growth and damage, and parasitism rates. Sampling for all the data was biweekly, starting 4 weeks after pruning of the trees (done at onset of cropping season) and continued until the beginning of the next cropping season, when the leucaena trees were pruned again. Ten leucaena plants per plot were randomly selected and marked using pegs. The number of flushing shoots were recorded from these trees to get the amount of leucaena growth at that sampling occasion. At the same time, data on leucaena damage were obtained by use of a modification of a rating scale adapted from Ogol and Spence (1997). The damage to each shoot was scored

on a 4-point scale (1= healthy, 2= slight damage, 3= heavy damage and 4= dead). The rating was based on the general condition and health of leaves and stems and on an estimate of percentage of leaf loss due to psyllid damage. The overall damage rating was calculated by averaging the ratings of the shoots per sampling occasion.

Psyllids were sampled using a modification of the method of Elder and Mayer (1990). From the 10 marked trees, shoot terminals consisting of one expanded and two unexpanded, plus the next three leaves were carefully cut from individual plants and placed in vials containing 70% ethanol. In the laboratory, the number of psyllid nymphs were counted under a dissecting microscope. The numbers of small (instars 1 and 2), medium (instars 3 and 4) and large (instar 5) nymphs were recorded. Data obtained were expressed as number of nymphs per shoot.

Data on parasitism were obtained from the psyllid mummies, i.e. those parasitized by one of the two biocontrol agents, using the terminal shoots plus the next three leaves. The three leaves following the terminal shoots were sampled since the psyllid mummies are rarely found in the terminal shoots. Mummies were identified based on the psyllid stage/instar at mummification. It is known that psyllids parasitized by *P. yaseeni* (instars 1 and 2) continue to develop until instar 5, when they turn brown and mummify (Murai, 1986; Waage, 1989 and Funasaki *et al.*, 1989). It was thus assumed that fifth (large) nymphs recorded are those that had escaped parasitism.

Those psyllids parasitized by *T. leucaenae* appear to stop developing, as often occurs with ectoparasitoids, but after about 5 days after attack, the host dies and mummification begins. As *T. leucaenae* prefers to attack 3-4 instars and instars 3-5 last

about 6-7 days, it is thus assumed that fifth instars observed in the field are also the same age as the *T. leucaenae* mummies observed.

4.2.2 Weather Data

Weather data comprising mean monthly rainfall, temperature and relative humidity were obtained from the meteorological office of the Kenya Agricultural Research Institute (KARI) station at Mtwapa.

4.3 Data Analysis

The effect of a parasitoid is often expressed in terms of the percentage of hosts that are parasitized. Assessing this accurately is not easy, but an approximation or index of parasitism can be obtained by recording the number of parasitized hosts in the field, and expressing this as a percentage of an estimate of the total host population of the same age as those attacked. The information on the mummies is then used to calculate the parasitism index as follows:

$$= \frac{100 \times \text{No. mummies (one species)}}{\text{No. mummies (both species)} + \text{large nymphs}}$$

This was calculated separately for each of the biocontrol agents at each sampling occasion, using the number of mummies and large nymphs on the shoot plus the next three lower leaves. This method is not completely accurate but it offers realistic relative measure of the level of attack.

To help test the visual relationship between psyllid populations and levels of parasitism by *T. leucaenae*, the data were converted into monthly averages and then carried out regression analysis carried out.

4.4 Results

Both parasitoids were found associated with leucaena psyllid at every sampling occasion. *T. leucaenae* registered parasitism indices in the range of 7.7 to 71.75 while that of *P. yaseeni* was 0 to 32.5. Parasitism indices for *T. leucaenae* tended to increase as a response to an increase in psyllid populations and decrease with the decline in the host's populations (figure 8) showing density dependence.

The psyllid populations fluctuated from one sampling occasion to the other and appeared to be lower during extreme weather conditions (wet and dry) and higher during moderate weather condition (figure 9). Increases in psyllid populations followed the re-emergence of new growths on recently cut leucaena. Later in the season, the psyllid populations tended to decline as the leucaena matured towards flowering and fruiting.

The highest shoot damage by the psyllid followed periods of high leucaena growth (figure 10), further indicating the response of the psyllid populations to leucaena growth.

From the regression analysis, a regression coefficient of 0.72 was obtained and this was significant ($p=0.05$) (Figure 11), confirming the visual relationship that as the psyllid population increased, the parasitism levels by *T. leucaenae* also increased and vice versa. This was not done for *P. yaseeni* for the relatively insignificant mortality exerted by this parasitoid.

4.5 Discussion.

Both parasitoids were recorded at every sampling occasion, indicating their establishment since they are present in the field three years after introduction. From the parasitism indices obtained, it is evident that the parasitoids are having a significant impact on the pest population. This however does not appear to provide effective control of the pest since high pest levels and damage could still be registered. Probably sampling over a longer period of time may record greater mortality because parasitism is known to vary in time and space. But the fact that they were detected causing significant mortality indicated their contribution towards the overall aim of reducing the pest load and keeping it under control. Their establishment, though a necessary step in classical biological control, does not guarantee that the parasitoids will be effective in controlling the pest. Indeed there are areas where establishment of natural enemies has occurred but has not provided effective control of the pest (Stiling, 1990)

Tamarixia leucaenae appears to be more important in regulating the population of the psyllid than *P. yaseeni* since it was causing more mortality. Its population also seemed to respond numerically to the psyllid population as indicated by the correlation analysis, a useful characteristic of a biocontrol agent. Funasaki *et al.* (1989) reported a similar trend in a survey where they monitored the two parasitoids and other natural enemies in Hawaii. In the survey, *T. leucaenae* registered a significantly higher parasitism throughout the sampling period. McClay (1989) studied biocontrol of the leucaena psyllid in Mexico and observed that both *T. leucaenae* and *P. yaseeni* occurred throughout the range of *H. cubana* but the former always exerted higher parasitism/mortality. Possible reasons can be

advanced for the better performance of *T. leucaenae* over *P. yaseeni*. The former has been reported as having a shorter generation time. It is also known to be thelyotokous (all-female producing) and attacks later nymphal stages of the psyllid than the later. *Psyllaphaegus yaseeni* on the other hand, has been found to be associated with several hyperparasitoids wherever it is established (Funasaki *et al.*, 1989; McClay, 1989), even though none was obtained in this study. This parasitoid however, is reported to be established and effective in some Asia and Pacific regions (Funasaki *et al.*, 1989; Day *et al.*, 1995).

The findings of the current study and those from previous studies (Waage, 1989; Napompeth, 1994 and Ogol and Spence, 1997) demonstrate that the populations of *H. cubana* in Mtwapa as well as in any other areas fluctuate widely in space and time. Various factors besides the natural enemies were found responsible for this. Extremely wet and dry periods have been shown to detrimentally affect the pest population (Ogol and Spence, 1997). Psyllid populations are affected negatively by high moisture conditions. Adequate moisture in the environment encourages new shoot development in leucaena, but moisture also encourages psyllid reproduction and also its pathogens (Lina *et al.*, 1988).

The psyllid is dependent on the fresh terminal shoots and these are often limiting during the extreme dry weather conditions. These weather conditions also negatively affect the reproduction of the pest as well as washing away (wet conditions), dehydrating (dry conditions) and killing both the immature and adult stages of the pest (Lina *et al*, 1988). Regular pruning of leucaena hedgerows also significantly reduces the populations of the immature insects. This however, is soon overtaken by the few survivors that then

reproduce fast (repopulating) due to the new flushing shoots that normally come up following pruning. Later in the season, the development of the leucaena trees towards maturity tends to revert this upward trend. At the time of flowering and fruiting, the number of new flushing leaves and growing shoots is depressed and this appears to reduce the psyllid numbers.

It appears evident that natural enemies certainly have a role to play in the control of the leucaena psyllid. However, based on these results, they appear incapable of offering effective control of the pest. It is desirable that their activity be complemented with other control measures. The effective control strategy would be the integration of other control strategies that include selective use of chemicals in the nursery at the seedling stage, use of resistant cultivars, cultural practices and biological control. These are likely to exert sustained mortality on the pest, thus severely depressing their population, in addition to other mortality factors. Thus, life table studies will be desirable to assist in identifying the various mortality factors acting on the leucaena psyllid at various stages. This information could then be utilized to help design the most effective control approach.

Figure 8. Mean parasitism index of *P. yaseeni* and *T. leucaenae* and mean number of *H. cubana* nymphs per shoot. Means represent data averages per sampling period during each month.

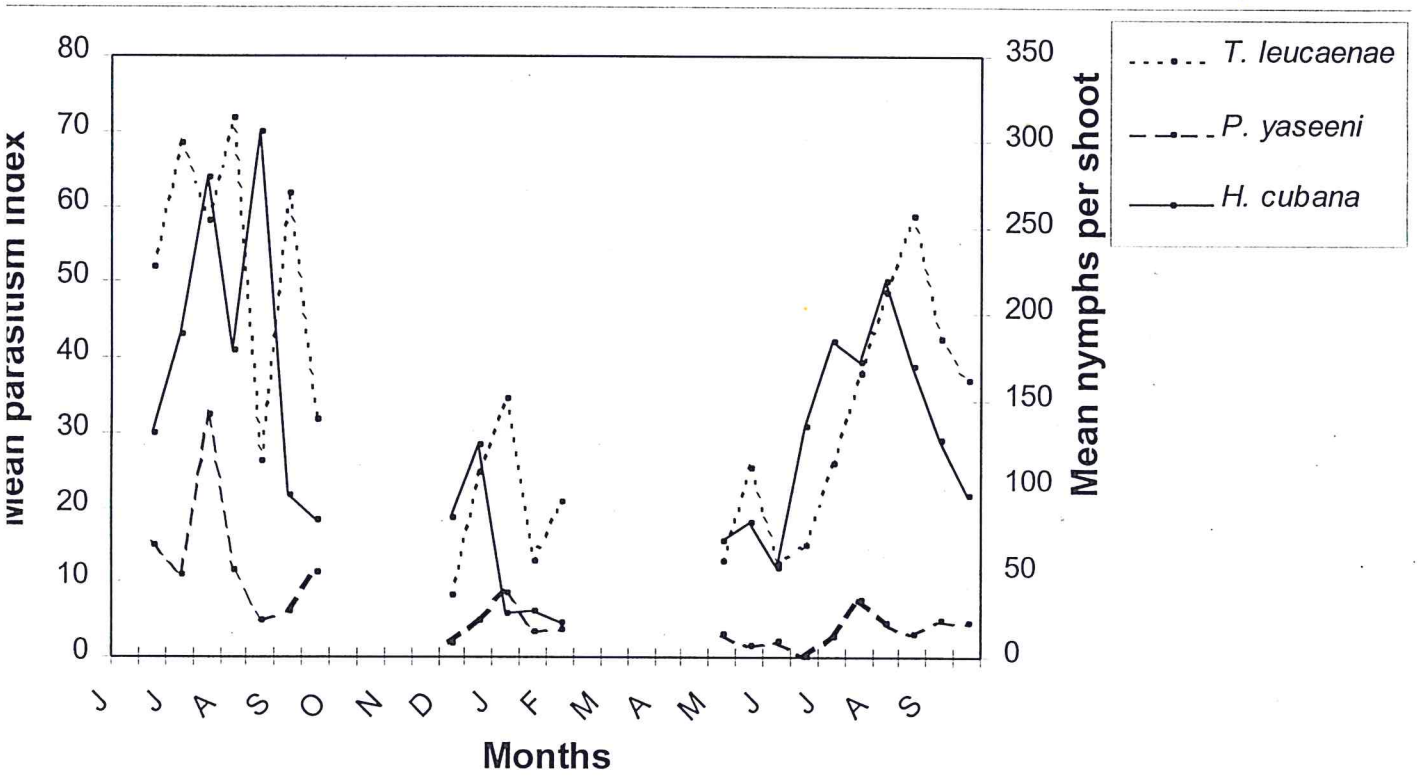


Figure 9. Seasonal abundance of leucaena psyllid nymphs in relation to rainfall. Means represent data averages per sampling period during each month.

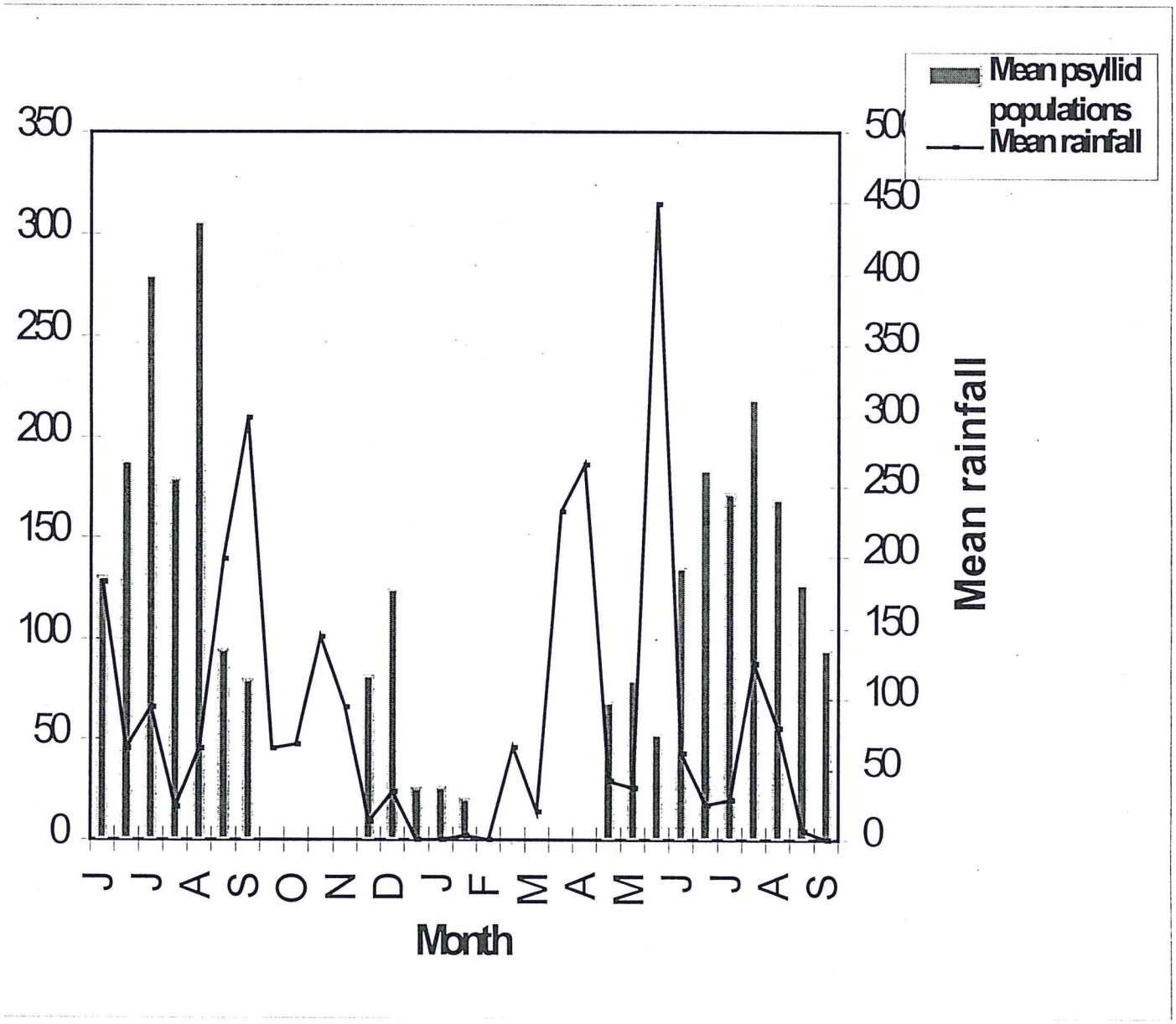


Figure 10. Mean damage rating of leucaena plants by the leucaena psyllid per month. Means represent data averages per sampling period during each month.

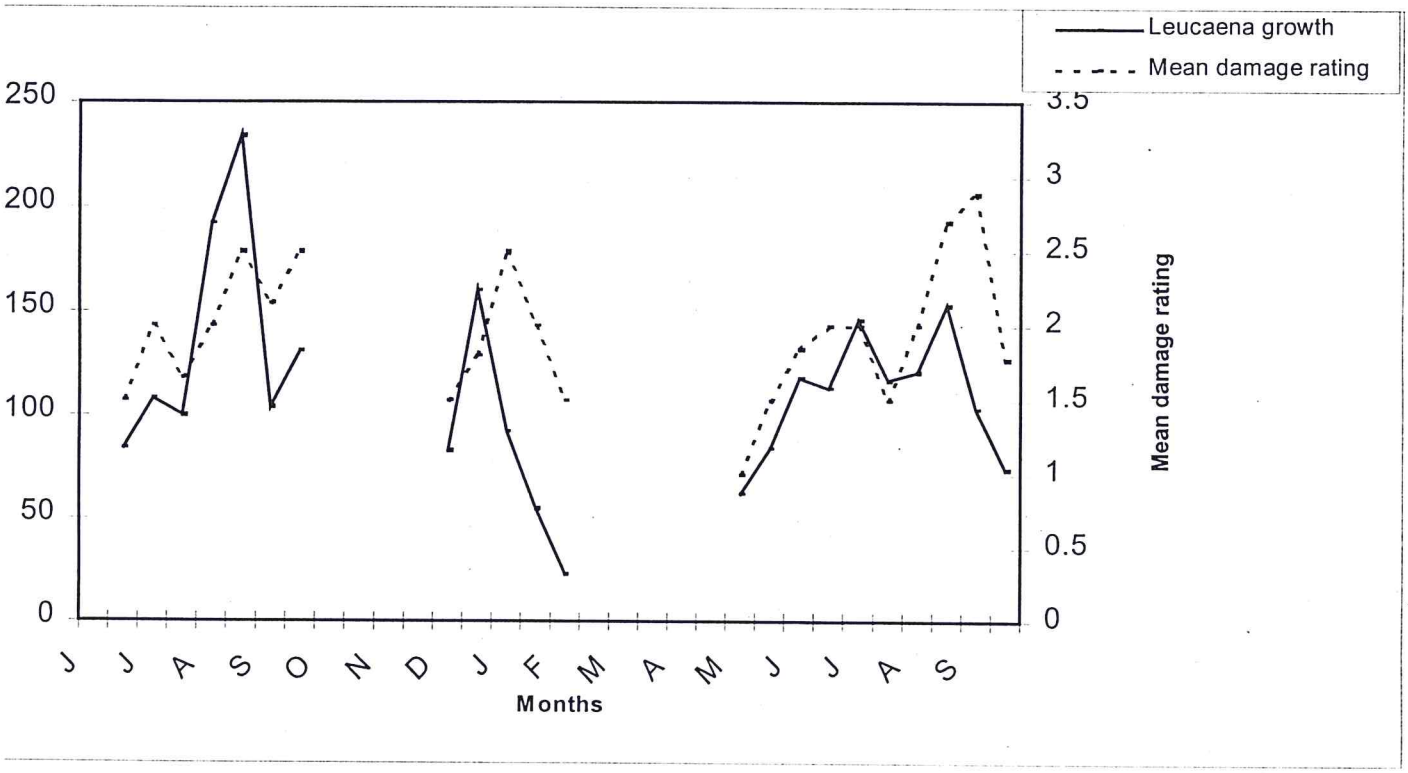
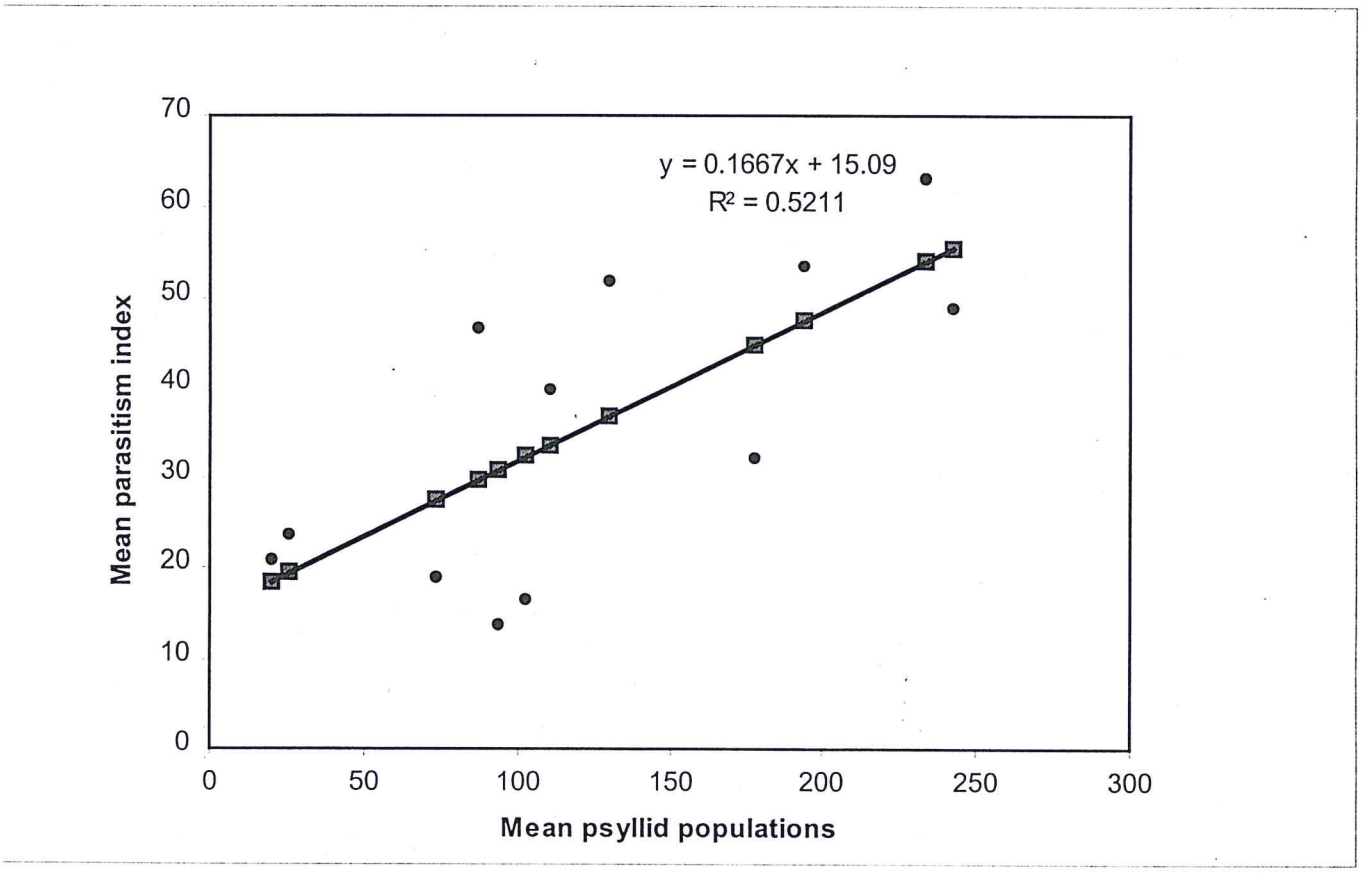


Figure 11. Regression showing the response of *T. leucaena* to psyllid populations. Means represent data averaged per month (P=0.008)



CHAPTER FIVE

5 GENERAL DISCUSSION, CONCLUSIONS AND RECOMENDATIONS

5.1 Natural enemy abundance and activity.

No evidence of enemies hypothesis was observed in this study, indicating that the vegetation structure and cultural treatments established in the study did not enhance the activity levels of the stemborer natural enemies. Parasitoids, predators and microbial mortality factors acted in the same way, irrespective of the cropping system. It had been hoped that if the enemies hypothesis held, the more diverse cropping system comprising of leucaena-gliricidia-cowpea-maize would have led to higher numerical and/or efficacy levels of the natural enemies that would have resulted to lower stemborer incidence. The study thus yielded a neutral response to the enemies hypothesis with whose possible explanations have been discussed in the text. However natural enemies had a role to play in lowering stemborer populations because high egg parasitism rates were observed in the study. These results show that there is no rule of thumb on the response of natural enemies to agroecosystem diversification. There are several interactions among the biotic and abiotic components in an agroecosystem that could possibly influence the natural enemy responses. Different studies in this area have yielded different results. There is thus a need to evaluate each case of vegetational diversification on an individual basis. This should lead us to a clearer understanding of how natural enemies are influenced by different vegetation combinations for a more effective and exhaustive utilisation of pest management benefits of agroecosystem diversification.

5.2 Life tables, key factor analysis and density relations in natural populations of stemborers

The results showed very little variation in total intergeneration and mean real generation mortality implying absence of evidence to support the notion that agroecosystem diversification leads to higher numerical and/or efficacy levels of natural enemies. The main mortality factor was found to be 'disappearance' in all the cropping systems established in this study. This covers mortality and losses due to predation, emigration, biotic and abiotic sources other than parasitism. The early stages of the stemborer (instars1, 2 and 3) recorded more mortality than the large (instars 4 and 5) larvae and pupae. The early stages are exposed and this predisposes them to mortality factors. Also, it is at these stages that they balloon-off and some may land on the wrong hosts leading to death. Mean real generation mortality implies that in all the cropping systems studied, less than 10% of the small larvae survive to adult stage, signifying the magnitude of natural mortality on the stemborer populations at the Kenyan coast.

Parasitoids contributed very minimally to stemborer population regulation in the study. They were not identified as key factors but it is noteworthy that natural enemies in most cases do not appear as key factors in life tables of their hosts. This does not mean they are not important in population regulation of their hosts, as identification of a key factor does not necessarily point to the factor(s) that may regulate the population density. They certainly have a contribution to make in lowering stemborer populations.

Failure to observe significant contributions of agoforestry and intercropping in enhancing natural enemy activity levels in this study does not in any way suggest absence of pest management benefits of these systems. Life table data are population estimates and so

there is a possibility of underestimation of the activity of the natural enemies. There is thus a need to carry out a detailed life table study that incorporates all the stemborer life stages as response to agroecosystem diversification could be experienced at any developmental stage of the pest.

5.3 Establishment and efficacy of biocontrol agents against the leucaena psyllid

Both *Tamarixia leucaenae* and *Psyllaephaegus yaseeni* were recorded as having established in Mtwapa, coastal Kenya since they were still in the field three years after introduction. The former was found exerting more mortality than the later with its population responding numerically to that of the psyllid. Leucaena damage level by the psyllid was found to correspond to psyllid populations which in turn was found to be influenced by leucaena growth and stage after pruning, weather conditions and natural enemies. The populations were highest during highly vegetative stages of leucaena (shortly after pruning) and moderate weather.

The parasitoids were found exerting significant mortality on the psyllid although high damage levels could still be registered. This notwithstanding, they certainly have a niche in the overall process of controlling the psyllid and keeping it under check. On their own they have shown that they are incapable of offering effective control. The right control strategy should be one that employs an integration of all the available methods including use of resistant varieties, pesticides at the seedling stage in the nursery and natural enemies. There is thus a need to carry out a life table study to help identify the main mortality factors especially the natural enemies that could be incorporated in the integrated management of the leucaena psyllid.

REFERENCES

Ajayi, O. (1989). Stemborers of sorghum in west Africa with emphasis on Nigeria. In: International workshop on sorghum stemborers, Patancheru India, 17-20, November, 1987. International Crops Research Institute for the Semi Arid Tropics, Patancheru, India, pp, 27-30.

Altieri, M.A., and D.K. Letourneau (1982). Vegetational Management and biological control in agroecosytems. Crop protection 1:402-404.

Altieri, M.A., W.J. Lewis, D.A. Nordlund, R.C. Gueldner, and J.W. Todd (1981). Chemical interactions between plants and *Trichogramma* sp. wasps in Georgia soybean fields. Prot. Ecol. 3: 259-263.

Ampofo, J.K.O (1986). Maize stalk borer (Lepidoptera:pyralidae). Damage and plant resistance. Environmental Entomology 15:1124-1129.

Ampofo, J.K.O., Saxena, K.N., Kibuka, J.G. and Nangiri, E.O. (1986). Evaluation of some maize cultivars for resistance to the stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) in western Kenya. Maydica 31:379-389.

Andow, D.A.(1991). Vegetational diversity and arthropod population response. Ann. Rev. Entomol. 36: 561-586.

Bellows, T.S. Jr., R.G. Van Driesche and J.S. Elkington (1992). Life table construction and analysis in the evaluation of natural enemies. Ann. Rev. Entomol. 37: 587-614.

Berger, A. (1989). Balloning activity of *Chilo partellus* larvae in relation to size of mother, egg batches, eggs and larvae and age of mother. Entomologia Experimentalis et Applicata 50, 125-132.

Bonhof, M.J. (2000). The impact of predators of maize stemborers in coastal Kenya. Ph.D. dissertation, Wageningen Agricultural University, Netherlands, 181pp.

Bugg, R.L., L.E. Ehler and L.T. Wilson (1987). Effect of common knotweed (*Polygonium aviculare*) on abundance and efficiency of insect predators of crop pests. Hilgardia 55: 1-51.

Chitere, P.O. and B.A. Omolo, (1993). Farmers' indigenous knowledge of crop pests and their damage in western Kenya. International Journal of Pest Management 39(2): 126-132.

CIBC (1968-1972). Annual Reports of the Commonwealth Institute of Biological Control, Farnham Royal.

Cock, M.J.W. (1986). Requirements for biological control: An ecological perspective. Biocontrol News and Information 7: 7-12.

Dabrowski, Z.T. and Kidiavai, E.L. (1983). Resistance of some sorghum lines to the spotted stalk borer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) under western Kenya conditions. . Insect Science and its Application 4(1-2): 119-126.

Day, R. K., Hill, M. G., Murphy, S. T. and Nyambo, B. (1995) Candidate agents for biological control of leucaena psyllid in Africa, pp. 169-189. In W. M. Ciesla and L. Nshubemuku (eds) *Leucaena psyllid: a threat to agroforestry in Africa.* FAO, Rome.

DeBach, P., Huffacker, C.B., MacPhee, A.W., (1976). Evaluation of the impact of natural enemies. In: Theory and practice of Biological Control, ed. C.B. Huffacker, P.S. Messenger, pp 225-285. New York Academic 788pp.

Deevay, E.S. Jr. (1947). Life tables for natural populations of animals. Quart. Rev. Biol. 22: 283-314.

Elder R. J.and Mayer D. G. (1990) An improved sampling method for *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) on *Leucaena leucocephala. J. Aust. ent. Soc.* 29, 131-137.

FAO (1994) Leucaena psyllid in the Asia-Pacific Region: Implications for its management in Africa. Regional Office for Asia and the Pacific (RAPA) Publication 1994/13. 27pp.

Funasaki Y. G., Lai P. and Nakahara M. L. (1989) Status of natural enemies of *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) in Hawaii, pp. 153-158. In *Leucana psyllid: Problems and Management* (Edited by B. Napompeth and K. G. MacDicken). Proceedings of a workshop, January 16-21, Winrock International/IDRC/NFTA, Bogor, Indonesia.

Greathead, D.J. (1990). Utilization of natural enemies of *Chilo spp.* for management in Africa. Insect Science and its Application II; 467-477.

Grisley, W., (1997). Crop pest yield loss: a diagnostic study in the Kenya highlands. International Journal of Pest Management 43(2): 137-142.

Harcourt, D.G., (1969). The development and use of life tables in the study of natural insect populations. Ann. Rev. Entomol. 14: 175-169.

Harris, K.M. (1990). Bioecology and *Chilo* species. Insect Sci. Applic. 11: 467-477.

Herzog, D.C. and J.E. Funderburk (1986). Ecological basis for habitat management and pest control, pp.217-250. In M. Kogan (ed.), Ecological theory and integrated pest management practice. Wiley, New York.

Heydon D. and Affonso M. (1989) Economic review of psyllid damage on leucaena in South East Asia and Australia. Report prepared for the Australian International Development Assistance Bureau. CAB International Development Service, Wallington, U.K. 129pp.

Hollis, D. (1992). Leucaena psyllid, *Heteropsylla cubana* Crawford newly recorded in Mauritius and Reunion. F.A.O Plant Prot. Bull. 40, 49-50. ICIPE Annual Report (1994) pp 29.

Ingram, W.R. (1958). The lepidopterous stalk borers associated with Graminae in Uganda. Bull. Ent. Res. 49:367-383. Graminaceous stemborers in East Africa. Commonwealth Institute of Biological Control (cyclostyled report).

Kang, B.T., G.F. Wilson, and T.L. Lawson (1984). Alley cropping: a stable alternative to shifting cultivation: IITA, Ibadan, Nigeria.

Khan, Z.R., Chilishwa, P., Ampong-Nyarko, K., Smart, L.E., Polaszek, A., Wandera, J. and Mulaa, M.A. (1997). Utilisation of wild gramineous plants for the management of cereal stemborers in Africa. Insect Sci. Applic. 17(1): 143-150.

Knutson, A.E. and F.E. Gilstrap (1989a). Direct evaluation of natural enemies of the southwestern corn borer (Lepidoptera: Pyralidae) in Texas corn. Environ. Entomol. 18: 732-739.

Knutson, A.E. and F.E. Gilstrap (1989b). Predators and parasites of the southwestern corn borer (Lepidoptera: Pyralidae) in Texas corn. J. Kansas Entomol. Soc. 62: 511-520.

Knutson, A.E. and F.E. Gilstrap (1990). Life tables and population dynamics of the southwestern corn borer (Lepidoptera: Pyralidae) in Texas corn. Environ. Entomol. 19(3): 684-696.

Kumar, H. (1993). Responses of *Chilo partellus* (Lepidoptera: Crambidae) and *Busseola fusca* (Lepidoptera: Noctuidae) to hybrids of a resistant and a susceptible maize. Journal of Economic Entomology 86(3): 962-968.

Kumar, H. and Saxena, K.N. (1992). Resistance in certain maize cultivars to first and third instar *Chilo partellus* larvae. Entomologia Experimentalis et Applicata 65(1): 75-80.

Lina T., V. Rowena V. P. and Robin P. R. (1989) Factors affecting leucaena psyllid populations in Leyte, Philippines, pp. 122-128. In *Leucaena psyllid: Problems and Management* (Edited by B. Napompeth and K. G. MacDicken). Proceedings of a workshop, January 16-21, Winrock International/IDRC/NFTA, Bogor, Indonesia.

Litsinger, J.A. and K. Moody (1976). Integrated pest management in multiple cropping systems, PP. 293-316. In G.B. Triplett, P. Sanchez and R.I. Papendick (eds.), multiple cropping Am. Soc. Agron spec. Publ. 27.

Mallya, G.A. (1985). Maize entomology. In: National Maize Research Programme 1984-1985. Progress Report presented to National Maize Research Coordinating Committee by A.J. Moshi, 4 November 1985, pp. 41-43.

Luck, R.F., (1971). An appraisal of two methods of analysing insect life tables. Can. Entomol. 103: 1261-1271.

Mallya, G.A. (1985). Maize entomology. In: National Maize Research Programme 1984-1985. Progress Report presented to National Maize Research Coordinating Committee by A.J. Moshi, 4 November 1985, pp. 41-43.

Mallya, G.A. (1986). Maize entomology. In: National Maize Research Programme 1985-1986. UAC, Mbeya, Tanzania, pp. 27-31.

Marandu, W.Y.F., Temu, A.E.M., and Kabango, D. (1987). Plant protection. In: Maize Improvement Programme Annual Progress Report 1987. UAC, Mbeya, Tanzania, p. 3.

Mathez, F.C. (1972). *Chilo partellus* Swinh.(Lep. Pyralidae), *C. orichalcocilliellus* Strand (Lep. Crambidae) and *Sesamiae calamistis* Hmps. (Lep. Noctuidae) on maize in the coast province, Kenya.

McClay A. S. (1989) Distribution of leucaena psyllid and its natural enemies in Mexico: Implications for biological control, pp. 139-143. In *Leucaena psyllid: Problems and Management* (Edited by B. Napompeth and K. G. MacDicken). Proceedings of a workshop, January 16-21, Winrock International/IDRC/NFTA, Bogor, Indonesia.

Milner, J.E.D. (1967). Final report on a survey of the parasitoids of Graminaceous stemborers in East Africa. Commonwealth Institute of Biological Control (Cyclostyled report).

Minja, E.M.K. (1990). Management of *Chilo spp* infesting cereals in Eastern Africa. Insect Sci. Applic. II,489-499.

Mohyuddin, A.I. and Greathead D.J. (1970). An annotated list of the parasites of graminaceous stemborers in East Africa, with a discussion of their potential in Biological control. Entomophaga 15, 241-274.

Morris, R.F. (1959). Single factor analysis in population dynamics. Ecology 40: 580-588.

Morris, R.F. and C.A. Miller (1954). The development of life tables for the spruce bud worm. Can. J. Zool. 32: 283-301.

Mugoya, C.F. and Chinsembu, K.C. (1995). Potential of *Tephrosia vogelii* water extracts for controlling maize stemborer and maize streak virus in Zambia. In: Proceedings of the 10th Meeting and Scientific Conference of the African Association of Insect Scientists, 5-10 September 1993, Mombasa, Kenya. ICIPE Science Press, Nairobi, Kenya.

Murai K. T. (1986) Host range study of the psyllid parasitoid, Psyllaephagus sp. nr. Rotundiformis (Howard). Report

Nakahara L., Nagamine W., Matayoshi S. and Kumashiro B. (1987) *Heteropsylla cubana* and its predators. *Leucaena Research Report* 7 (2):39-44.

Napompeth B. (1990) Leucaena psyllid problems in Asia and the Pacific, pp.1-7. In *Leucaena psyllid: Problems and Management* (Edited by B. Napompeth and K. G. MacDicken). Proceedings of a workshop, January 16-21, Winrock International/IDRC/NFTA, Bogor, Indonesia.

Napompeth B. (1994) Leucaena psyllid in the Asia Pacific region: Implications for its management in Africa. *RAPA-FAO publication* 1994/13. Bangkok, Thailand. 27pp.

Ngi-Song, A.J., Overholt, W.A., and Ayertey, J.N. (1995). Suitability of African graminaceous stemborers for the development of *Cotesia flavipes* and *Cotesia sesamiae* (Hymenoptera: Braconidae). Environmental entomology 24(4): 978-984.

Nordland, D.A., R.B. Chalfant and W.J. Lewis (1984). Arthropod populations, yield and damage in monocultures and polycultures of corn, beans and tomatoes. Agric. Ecosyst. Environ. 11:353-367.

Nordland, D.A., W.J. Lewis, and M.A. Altieri (1988). Influences of plant produced allelochemicals on the host and prey selection behaviour of entomophagous insects, *In* P. Barbosa and D.K. Letourneau [eds.], Novel aspects of insect-plant interactions. Wiley, New York.

Odindo, M.O., W.A. Otieno, G.W. Oloo, J. Kilori, and R.C. Odhiambo (1989). Prevalence of microorganisms in field sampled borers on sorghum, maize and cowpea in western Kenya. Insect Sci. Appl. 10: 225-228.

Ogeda, K. (1999). Evaluation of the impact of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) and indigenous parasitoids on stemborer populations in southwestern Kenya. Msc. thesis dissertation.

Ogol, C.K.P.O., J.R. Spence and A. Keddie, (1998). Natural enemy abundance and activity in a maize-leucaena agroforestry system in Kenya. Environ. Entomol. 27(6): 1444-1451.

Ogol C. K. P. O. and Spence J. R. (1997) Abundance, population dynamics and impact of the leucaena psyllid *Heteropsylla cubana* Crawford in a maize-leucaena agroforestry system in Kenya. *Insect Sci. Applic.* Vol. 17, No. 2, pp. 183-192.

Oloo, G.W. (1989). The role of local natural enemies in population dynamics of *Chilo partellus* (Sinh.) (Pyralidae) under subsistence farming systems in Kenya. Insect Sci. Applic. 10(2): 243-251.

Oloo, G.W. and K. Ogeda, (1990). The incidence of *Chilo partellus* (Sinh.) (Pyralidae) and the contribution of natural enemies to its mortality under intercropping systems in Kenya. Trop. Pest Manag. 36(3): 244-248.

Omolo, E.O. (1983). Screening of local and exotic maize lines for stemborer resistance with special reference to *Chilo partellus.* Insect Sci. Applic. 4(1-2): 105-108.

Omwega, C.O., Kimani, S.W., Overholt, W.A. and Ogol, C.K.P.O. (1995). Evidence of the establishment of *Cotesia flavipes* (Hymenoptera:Braconidae) in continental Africa. Bulletin of Entomological Research 85: 525-530.

Overholt, W.A. (1998). Biological control of cereal stemborers. In Polaszek, A. (ed.) African cereal stemborers. Economic importance, taxonomy natural enemies and control. CAB International, Wallingford Oxon, United Kingdom, pp. 349-362.

Overholt, W.A., Ogeda, K., and Lammers P.M. (1994a). Distribution and sampling of *Chilo partellus* (Swinhoe) (Lepidoptera:pyralidae) in maize and sorghum at the Kenya coast. Bulletin of Entomological Research 84: 367-378.

Overholt, W.A.,Ngi-Song A.J., Kimani, S.W., Mbapila, J., Lammers P.M. and Kioko, E. (1994b). Environmental considerations of the introduction of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) for biological control of *Chilo partellus* (Swinhoe) (Lepidoptera:pyralidae) in Africa. Biocontrol News and Information 15(2): 19N-24N.

Overholt, W.A., Ochieng, J.O., Ogeda, K., and Lammers P.M. (1994c). Rearing and field release methods for *Cotesia flavipes* Cameron (Hymenoptera: Braconidae), a parasitoid of tropical graminaceous stemborers. Insect Sci. Applic. 15: 253-259.

Overholt, W.A., Ngi-Song, A.J., Omwega, C.O., Kimani-Njogu, S.W., Mbapila, J., Sallam, M.N. and Ofomata, V. (1997). A review of the introduction and establishment of *Cotesia flavipes* Cameron (Hymenoptera:Braconidae) in Africa for biological control of cereal stemborers. Insect Sci. Applic. 17(1): 19-35.

Pavuk, D.M., and G.W. Barret (1993). Influence of successional and grassy corridors on parasitism of *Plathypena scabra* (F.) (Lepidoptera: Noctuidae) larvae in soybean agroecosystems. Environ. Entomol. 22: 541-546.

Perrin, R.M. (1975). The role of the perennial stinging nettle, *Urtica dioica*, as a reservoir of beneficial natural enemies. Ann. Appl. Biol. 81: 289-297.

Perrin, R.M. (1977). Pest management in multiple cropping systems. Agroecosystems 3: 93-118.

Perrin, R.M. (1980). The role of environment diversity in crop protection. Prot. Ecol. 2: 77-114.

Perrin, R.M. and M.L. Phillips (1978). Some effects of mixed cropping on the population dynamics of insect pests. Entomol. Exp. Appl. 24:585-593.

Podoler, H. and D. Rogers (1975). A new method for the identification of key factors from life table data. J. Anim. Ecol. 48: 85-115.

Pollard, E. (1971). Hedges Vl. Habitat diversity and crop pests: a study of *Brevicoryne brassicae* and its syrphid predators. J. appl. Ecol. 5: 109-123.

Reynolds, L and Bimbuzi S. (1992). Leucaena psyllid arrives in Kenya. Agroforestry Today 4,2.

Risch, S.J. (1983). Intercropping as a cultural pest control: prospects and limitations. Environ. Manage. 7: 9-14.

Risch, S.J., D. Andow, and M.A. Altieri (1983). Agroecosystem diversity and pest control: data, tentative conclusions and new research directions. Environ. Entomol. 12: 625-629.

Root, R.B. (1973). Organisation of plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleraceae*). Ecol. Monogr. 43: 95-124.

Russel, E.P. (1989). Enemies hypothesis: a review of the effect of vegetational diversity on predatory insects and parasitoids. Environ. Entomol. 18: 590-599.

SAS Institute (1985). SAS user's guide. Statistics, version 5 ed. SAS Institute, Cary, NC.

Saxena, K.N. (1985). Behavioural basis of plant resistance or susceptibility to insects. Insect Sci. Applic. 6: 303-313.

Saxena, K.N. (1990). Mechanisms of resistance/susceptibility of certain sorghum cultivars to the stemborer *Chilo partellus:* role of behaviour and development. Entomologia Experimentalis et Applicata 55: 91-99.

Seshu Reddy, K.V. (1983). Studies on the stemborer complex in Kenya. Insect Sci. Applic. 4: 3-10.

Seshu Reddy, K.V. (1985). Relative susceptibility and resistance of some sorghum lines to stemborers in western Kenya. Insect Sci. Applic. 6(3): 401-404.

Seshu Reddy, K.V. (1988). Assessment of on-farm yield losses in sorghum due to insect pests. Insect Sci. Applic. 9(6): 679-685.

Seshu Reddy, K.V. (1998). Maize and sorghum: East Africa. In Polaszek, A. (ed.) African cereal stemborers. Economic importance, taxonomy natural enemies and control. 530pp. CAB International, Wallingford Oxon, United Kingdom, pp. 25-29.

Seshu Reddy, K.V. and Sum, K.O.S. (1991). Determination of economic injury level of the stemborer of the stemborer, *Chilo partellus* (Swinhoe) in maize (*Zea mays* L.). Insect Sci. Applic. 12(1-3): 269-274.

Seshu Reddy, K.V. and P.T. Walker, (1990). A review of the yield losses in graminaceous crops caused by *Chilo* spp. Insect Sci. Applic. 11: 563-569.

Sheehan,W. (1986). Response by specialist and generalist natural enemies to agroecosystem diversification: a selective review. Environ. Entomol. 15: 456-461.

Sithole, S.Z. (1990). Status and control of the stemborer, *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) in southern Africa. Insect Sci. Applic. 11: 481-488.

Skovgard, H. and P. Pats, (1996). Effects of intercropping on maize stemborers and their natural enemies. Bulletin of Entomological Research 86: 599-607.

Starks, K.J. (1969). Some cereal crop insects in East Africa. East Africa Agriculture and Forestry Organisation. Serere Res. Sta. Uganda, (Mimeo).

Southwood, T.R.E. (1967). The interpretation of population change. J. Anim. Ecol. 36: 519-529.

Southwood, T.R.E. (1978). Ecological Methods. John Wiley and sons. New York 419pp.

Southwood, T.R.E., and W.F. Jepson (1962). Studies on the populations of *Oscinella frit L.* (Diptera: Chloropidae) in the oat crop. J. Anim. Ecol. 31: 481-495.

Stiling P. (1990) Calculating the establishment rates of parasitoids in classical biological control. *American Entomologist* 26, 225-230.

Tams, W.H.T. (1932). New species of African Heterocera. Entomologist 65: 1241-1249.

Unnithan, G.C. and Saxena, K.N. (1990). Factors determining pheromone trapping of the stemborer , *Chilo partellus* Swinhoe (Lepidoptera: Crambidae). Journal of Applied Entomology 110: 183-193.

USAID (1991) Environmental assessment of the classical biological control of the leucaena psyllid in Indonesia, Laos, Malaysia, Nepal, the Philippines and Thailand. Office of Forestry and Natural Resources, Bureau for Science and Technology, United States Agency for International Development, Washington D.C. 94pp. plus appendices.

Van den Berg, J., Nur, A.F. and Polaszek, A. (1998). Cultural control. *In* Polaszek, A. (ed.) African cereal stemborers. Economic importance, taxonomy, natural enemies and control. CAB International. Wallington, Oxon, United Kingdom, pp.333-349.

van Rensburg, J.B.J. and van den Berg, J. (1992). Stemborers in grain sorghum: I. Injury patterns with time after crop emergence. South African Journal of Plants and Soil 9: 73-80.

van Rensburg, J.B.J. and Malan, C. (1992). Resistance of maize genotypes to the maize stalk borer , *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). Technical Communication, Department of Agricultural Development of South Africa 232: 98-99.

Varley, G.C., and G.R. Gradwell (1960). Key factors in population studies. J. Anim. Ecol. 29: 664-669.

Varley, G.C., and G.R. Gradwell (1968). Population models for the winter moth, pp. 132-142, in T.R.E. Southwood (Ed.) Insect Abundance. 4th Symp. Roy. Entomol. Soc. London 160pp.

Varley, G.C., and G.R. Gradwell (1970). Recent advances in insect population dynamics. Ann. Rev. Entomol. 15: 1-24.

Waage J. (1989) Exploration for biological control agents of leucaena psyllid in tropical America, pp.144-152. In *Leucaena psyllid: Problems and Management* (Edited by B. Napompeth and K. G. MacDicken). Proceedings of a workshop, January 16-21, Winrock International/IDRC/NFTA, Bogor, Indonesia

Warui, C.M. and Kuria, J.N. (1983). Population incidence and the control of maize stalkborers *Chilo partellus* Strand and *Chilo orichalcocilliellus* Strand and *Sesamiae calamistis* Hmps in Coast province, Kenya. Ins. Sci. Applic. 4: 11-18.

Whitney, W.K. (1977). Insect and mite pests and their control in food crops of the lowland tropics. (Ed. Leakey C.L.A. and Wills J.B.) Oxford University press.

Williams, C.E., D.M. Pavuk, D.H. Taylor, and T.H. Martin (1995). Parasitism and disease incidence in the green cloverworm (Lepidoptera: Noctuidea) in strip-intercropped soybean agroecosystems. Environ. Entomol. 24: 253-260.

Youdeowei, A., (1989). Major arthropod pests of food and industrial crops of Africa and their economic importance, pp31-50. In: Biological control: A sustainable solution to crop pest problems in Africa. Edited by J.S. Yaninek and H.R. Herren. Ibadan, Nigeria, IITA.

Zhou, G., J. Baumgartner and W.A. Overholt (2001). Impact assessment of an exotic parasitoid on stemborer population dynamics in Kenya. Ecological Applications (in press).

Appendix 1. PARTIAL ECOLOGICAL LIFE TABLES FOR FOUR GENERATIONS OF *CHILO PARTELLUS* UNDER MAIZE-LEUCAENA CROPPING SYSTEM

GENERATION 1 LR 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	20	Parasitism	0	0	0
		Disappearance	9	45	45
		Total	9	45	45
Medium larvae	11	Parasitism	0	0	0
		Disappearance	6	54.5	30
		Total	6	54.5	30
Large larvae	5	Parasitism	0	0	0
		Disappearance	2	40	10
		Total	2	40	10
Pupae	3	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 2 SR' 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	27	Parasitism	0	0	0
		Disappearance	8	29.63	26.93
		Total	8	29.63	26.93
Medium larvae	19	*Cotesia flavipes*	1	5.26	3.7
		Disappearance	14	73.68	51.85
		Total	15	78.95	55.56
Large larvae	4	Parasitism	0	0	0
		Disappearance	3	75	11.11
		Total	3	75	11.11
Pupae	1	Parasitism	0	0	0
		Disappearance	0	0	0

GENERATION 3 LR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	12	Parasitism	0	0	0
		Disappearance	3	25	25
		Total	3	25	25
Medium larvae.	9	Parasitism	0	0	0
		Disappearance	3	33.3	25
		Total	3	33.3	25
Large larvae	6	Parasitism	0	0	0
		Disappearance	5	83.3	41.7
		Total	5	83.3	41.7
Pupae	1	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 4 SR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	22	Parasitism	0	0	0
		Disappearance	7	31.8	31.8
		Total	7	31.8	31.8
Medium larvae	15	*Cotesia sesamiae*	3	20	13.6
		Disappearance	1	6.6	4.5
		Total	4	28.5	18.2
Large larvae	11	Parasitism	0	0	0
		Disappearance	6	54.5	27.3
		Total	6	54.5	27.3
Pupae	5	Disappearance	3	60	13.6
		Total	3	60	13.6

Appendix 2. PARTIAL ECOLOGICAL LIFE TABLES FOR FOUR GENERATIONS OF *CHILO PARTELLUS* UNDER MAIZE-GLIRICIDIA CROPPING SYSTEM

GENERATION 1 LR 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	27	Parasitism	0	0	0
		Disappearance	10	37	37
		Total	10	37	37
Medium larvae	17	*Cotesia sesamiae*	1	5.8	3.7
		Disappearance	11	64.7	40.7
		Total	12	78.5	44.4
Large larvae	5	Parasitism	0	0	0
		Disappearance	2	40	7.4
		Total	2	40	7.4
Pupae	3	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 2 SR' 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	10	Parasitism	0	0	0
		Disappearance	1	10	10
		Total	1	10	10
Medium larvae	9	*Cotesia sesamiae*	1	11.11	10
		Disappearance	6	66.67	60
		Total	7	77.78	70
Large larvae	2	Parasitism	0	0	0
		Disappearance	2	100	20
		Total	2	100	20
Pupae	0	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 3 LR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	23	Parasitism	0	0	0
		Disappearance	11	47.8	47.8
		Total	11	47.8	47.8
Medium larvae	14	*Cotesia sesamiae*	1	7.1	4.3
		Disappearance	6	42.8	26.1
		Total	7	50	30.4
Large larvae	7	Parasitism	0	0	0
		Disappearance	3	42.8	13
		Total	3	42.8	13
Pupae	4	Parasitism	0	0	0
		Disappearance	2	50	8.7
		Total	2	50	8.7

GENERATION 4 SR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	23	Parasitism	0	0	0
		Disappearance	3	13	31.8
		Total	3	13	31.8
Medium larvae	20	*Cotesia sesamiae*	1	5	13.6
		Disappearance	3	15	4.5
		Total	4	20	18.2
Large larvae	16	Parasitism	0	0	0
		Disappearance	13	81.2	27.3
		Total	13	81.2	27.3
Pupae	3	*Pediobius furvus*	1	33.3	0
		Disappearance	2	66.6	13.6
		Total	3	100	13.6

Appendix 3. PARTIAL ECOLOGICAL LIFE TABLES FOR FOUR GENERATIONS OF *CHILO PARTELLUS* UNDER MAIZE-COWPEA-LEUCAENA-GLIRICIDIA CROPPING SYSTEM

GENERATION 1 LR 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	21	Parasitism	0	0	0
		Disappearance	6	28.5	28.5
		Total	6	28.5	28.5
Medium larvae	15	Parasitism	0	0	0
		Disappearance	10	66.67	47.6
		Total	10	66.67	47.6
Large larvae	5	Parasitism	0	0	0
		Disappearance	3	60	14.3
		Total	3	60	14.3
Pupae	2	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 2 SR' 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	24	Parasitism	0	0	0
		Disappearance	14	58.33	58.33
		Total	14	58.33	58.33
Medium larvae	10	*Cotesia sesamiae*	2	20	8.33
		Cotesia flavipes	1	10	4.17
		Disappearance	4	40	16.67
		Total	7	70	29.17
Large larvae	3	Parasitism	0	0	0
		Disappearance	3	100	12.5
		Total	3	100	12.5
Pupae	0	Parasitism	0	0	0
		Disappearance	0	0	0

GENERATION 3 LR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	12	Parasitism	0	0	0
		Disappearance	5	41.6	41.6
		Total	5	41.6	41.6
Medium larvae	7	*Cotesia sesamiae*	1	14.2	8.3
		Cotesia flavipes	1	14.2	8.3
		Disappearance	0	0	0
		Total	2	28.5	16.7
Large larvae	5	Parasitism	0	0	0
		Disappearance	3	60	25
		Total	3	60	25
Pupae	2	Parasitism	0	0	0
		Disappearance	1	50	8.3
		Total	1	50	8.3

GENERATION 4 SR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	18	Parasitism	0	0	0
		Disappearance	4	22.2	22.2
		Total	4	22.2	22.2
Medium larvae	14	*Cotesia sesamiae*	1	7.1	5.5
		Cotesia flavipes	1	7.1	5.5
		Disappearance	0	0	0
		Total	2	14.2	11.1
Large larvae	12	Parasitism	0	0	0
		Disappearance	10	83.3	55.5
		Total	10	83.3	55.5
Pupae	2	Parasitism	0	0	0
		Disappearance	1	50	5.5
		Total	1	50	5.5

Appendix 4. PARTIAL ECOLOGICAL LIFE TABLES FOR FOUR GENERATIONS OF *CHILO PARTELLUS* UNDER MAIZE-LEUCAENA-GLIRICIDIA CROPPING SYSTEM

GENERATION 1 LR 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	29	Parasitism	0	0	0
		Disappearance	11	37.9	37.9
		Total	11	37.9	37.9
Medium larvae	18	*Cotesia sesamiae*	1	5.56	3.4
		Disappearance	10	55.56	34.5
		Total	11	61.1	37.9
Large larvae	7	Parasitism	0	0	0
		Disappearance	5	71.4	17.2
		Total	5	71.4	17.2
Pupae	2	Parasitism	0	0	0
		Disappearance	1	50	3.4
		Total	1	50	3.4

GENERATION 2 SR' 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	19	Parasitism	0	0	0
		Disappearance	7	36.84	36.84
		Total	7	36.84	36.84
Medium larvae	12	Parasitism	0	0	0
		Disappearance	7	58.33	36.84
		Total	7	58.33	36.84
Large larvae	5	Parasitism	0	0	0
		Disappearance	5	100	26.31
		Total	5	100	26.31
Pupae	0	Parasitism	0	0	0

GENERATION 3 LR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	12	Parasitism	0	0	0
		Disappearance	1	8.3	8.3
		Total	1	8.3	8.3
Medium larvae	11	Parasitism	0	0	0
		Disappearance	4	36.3	33.3
		Total	4	36.3	33.3
Large larvae	7	Parasitism	0	0	0
		Disappearance	4	57.1	33.3
		Total	4	57.1	33.3
Pupae	3	Parasitism	0	0	0
		Disappearance	2	66.6	16.7
		Total	2	66.6	16.7

GENERATION 4 SR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	13	Parasitism	0	0	0
		Disappearance	3	23.1	23.1
		Total	3	23.1	23.1
Medium larvae	10	*Cotesia sesamiae*	1	10	7.7
		Cotesia flavipes	1	10	7.7
		Disappearance	1	10	7.7
		Total	3	30	23.1
Large larvae	7	Parasitism	0	0	0
		Disappearance	4	57.1	30.8
		Total	4	57.1	30.8
Pupae	3	*Pediobius furvus*	1	33.3	7.7
		Disappearance	1	33.3	7.7
		Total	2	66.6	15.4

Appendix 5. PARTIAL ECOLOGICAL LIFE TABLES FOR FOUR GENERATIONS OF *CHILO PARTELLUS* UNDER MAIZE-COWPEA INTERCROPPING SYSTEM

GENERATION 1 LR 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	31	Parasitism	0	0	0
		Disappearance	6	19.3	19.3
		Total	6	19.3	19.3
Medium larvae	25	Parasitism	0	0	0
		Disappearance	19	76	61.3
		Total	19	76	61.3
Large larvae	6	Parasitism	0	0	0
		Disappearance	4	66.7	12.9
		Total	4	66.7	12.9
Pupae	2	Parasitism	1	50	3.2
		Disappearance	0	0	0
		Total	1	50	3.2

GENERATION 2 SR' 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	14	Parasitism	0	0	0
		Disappearance	3	21.43	21.43
		Total	3	21.43	21.43
Medium larvae	11	Parasitism	0	0	0
		Disappearance	8	72.73	47.14
		Total	8	72.73	47.14
Large larvae	3	Parasitism	0	0	0
		Disappearance	3	100	21.43
		Total	3	100	21.43
Pupae	0	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 3 LR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	28	Parasitism	0	0	0
		Disappearance	13	46.4	46.6
		Total	13	46.4	46.6
Medium larvae	15	*Cotesia sesamiae*	1	6.6	3.6
		Disappearance	7	46.6	25
		Total	8	53.3	28.6
Large larvae	7	Parasitism	0	0	0
		Disappearance	4	57.1	14.3
		Total	4	57.1	14.3
Pupae	3	*P. furvus*	1	33.3	3.6
		Disappearance	1	33.3	3.6
		Total	2	66.6	7.1

GENERATION 4 SR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	26	Parasitism	0	0	0
		Disappearance	10	38.4	38.5
		Total	10	38.4	38.5
Medium larvae	16	*Cotesia sesamiae*	3	18.7	11.5
		Disappearance	3	18.7	11.5
		Total	6	37.5	23
Large larvae	10	Parasitism	0	0	0
		Disappearance	8	80	30.8
		Total	8	80	30.8
Pupae	2	Parasitism	0	0	0
		Disappearance	2	100	7.7
		Total	2	100	7.7

Appendix 6. PARTIAL ECOLOGICAL LIFE TABLES FOR FOUR GENERATIONS OF *CHILO PARTELLUS* UNDER MULCHED MAIZE MONOCROP SYSTEM

GENERATION 1 LR 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	26	Parasitism	0	0	0
		Disappearance	4	15.4	15.4
		Total	4	15.4	15.4
Medium larvae	22	*Cotesia sesamiae*	1	4.5	3.8
		Disappearance	12	54.5	46.1
		Total	13	59.1	50
Large larvae	9	Parasitism	0	0	0
		Disappearance	7	77.78	26.9
		Total	7	77.78	26.9
Pupae	2	Parasitism	0	0	0
		Disappearance	1	50	3.8
		Total	1	50	3.8

GENERATION 2 SR' 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	15	Parasitism	0	0	0
		Disappearance	3	20	20
		Total	3	20	20
Medium larvae	12	Parasitism	0	0	0
		Disappearance	6	50	40
		Total	6	50	40
Large larvae	6	Parasitism	0	0	0
		Disappearance	6	100	40
		Total	6	100	40
Pupae	0	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 3 LR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	23	Parasitism	0	0	0
		Disappearance	6	26	26
		Total	6	26	26
Medium larvae	17	*Cotesia sesamiae*	1	5.8	4.3
		Cotesia flavipes	2	11.7	8.7
		Disappearance	2	11.7	8.7
		Total	5	29.4	21.7
Large larvae	12	Parasitism	0	0	0
		Disappearance	7	58.3	30.4
		Total	7	58.3	30.4
Pupae	5	Parasitism	0	0	0
		Disappearance	2	40	8.7
		Total	2	40	8.7

GENERATION 4 SR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	25	Parasitism	0	0	0
		Disappearance	11	44.4	44.4
		Total	11	44.4	44.4
Medium larvae	14	*Cotesia sesamiae*	2	14.2	8
		Cotesia flavipes	2	14.2	8
		Disappearance	2	14.2	8
		Total	6	42.8	24
Large larvae	8	Parasitism	0	0	0
		Disappearance	3	37.5	12
		Total	3	37.5	12
Pupae	5	Parasitism	0	0	0
		Disappearance	2	40	8
		Total	2	40	8

Appendix 7. PARTIAL ECOLOGICAL LIFE TABLES FOR FOUR GENERATIONS OF *CHILO PARTELLUS* UNDER UNMULCHED MAIZE MONOCROP

GENERATION 1 LR 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	23	Parasitism	0	0	0
		Disappearance	6	26	26
		Total	6	26	26
Medium larvae	17	Parasitism	0	0	0
		Disappearance	8	47	34.8
		Total	8	47	34.8
Large larvae	9	Parasitism	0	0	0
		Disappearance	5	55.56	21.7
		Total	5	55.56	21.7
Pupae	4	Parasitism	0	0	0
		Disappearance	1	25	4.3
		Total	1	25	4.3

GENERATION 2 SR' 1999

x	lx	dxF	dx	100qx	100rx
Small larvae	14	Parasitism	0	0	0
		Disappearance	2	14.29	14.29
		Total	2	14.29	14.29
Medium larvae	12	*Cotesia sesamiae*	1	8.33	7.14
		Disappearance	9	75	64.29
		Total	10	83.3	71.43
Large larvae	2	Parasitism	0	0	0
		Disappearance	2	100	14.29
		Total	2	100	14.29
Pupae	0	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0

GENERATION 3 LR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	34	Parasitism	0	0	0
		Disappearance	20	58.8	58.8
		Total	20	58.8	58.8
Medium larvae	14	*Cotesia sesamiae*	3	21.4	8.8
		Cotesia flavipes	1	7.1	2.9
		Disappearance	0	0	0
		Total	4	28.5	11.8
Large larvae	10	Parasitism	0	0	0
		Disappearance	6	60	17.6
		Total	6	60	17.6
Pupae	4	Parasitism	0	0	0
		Disappearance	3	75	8.8
		Total	3	75	8.8

GENERATION 4 SR' 2000

x	lx	dxF	dx	100qx	100rx
Small larvae	32	Parasitism	0	0	0
		Disappearance	16	50	50
		Total	16	50	50
Medium larvae	16	*Cotesia sesamiae*	2	12.5	6.2
		Cotesia flavipes	2	12.5	6.2
		Disappearance	6	37.5	18.7
		Total	10	62.5	31.2
Large larvae	6	Parasitism	0	0	0
		Disappearance	4	66.6	12.5
		Total	4	66.6	12.5
Pupae	2	Parasitism	0	0	0
		Disappearance	0	0	0
		Total	0	0	0